NANOSERIES®

#NanoSeries2026

5th Edition Conference on

Global Nanotechnology

Dates: June 15–17, 2026

Venue: Polytechnic University of Turin, Italy

Abstract Book

IN ASSOCIATION WITH

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#NanoSeries2026
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Foreword

It is our great pleasure to present the Abstract Book of the 5th Edition Conference on Global Nanotechnology (#NanoSeries2026), held from 15–17 June 2026 at the Polytechnic University of Turin, Italy.

Over the past five editions, NanoSeries has evolved into an international platform that brings together researchers, innovators, industry professionals, and emerging scholars working across the broad and rapidly advancing landscape of nanoscience and nanotechnology. What began as an initiative to foster interdisciplinary scientific dialogue has grown into a vibrant global community dedicated to advancing fundamental discoveries and translating nanoscale innovations into technologies that can address some of society's most pressing challenges.

This edition of NanoSeries welcomes more than 300 participants representing over 40 countries, reflecting the increasingly global and collaborative nature of contemporary scientific research. The breadth of contributions featured in this Abstract Book illustrates both the remarkable diversity and the interdisciplinary spirit of the nanotechnology community. The programme spans a wide range of topics, including advanced nanomaterials, energy systems, nanoscale engineering for sustainability, photonics and optoelectronics, bioelectronics and biosensors, nanomedicine, hierarchical assembly of functional materials, artificial intelligence in nanomaterials research, and emerging directions in intelligent and autonomous nanosystems.

The abstracts compiled in these pages represent more than summaries of presentations. They capture current scientific thinking, emerging concepts, new methodologies, and collaborative efforts that collectively shape the future of nanoscience and technology. They reflect the creativity, dedication, and curiosity of researchers working across disciplines and geographical boundaries, united by a common objective: to understand, engineer, and harness matter at the nanoscale for the benefit of society.

NanoSeries has always believed that scientific conferences should extend beyond the dissemination of research findings. They should serve as catalysts for collaboration, mentorship, and the exchange of ideas across disciplines and cultures. In this spirit, #NanoSeries2026 places particular emphasis on supporting Early Career Researchers, encouraging interdisciplinary interactions, and creating opportunities for meaningful dialogue between academia, industry, and emerging innovators. Through technical sessions, workshops, poster forums, networking activities, and dedicated mentoring initiatives, we aspire to cultivate an environment where new partnerships and future scientific directions can emerge.

We hope that this Abstract Book will serve not only as a record of the scientific programme of #NanoSeries2026 but also as a lasting reflection of the collective knowledge, enthusiasm, and collaborative spirit that define our global nanotechnology community. We trust that the ideas presented herein will inspire new conversations, stimulate innovative research directions, and encourage continued international cooperation long after the conference concludes.

On behalf of the Organizing Committee, International Scientific Advisory Board, Conference Chairs, Partners, and Collaborators, we extend our sincere gratitude to all authors, speakers, session chairs, reviewers, sponsors, and participants whose contributions have made #NanoSeries2026 possible.

We are honoured to present this collection of scientific contributions and look forward to the discoveries, collaborations, and innovations that will emerge from the interactions fostered during these three days in Turin.

Warmest regards,

#NanoSeries2026 Organizing Committee

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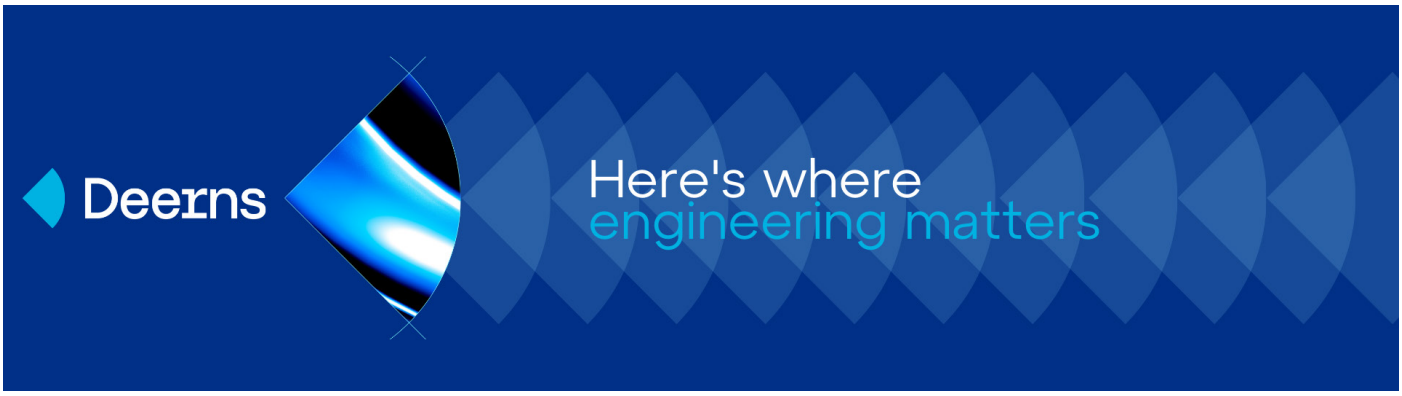

Founded in 1928, **Deerns** is an international engineering firm specializing in **Building Services**. We provide the comprehensive technical expertise and professional services required to design, implement, and operate buildings that are efficient, secure, and sustainable. The Deerns approach is rooted in an **integrated vision** that bridges technology and innovation with environmental stewardship, delivering solutions that ensure occupant comfort, system reliability, energy efficiency, and carbon footprint reduction.

Today, our multinational organization employs over **800 professionals** across a network of **17 operational offices** in 10 countries: Brazil, Colombia, France, Germany, Italy, India, Kuwait, Spain, the Netherlands, and the United Kingdom, complemented by a strategic partnership in Indonesia. This international footprint enables Deerns to provide agile, localized responses to market demands while upholding rigorous **global quality standards**.

Through established collaborations and local alliances, Deerns has successfully delivered projects in over **60 countries**, generating an annual turnover exceeding **€80 million** in high-value services and products. Our expertise is particularly renowned for Advanced MEP (Mechanical, Electrical, and Plumbing) design, Smart Building Solutions and Sustainable Engineering Practices practices that harmonize technological innovation with environmental responsibility.

Our core markets span a diverse range of high-tech and mission-critical sectors, including **Electronics, Data Centres, Life Sciences, Real Estate, Healthcare, and Airports**. In **Italy**, Deerns has maintained a presence since 1980 through its Milan office, which officially joined the Group in 2012. Today, **Deerns Italy** boasts a team of over **170 professionals** operating across two branches—**Milan** and **Rome**. With a proven track record of more than **2,000 successful projects**, we are a leading engineering partner across all major domestic industries.

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Publication Opportunity for #NanoSeries2026 Attendees

#NanoSeries2026 participants will have the opportunity to engage with leading international journals through special collections, editorial collaborations, publication initiatives, and dedicated discussions on scientific publishing and research visibility.

Selected contributions from #NanoSeries2026 will be invited for submission to special collections and partner journals, including:

- Small Structures
- Advanced Materials Technologies
- Particle & Particle Systems Characterization

All submissions will undergo the standard peer-review and editorial evaluation processes of the respective journals.

As part of this ongoing collaboration, participants are also encouraged to explore the evolving #NanoSeries2025 special collection:

“Shaping the Future: Emerging Frontiers in Nanoscience and Technology”

which highlights research contributions emerging from the NanoSeries community and continues to grow with newly published articles and future updates.

The collection can be explored here:

Previous NanoSeries2025 Special Collection – Small Structures

Through these collaborations, participants gain:

- visibility within internationally recognized journal platforms,
- opportunities to contribute to curated special collections,
- exposure to editorial perspectives and publishing strategies,

and access to discussions focused on scientific communication, research impact, and publication pathways.

NanoSeries2026 will also feature dedicated editorial interactions and publishing-focused discussions designed to support researchers, particularly early- and mid-career scientists, in navigating the evolving landscape of scientific publishing and interdisciplinary dissemination.

Additional updates regarding special collections, publication opportunities, and editorial initiatives will be shared throughout the conference.

#NanoSeries2026 ECR and Poster Awards Travel Grants

The NanoSeries Innovation Foundry was launched by Team NanoSeries in 2022 with a simple but meaningful vision to give back to the global research community by supporting talented researchers and creating opportunities for scientific growth, recognition, and collaboration.

Since its inception, the initiative has focused on supporting outstanding researchers through travel grants, awards, and accessibility programs designed to encourage broader participation in international scientific exchange. Recipients are selected through independent evaluation committees across each edition of NanoSeries, ensuring a fair and merit-driven process.

Over the past two editions, the Innovation Foundry has continued to evolve with a stronger emphasis on inclusivity and accessibility. We have introduced reduced registration opportunities for participants from economically challenged regions, helping create a conference environment where scientific merit and innovation are valued above all else — regardless of background, gender, ethnicity, or geography.

As NanoSeries continues to grow, we are further strengthening this commitment by facilitating no-fee participation opportunities for exceptional researchers from underrepresented regions of the world. We firmly believe that financial barriers should never limit access to scientific dialogue, collaboration, and global visibility.

In addition to supporting accessibility, the NanoSeries Innovation Foundry also recognizes excellence through dedicated award initiatives, including:

- **5 Early Career Researcher (ECR) Awards,** each including a **€500 Travel Grant**, selected by an independent ECR evaluation panel
- **3 Best Poster Awards**, each including a **€500 Travel Grant**, selected by the Poster Jury Panel

We extend our sincere appreciation to Deerns Italia SpA for their generous Gold Sponsorship, which directly supports the NanoSeries2026 Travel Grants. Their contribution represents more than financial support — it reflects a shared commitment to nurturing emerging talent, encouraging innovation, and strengthening the global scientific community.

We also warmly welcome scientific partners, institutions, organizations, and sponsors to join us in supporting these initiatives. Together, we can continue building a more inclusive and collaborative scientific ecosystem that empowers diverse voices and creates meaningful opportunities for researchers worldwide.

At NanoSeries, we believe conferences should leave a lasting impact — not only through scientific presentations and publications, but through the people they support, the connections they create, and the opportunities they open for the next generation of researchers.

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Supporting Sponsors for the Awards Programme at #NanoSeries2026

To recognize outstanding achievements in nanoscience and nanotechnology, #NanoSeries2026 presents two prestigious award categories. These awards celebrate individuals who have demonstrated excellence through innovative research, impactful contributions, and high-quality scientific presentations.

1. Emerging Talent of the Year 2026

This award honors early-career researchers, students, and professionals (under 35) who have demonstrated exceptional innovation and future potential in their field. Applications and self-nominations were evaluated by a panel of distinguished experts based on originality, impact, and long-term promise.

Awards & Benefits:

Top 3 Finalists

- €500 Travel Grant (sponsored by NanoSeries Innovation Foundry)
- Early Career Researcher Awards from:
    - *Royal Society of Chemistry – Nanoscale Horizons*
    - *Royal Society of Chemistry – Nanoscale*
    - *Royal Society of Chemistry – Nanoscale Advances*
- RSC journal-branded certificate
- 1-year RSC membership
- £100–£200 book voucher

Ranked 4th & 5th Finalists

- €500 Travel Grant (NanoSeries Innovation Foundry)
- Springer Nature – Microchimica Acta: Two vouchers (€150 each) for Early Career Researcher recognition

2. Best Poster Awards

These awards recognize outstanding poster and presentation contributions showcased during NanoSeries2026, highlighting excellence in scientific communication, innovation, and research quality.

Top 3 Awardees

- €500 Travel Grant (NanoSeries Innovation Foundry)
- Sponsored by Wiley (Small Structures Journal)
- Tango Card Prizes (Total Prize Pool: €450)
- Certificate of Recognition

Next 3 Finalists

- Best Poster Awards by Royal Society of Chemistry
  (Nanoscale Horizons I Nanoscale I Nanoscale Advances)

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- RSC Journal-Branded Certificate
- 1-Year RSC Membership
- £100–£200 Book Voucher
- Springer Nature – Microchimica Acta
  €150 Voucher each for Top 4 and Top 5

Acknowledgment of Our Sponsors and Supporters

We extend our sincere thanks to our partners and sponsors for making these awards possible:

NanoSeries Innovation Foundry

Deerns Italia SpA

Small Structures (Wiley-VCH)

Microchimica Acta (Springer Nature)

Nanoscale Journal Family (Royal Society of Chemistry)

We look forward to celebrating excellence, innovation, and global collaboration at #NanoSeries2026.

Tourism Partner

We gratefully acknowledge the support of Turismo Torino and Provincia Convention Bureau for NanoSeries2026 in Turin, Italy. Their valued contribution includes complimentary tourist information brochures and city maps for delegates, along with access to the Torino+Piemonte Congress Card for participants and accompanying persons. The card offers cultural benefits, discounted local transport, and special airport shuttle fares, enhancing the overall experience for our international attendees.

Together with our partners, we are delighted to present #NanoSeries2026 as a platform for scientific collaboration, cultural exchange, and unforgettable experiences in the vibrant city of Turin.

#NanoSeries2026 Programme at a Glance
June 15-16, 2026 (Day 1 & Day 2)

Location	Monday Day 1, June 15th, 2026	Tuesday Day 2, June 16th, 2026
Aula Magna - Main Building	Registration and Badge Collection (08:00-08:50)	Registration and Badge Collection (08:00-08:50)
Aula Magna - Main Building	Country Welcome and Opening Ceremony (08:50-09:10)	
	Plenary: Prof. Xinliang Feng(09:10-09:50)	Plenary: Prof. Luisa Torsi (09:00-09:40)
	Plenary Prof. Eugenio Coronado (09:50-10:30)	Plenary: Prof. Yoshihiro Iwasa (09:40-10:20)
Aula Magna - Main Building	EPS Emmy Noether Distinction 2025 (mid-career) Ceremony (10:30-10:45)	
Hall S. Emma Strada	**Networking Coffee Break (10:45-11:10)**	**Networking Coffee Break (10:20-10:45)**
Aula Magna - Main Building	Plenary : Prof. Silvia Vignolini (11:15-11:55)	Plenary: Prof. Younan Xia (10:50-11:30)
		Plenary: Prof. Hernán Míguez (11:30-12:10)
Transition Break	Moving to Cittadella Campus for the NanoSeries Posters, Technical Sessions and Workshops (11:55-12:10)	Moving to Cittadella Campus for the NanoSeries Posters, Technical Sessions and Workshops (12:10-12:25)
Cittadella – Pergola/ underground court-yard	GLOBAL POSTER COMPETITION (12:10-13:10)	GLOBAL POSTER COMPETITION (12:25-13:10)
Cittadella – Pergola/ underground court-yard	**Networking Lunch Break (13:10-13:55)**	**Networking Lunch Break (13:10-13:55)**
Location	Technical Sessions: NS (B), NS (C), NS (D), NS (E), NS (F), NS (C1) & NS (H) Technical Workshops: NSAW1 and NSAW2 Coffee Break Area: Cittadella – Pergola/underground courtyard	Technical Sessions: NS (A), NS (B), NS (C), NS (G), NS (F) and NS (C1) Technical Workshops: NSAW3, NSAW4 and NSAW5 Coffee Break Area: Cittadella – Pergola/underground courtyard
Cittadella Politecnica - Room 1I	**Session Time:-(14:00-18:38); Coffee Break:-(15:52–16:12)**	**Session Time:-(14:00-17:31); Coffee Break:-(15:44–16:12)**
	#NanoSeries2026 Technical Session: NS (A)	#NanoSeries2026 Technical Session: NS (A)
Cittadella Politecnica - Room 3I	**Session Time:-(14:00-18:30); Coffee Break:-(15:45–16:05)**	**Session Time:-(14:00-17:35); Coffee Break:-(15:50–16:10)**
	#NanoSeries2026 Technical Session: NS (B)	#NanoSeries2026 Technical Session: NS (B)
Cittadella Politecnica - Room 5I	**Session Time:-(14:00-18:40); Coffee Break:-(15:55–16:10)**	**Session Time:-(14:00-17:40); Coffee Break:-(15:55–16:15)**
	#NanoSeries2026 Technical Session: NS (C)	#NanoSeries2026 Technical Session: NS (C)
Cittadella Politecnica - Room 7I	**Session Time:-(14:00-18:40); Coffee Break:-(15:52–16:12)**	**Session Time:-(14:00-17:25); Coffee Break:-(15:54–16:14)**
	#NanoSeries2026 Technical Session: NS (D)	#NanoSeries2026 Technical Session: NS (G)
Cittadella Politecnica - Room 9I	**Session Time:-(14:00-18:09); Coffee Break:-(16:12–16:32)**	**Session Time:-(14:00-17:36); Coffee Break:-(15:42–16:02)**
	#NanoSeries2026 Technical Session: NS (E)	#NanoSeries2026 Technical Session: NS (F)& NS (C1)
Cittadella Politecnica - Room 1T	**Session Time:-(14:00-18:22); Coffee Break:-(15:45-16:05)**	**Session Time:-(14:00-17:30); Coffee Break:-(15:50–16:10)**
	#NanoSeries2026 Technical Session: NS (F)& NS (C1)	#NanoSeries2026 Technical Workshop: NSAW3
Cittadella Politecnica - Room 2T	**Session Time:-(14:00-18:35); Coffee Break:-(15:50-16:05)**	**Session Time:-(14:00-17:45); Coffee Break:-(15:45–16:05)**
	#NanoSeries2026 Technical Workshop: NSAW1 #NanoSeries2026 Technical Session: NS (H)	#NanoSeries2026 Technical Workshop: NSAW4
Cittadella Politecnica - Room 4T	**Session Time:-(14:00-18:40); Coffee Break:-(15:30-15:50)**	**Session Time:-(14:00-16:50); Coffee Break:-(15:40–16:00)**
	#NanoSeries2026 Technical Workshop: NSAW2	#NanoSeries2026 Technical Workshop: NSAW5
Day 1, June 15th, 2026 Welcome Aperitivo and Networking Venue: Cittadella – Pergola/underground courtyard Time: From 18:50-20:00		**Day2, June 16th, 2026 Social Dinner and Networking Venue: Palazzo della Luce (https://share.google/Wj7CcIlLm1HmXYZHy) Address: V. Antonio Bertola, 40, 10122 Torino TO, Italy Time: From 20:00 Onwards**

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#NanoSeries2026 Programme at a Glance
June 17th, 2026 Day 3

Location	Wednesday Day3, June 17th, 2026
	Technical Sessions: NS (A), NS (B)-I, II, NS (C), NS (C1), NS (E), NS (F) and NS (G)
Cittadella Politecnica- Room 1I	**Session Time:-(09:30-12:45); Coffee Break:-(10:39-11:01)**
	#NanoSeries2026 Technical Session: NS (A)
Cittadella Politecnica- Room 3I	**Session Time:-(09:30-12:49); Coffee Break:-(10:55-11:10)**
	#NanoSeries2026 Technical Session: NS (B)- I
Cittadella Politecnica- Room 5I	**Session Time:-(09:30-13:05); Coffee Break:-(10:50-11:10)**
	#NanoSeries2026 Technical Session: NS (B)-II
Cittadella Politecnica- Room 7I	**Session Time:-(09:30-12:20); Coffee Break:-(10:49-11:09)**
	#NanoSeries2026 Technical Session: NS (G)
Cittadella Politecnica- Room 9I	**Session Time:-(09:30-12:46); Coffee Break:-(10:54-11:14)**
	#NanoSeries2026 Technical Session: NS (E)
Cittadella Politecnica- Room 1T	**Session Time:-(09:30-13:16); Coffee Break:-(10:55-11:10)**
	#NanoSeries2026 Technical Session: NS (C)
Cittadella Politecnica- Room 2T	**Session Time:-(09:30-13:07); Coffee Break:-(10:55-11:15)**
	#NanoSeries2026 Technical Session: NS (F)
Cittadella Politecnica- Room 4T	**Session Time:-(09:30-13:04); Coffee Break:-(10:57-11:12)**
	#NanoSeries2026 Technical Session: NS (C1)
Cittadella – Pergola/underground courtyard	Networking Lunch Break (13:30-14:15)
Cittadella – Pergola/underground courtyard	14:15–14:30 I Awards Ceremony and Closing Remarks Presentation of the NanoSeries2026 Early Career Researcher (ECR) Awards and Best Poster Awards Closing Remarks Teresa Gatti, Polytechnic University of Turin, Italy Ilka Kriegel, Polytechnic University of Turin, Italy

#NanoSeries2026 Technical Sessions Codes and Titles

- NS (A):-Synthesis and Advanced Characterization of Nanomaterials & Nanostructures
- NS (B):-Nanomaterials for Energy Applications: From Batteries to Solar Cells with Sub-Section NS(B)-I and NS(B)-II
- NS (C):- Nano-Bioengineering for Medicine: Therapeutics, Diagnostics, and Regeneration
- NS (C1):-Bionanosensors and Bioelectronics: In Vitro and In Vivo Applications
- NS (D):-Hierarchical Assembly of Functional Nanomaterials
- NS (E):-2D Materials Research: Graphene and Beyond
- NS (F):-Next-Generation Light–Matter Interactions at the Nanoscale: Photonics and Optoelectronics
- NS (G):-Nanoscale Engineering for Sustainability
- NS (H):-AI-Enabled Nanomaterials Discovery and Neuromorphic Systems

#NanoSeries2026 Workshop Codes and Titles

- NSAW1: Nanoengineering for Advanced Sensing Applications
- NSAW2: Single-Molecule Electronics: From Fundamental Quantum Transport to Emerging Applications
- NSAW3: Smart Soft-nanomaterials – Development Directions and Challenges
- NSAW4: Probing Surface Chemical Processes on 2D Materials
- NSAW5: Advanced Materials, Catalysts and Industrial-Scale Electrolysis

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Day-1 Plenary

Organic 2D Crystals for Electronics and Quantum Materials

Xinliang Feng[1,2]

[1]*Max Planck Institute of Microstructure Physics*
[2]*Technische Universitaet Dresden*

Beyond graphene and inorganic two-dimensional materials, organic two-dimensional crystals (O2DCs) are emerging as a chemically programmable platform for electronics and quantum materials. Built from π-conjugated molecular building blocks, these synthetic layered systems combine structural precision, chemical tunability, and controllable interlayer interactions, enabling the design of electronic structures and transport properties down to the monolayer level. In this lecture, I will first introduce advances in electronically active organic 2D frameworks, including 2D conjugated polymers and conjugated metal–organic frameworks (2D c-MOFs). These materials feature periodic π-conjugated networks and tunable covalent/coordination lattices that enable the design of electronic band structures and strongly coupled electronic systems, opening opportunities to explore charge transport, photophysics, spin physics, and correlated electronic phenomena. These developments are also driving new device concepts in the emerging field of MOFtronics. Next, I will discuss our recent progress in the bottom-up synthesis of highly crystalline 2D polymer crystals, particularly through on-water/on-liquid surface synthesis strategies. The confined water surface provides a unique reaction environment that enables controlled 2D polymer growth and the formation of single- and few-layer 2D polymer crystals with long-range structural order. These materials exhibit extended in-plane conjugation, tunable electronic properties, and emerging charge and ion transport, establishing them as a new materials platform for organic electronics and energy-related applications. Finally, I will present our recent work on organic 2D van der Waals heterostructures. Using sequential on-water surface assembly, we achieve programmable layer-by-layer stacking of chemically distinct 2D crystals with controlled lattice registry, stacking sequence, and thickness. Such control over interlayer coupling enables emergent interfacial phenomena, including charge transfer, built-in electric fields, and novel electronic transport behavior. These advances establish O2DCs as a versatile materials platform bridging synthetic chemistry, materials science, and condensed-matter physics, opening new directions for next-generation electronics and quantum materials.

2D Magnetic Materials for Spintronics and Quantum Technologies

E. Coronado

Instituto de Ciencia Molecular, Universitat de Valencia, Paterna, Spain

The controlled assembly of 2D materials in van der Waals heterostructures provides the opportunity to design unconventional materials with novel properties. Here I will show with three examples the application of 2D magnets in spintronics and quantum technologies.

1) Artificial magnets obtained by creating a twisted 2D heterostructure formed by two ferromagnetic monolayers twisted by an angle of 90º [1]. These heterostructures show novel and tunable magneto-transport properties (multistep spin switching with the opening of hysteresis, which is absent in the pristine bilayer case (angle of 0º) [2] that may be of interest as ultrathin magnetic sensors and memories.

2) Smart molecular/2D heterostructures obtained by interfacing stimuli-responsive magnetic molecules with graphene, semiconducting layers (MoS2 and WSe2), a superconducting layer (NbSe2), or the magnetic layer CrSBr. A tuning of the properties of the “all surface” 2D material is achieved via an active control of the hybrid interface. As smart-molecular systems, I will choose magnetic spin-crossover materials able to switch between two spin states upon the application of an external stimulus (temperature, light or pressure) [3]. This spin transition is always accompanied by a significant change of volume in the material (by ca. 10%). Hence, this spin transition can be sensed via the 2D material [4-6].

3) 2D magnets integrated in quantum devices. I will focus on a new type of quantum cavity that exploit the magnetic excitations (magnons) generated in the 2D magnets by microwaves to coupled them with molecular spin qubits. In contrast with the weak spin-photon coupling observed in quantum cavities, a strong spin-magnon coupling can be achieved in these magnonic cavities [7]. This discovery inaugurates magnon quantum electrodynamics (QED) and experimentally demonstrates the ability to dynamically tune the spin-magnon coupling by adjusting magnon chirality. This last part has been developed in collaboration with the teams of M. J. Martínez-Pérez and D. Zueco (INMA, Zaragoza).

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Bio-Inspired Self-Assembled Chiral Architecture for Optics and Plasmonics

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Chirality transfer across length scales is an intriguing and universal phenomenon. Both in nature and in materials science, complex architectures composed of bio-based chiral building blocks are responsible for unique optical responses from bright and vividcolourations to extremely large dichroism. When it comes to working with naturally derived chiral building blocks, however, the challenge lies in understanding how the properties of individual building blocks relate to the emergent features of large-scale architectures and structures. Our research addresses this gap by investigating the origins of mesophase chirality in bio-derived particles such as cellulose and chitin nanocrystal suspensions. Through a combination of quantitative morphological analysis of individual nanoparticles, final architecture, and their assemblies,we showcase the functionality of such chiral materials in the context of optical materials, including plasmonic ones, also providing examples of how such materials can be produced at scale.

Day-1

NanoSeries2026 Technical Session: NS (A)

Synthesis and Advanced Characterization of Nanomaterials & Nanostructures

Insights Into the Halide-Driven Polymorph Control in the Synthesis of Metal Chalcogenides

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An ongoing challenge in solid-state and colloidal synthesis of materials is the ability to dial in reactions conditions that enable control of the final crystal structure. Of particular interest is the ability to access materials in a metastable structure and the discovery of new polymorphs. In colloidal synthesis, ligands can be used as handles to provide control over the final structure. However, there is a need to understand the underlying molecular chemistry in relation to the kinetic and thermodynamic pathways. This talk will focus on our efforts to interrogate, from a molecular perspective, the role of halide precursors in driving structure/phase control in the synthesis of Mn and Sn chalcogenide nanoparticles.1 In these systems, polymorph/phase control can be achieved by varying the halide precursor, under otherwise identical conditions as confirmed by powder X-ray diffraction. I will discuss in situ X-ray absorption and emission measurements, performed at relevant synthesis conditions to gain insights toward the coordination chemistry of the early stages of the reaction. The findings from these studies could potentially aid in the development of rational synthesis that achieve desired structure and phase control in other materials systems.

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Bottom-Up Nanotechnology Enabled by Molecular Assemblies at Metal Surfaces: Hints from First-Principles Simulations

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This paper aims at highlighting the contribution that Density Functional Theory (DFT) calculations can provide to modern surface science. Surface science experiments under well-controlled conditions permits to follow the process of aggregation, diffusion, and organization of molecular assemblies on metallic surfaces, whose conducting nature allows to use scanning tunneling microscopy for characterization. The actual nature of the chemical bond established by the molecules on the surface, though, may still be elusive, and this is where DFT calculations can provide a valuable output.

In a joint computational and experimental paper,1 recently, we showed how actual writing with N-heterocyclic olefins can be achieved on the Cu(111) surface at positive scanning bias. The mechanism enabling the writing, unraveled by combing the evidence from STM with vibrational spectroscopy and DFT calculations, is based on a switch of the molecules from a mobile, physisorbed form, to a fixed, chemisorbed form. The role of the scanning bias is two-fold: the tip-induced electric field stabilizes the chemisorbed form of the molecule, thanks to the interfacial dipole moment, and promotes the sp2-to-sp3 transition at the olefinic C atom, which enables the chemisorption.

Ongoing work is dedicated to the creation of stable and extended one- and two-dimensional networks of a specific class of N-heterocyclic carbenes, functionalized cyano-groups. The crucial, combined role of carbonic centers, CN groups, and metal adatoms in forming the networks is discussed.

The formation of well-defined and stable molecular assemblies on metallic surfaces is not only of fundamental interest, but paves the way towards applications in many fields, such as (electro)catalysis, microelectronics, and sensing.

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Transparent Metal for Large-Area Exfoliation and Deterministic Transfer of 2D Materials

Nicolò Petrini*[1], Nicola Curreli[2], Nastaran Kazemi Tofighi[3], Ilka Kriegel[1]

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We introduce a nanofabrication technique that integrates metal-assisted exfoliation with a dry transfer method to achieve large-area exfoliation and deterministic placement of 2D flakes on a variety of substrates without surface functionalization. The process employs a transparent phase-changing polymer that reversibly switches between solid and liquid states at specific transition temperature. This polymer enables the handling of a semi-transparent metal foil consisting of a gold layer supported by indium tin oxide (ITO) thin film. The gold surface provides efficient exfoliation of large monolayer flakes, while the transparency of the foil allows precise optical alignment and transfer onto substrates with prepatterned contacts or existing flakes. Finally, the polymer's phase transition enables the release of the flake–metal stack onto the target surface. Compared to conventional metal exfoliation employing thermalrelease tapes, the liquid polymer significantly reduces interfacial friction, improving adhesion and eliminating the need for substrate treatment. The polymer never contacts the flake, which remains protected by the gold/ITO stack. After transfer, both the polymer and metal layers are easily removed with standard solvents and etchants, leaving pristine flakes. This technique offers a clean, reproducible, and versatile platform for transferring 2D materials and fabricating large-area heterostructures with micrometer-scale precision.

Atomic-Scale Investigation of Laser-Induced Nanostructures at Metallic Surfaces

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Ultrashort laser pulses are an intriguing tool for tailoring materials at the nanoscale to obtain properties that cannot be achieved under equilibrium conditions. We advance the nanoscopic understanding of the fundamental steps involved in such processes and thedetails of the dynamics induced by fs-lasers at surfaces, utilising a unique setup that allows coupling a fs-laser beam directly into the tunnelling junction of a low-temperature scanning tunnelling microscope. With this local approach, weunravelled that the surface is severely altered at fluences far below its ablation threshold. In this talk, I will present atomic-scale details of the fluence-dependent electronically-driven restructuring of several metal surfaces, such as Ag(100), Cu(111), and Cu(511). Based on a real-space analysis of the resulting structures on the sub-nanometer scale, we demonstrate substantial variation in the induced changes across the micrometre-sized laserspotthrough a novel multi-scale approach. We discuss the origin of qualitatively different structures, highlighting the importance of the local fluence for specificstructural changes. I will discuss the unprecedented local view onnanoscale structural changesby laser excitation and their non-adiabatic origin.

Structural Engineering of Low-Dimensional Perovskites for Photonic Applications

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Low-dimensional metal halide perovskites are attracting great interest for photovoltaics and photonics. The type of B-site metal in conjunction with the organic templating cations play a crucial role to determine the properties of low dimensional perovskites.

Here we discuss how the molecular engineering of organic cations in terms of cationic head (ammonium vs imidazolium – Figure 1, mono- vs di-topic cations) as well as geometry, length and conjugation of the molecular core (alkyl vsaromatic derivatives) deeply affect the dimensionality, structural and optoelectronic properties of lead and tin perovskites. We employ solid state NMR (ssNMR) as a key technique to investigate the local structures at the atomic level via1H, 13C, 15N, 119Sn and 207Pb ssNMR spectroscopy,providing clear spectralfingerprints which are characteristic of perovskites with different structural motifs, allowing the identification of their supramolecular spatial arrangements.[1]We further apply spin-lattice relaxation dynamics measurements to investigate molecular motions and structural rigidity in low-dimensional systems, and discuss their impact on the perovskites' luminescence properties, relevant for lasing and photonic applications.[2,3]

Our studies shed light on how supramolecular engineering can guide the development of improved materials for optoelectronics.

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Photocatalytic Processes Through the Lens of EPR Spectroscopy

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Electron paramagnetic resonance spectroscopy provides a uniquely sensitive view of the elementary steps that govern photocatalysis, from charge separation and spin localization to reactive intermediate formation and catalyst dynamics. In this lecture, I will show how EPR uncovers structure activity relationships in photocatalysts for selective solar driven transformations. Examples will include copper porphyrinoid carbon dots for oxygen reduction to hydrogen peroxide, titania decorated with platinum single atoms that promote superoxide formation, multivalent palladium carbon nitride photocatalysts for transfer hydrogenation of unsaturated substrates using water as a proton source, and redox flexible iron dimers on nitrogen doped graphene for selective oxidation of biomass derived intermediates in water. Across these systems, EPR becomes more than a supporting characterization technique: it is a central mechanistic tool that reveals how local coordination, oxidation state flexibility, and catalyst architecture control reactivity, selectivity, efficiency, and the rational design of next generation photocatalysts for sustainable chemical synthesis.

Synchrotron Radiation as a Powerful Tool for Investigation of Complex and Functional Nanomaterials

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Modern radiation sources like synchrotrons accelerate electrons to near-light speed and generate brilliant beams of light from Terahertz to X-rays, which are used for academic and industry research. Therefore, synchrotron is the power tool for investigation of complex and functional nanomaterials, including carbon-based nanomaterials, Moirématerials, nanocomposite materials, 2D materials, organic compounds. Imagine techniques ensuretheir visualization, X-ray diffraction methods characterize the degree of crystallinity, spectroscopy provides information on the nature of chemical bonding.

Among such materials, carbon nanomaterials are of particular interest. Prof. H.W. Kroto (Nobel Prize laureate for the discovery of fullerenes) predicted that “21st century will be the carbon age”. This is greatly due to the diverse structural forms and functions of carbons. Controlling the physicochemical properties of carbon materials on the nanometer scale (nanocarbons) will be core technology for obtaining novel nanocarbons with new and extraordinary functions.Nanocarbons include various forms of carbon in the range from carbyne to nanoporous materials. At present, it is accepted that chemical functionalization of carbon nanostructures (CNS) can extend the field of application of these nanosystems in nanoelectronics, green chemistry, clean energy, sensorics, medicine, etc.

In this talk, will be presented results of combined investigations of atomic structure and electronic properties of functionalized carbon nanostructures using synchrotron radiation for different applications, among them, for nanoelectronics, clean energetics, aerospace [1-4].Major attention will be paid to discussion of changes that appeared in atomic and electronic structure of CNS under functionalization, the nature of chemical bonding between CNS andatoms/molecules or their ensembles during and after functionalization of CNS, new details on mechanism of CNS functionalization, the chemical state of atoms used for functionalization.

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Hybrid Inorganic-Organic Materials for Flexible Electromechanical Sensing Devices

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Thin-film materials have shown great potential for the development of next-generation wearable technologies, especially in health-related applications including physiological monitoring or motion tracking. For these purposes, sensing devices must be lightweight, flexible, and conform to soft, dynamic surfaces such as human skin or textiles. Polymer-based sensors are particularly attractive due to their mechanical flexibility, low cost and easy processing.

With this aim, we develop thin piezoelectrics fabricated by infiltrating piezoelectric semiconductors into polymers, creating hybrid inorganic-organic materials with enhanced electromechanical properties. We use polyvinylidene fluoride (PVDF) as a polymer matrix, which intrinsically shows piezoelectricity.1 This polymer is infiltrated with zinc oxide, as inorganic piezoelectric material2 which is easiest to grow by vapor phase processing techniques. The potential synergistic effects between organic and inorganic piezoelectric materials and the possible enhancement of sensitivity of the electrochemical sensor are evaluated thereafter.

Our processing technique of choice is Vapor Phase Infiltration (VPI), a solvent-free vapor-tosolid chemical deposition technology that allows diffusion of vaporized metal-containing precursor molecules into a ‘soft’ polymeric substrate and binding to the polymer backbone. It is derived from the thin-film coating technique Atomic Layer Deposition (ALD), but instead of exclusively forming a film on the substrate surface, VPI is designed to introduce inorganic materials into the polymer subsurface while simultaneously growing a film on their surface.

The infiltrated hybrids are then covered with electrodes and characterized for their piezoelectric current generation upon bending and pressing. They are also physically and chemically characterized by TEM on samples cross-sectioned by a focused ion beam (FIB), SEM for analyzing the surface morphology and various spectroscopies for characterizing the bonding state of the polymer and the metal and the composition (FTIR, EDX and XPS).

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Exceptional Thermal Stability of Individual Tobacco Mosaic Virus (TMV)

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Thermal processes in biological nanostructures play a critical role in their functionality, stability, and integration into nanoengineered systems. However, experimental access to heat-induced transformations at the level of individual biomolecular objects remains limited. In this work, we investigate the thermal response of single Tobacco Mosaic Virus (TMV) particles subjected to high temperatures in air, using Atomic Force Microscopy (AFM) as a nano/microscale thermal metrology platform [1].

TMV particles adsorbed on solid substrates were heated from room temperature up to 250 °C, both ex situ and in situ using integrated microheaters, enabling direct correlation between thermal loading and nanoscale structural evolution. By statistically analyzing height and lateral dimensions at the single-particle level, we identify three distinct thermal regimes: i) a stable regime up to ~175 °C with minimal structural change, ii) a transition regime between ~195 °C and 235 °C characterized by progressive flattening and lateral expansion, and iii) complete structural collapse above ~240-250 °C (Figure 1). A melting temperature of approximately 215 °C is extracted, consistent with ensemble diffraction measurements while revealing substantial heterogeneity in degradation pathways that is inaccessible to bulk techniques.

Remarkably, partially degraded TMV nanorods remain morphologically stable for at least one week after thermal treatment, indicating irreversible but long-lived thermally driven reconfigurations. In situ AFM experiments further demonstrate rapid thermal equilibration and stability over extended heating times, underscoring the low thermal mass and robust energy dissipation characteristics of individual virions.

These results provide quantitative insight into thermal processes in biological systems at the nanoscale, highlighting the role of interfacial constraints, hydration loss, and protein reorganization under extreme thermal stress. Beyond biological relevance, this work establishes AFM-based approaches as powerful tools for nano/microscale thermal metrology of soft and hybrid materials and supports the use of virus-based nanostructures as model systems and functional components in thermally demanding nano/micro devices.

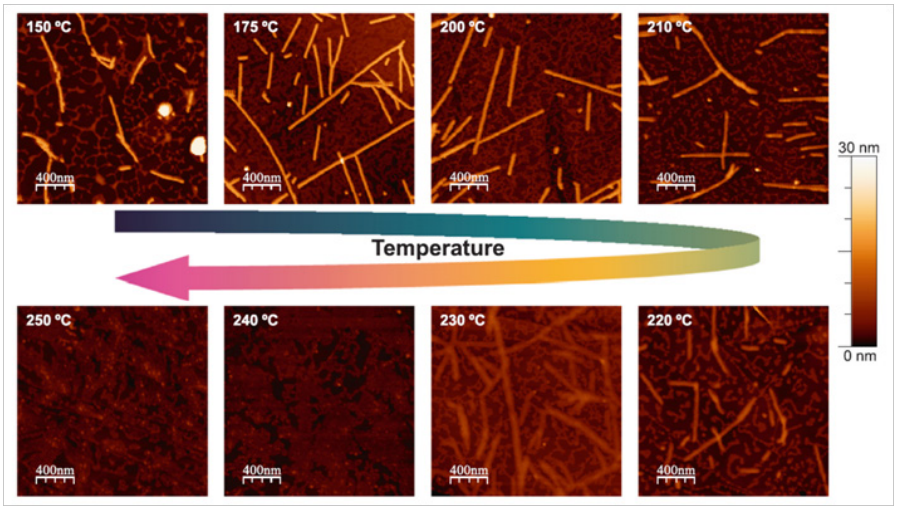

Figure 1: Evolution of the structure of TMVs deposited on HOPG heated in air from room temperature up to 250 °C.

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Electrochemical Synthesis and Photoelectrochemical Properties of Tungsten Oxide-Based Nanomaterials

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Photoelectrochemical (PEC) water splitting under solar irradiation offers a sustainable route for hydrogen production but remains limited by low efficiency and reliance on UV light. Nanostructured WO_3 is a promising photoanode material due to its stability and ~2.7 eV band gap, enabling absorption of about 12% of the solar spectrum [1]. Electrochemical anodization of tungsten provides a simple, cost-effective method to produce well-adherent WO_3 layers with vertically aligned nanochannels that enhance electron transport. The morphology of these anodic films can be tuned through anodizing parameters such as voltage, temperature, time, and electrolyte composition [2].To improve PEC performance, strategies including doping and heterojunction formation have been applied to anodic WO3. This work examines WO_3-based photoanodes (Fig.1) and their modified forms (C,N-WO_3, Co-WO_3, Fe-WO_3, Cu-WO_3, CuO-WO_3, Fe_2O_3-WO_3). Comprehensive SEM/EDS, XRD, XPS, and UV-Vis DRS analyses reveal correlations between the materials' morphology, composition, structure, and their optical, semiconducting, photoelectrochemical, and electrochemical properties.

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Direct Determination of Carrier Parameters in Indium Tin Oxide Nanocrystals Using Concepts from Magnetoplasmonics

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Indium Tin Oxide (ITO) is the prototype conductive oxide, which has recently gathered interestin nano-optics,1

owing to the excellent plasmonic properties displayed by ITO nanocrystals (NCs) in the infrared spectral region. Unlike noble metals, the plasmonic resonance frequency in spherical ITO NCs can betuned synthetically by controlling the tin content.2

Nanostructuration typically introduces several challenges in the characterization of electronic parameters in NCs, hampering advanced material design. Indeed, while films of doped oxides are routinely studied through electrical experiments, these cannot be reliably applied to NCs, since the insulating ligand layer forces charge hopping and results in a complexbehaviour. Moreover, the surface potential creates a depletion region near the surface, which typically requires core@shell models with a purely dielectric shell to fit the extinction spectrum.3

In this work,4 we present an integrated approach (Figure 1) based on magneto-optics, single-particle Electron Energy Loss (EELS) spectroscopy and 119Sn Solid State Nuclear Magnetic Resonance (SSNMR)spectroscopy to extract the fundamental electronic parameters of a series of ITO NCs with variable tin doping. Our methodology overcomes the limitations of standard fitting approaches based on extinction spectroscopy, which can only determine the ratio between carrier density and mass. Conversely, exploiting concepts from magnetoplasmonics5,6 we determined the carrier effective mass directly on the NCs, discarding the use of literature values. The effective mass was found to deviate from the parabolic approximation at high carrier density. This approach can be generalized to other plasmonic heavily-doped semiconductor nanostructures and represents, to the best of our knowledge, the only method to date to characterize the full Drude parameter space of 0-D nanosystems.

This research has received funding from the EU through Horizon 2020 program (grant agreement No. 823717–ESTEEM3), and through Horizon Europe program (grant agreement No. 101161583-GreenSWaP).

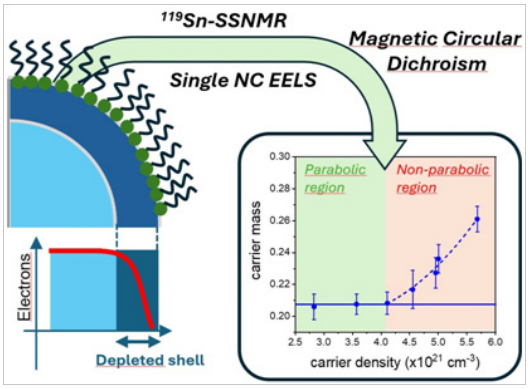

Fig. 1The multitechnique approach employed to extract the relation between carrier mass andcarrier density in a series of chemically prepared ITO NCs with variable Sn content.

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Adsorption Driven by Silver Nanoparticle Surface Potential

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The incomplete understanding of silver nanoparticle (AgNP) interfacial chemistry limits mechanistic control and compromises reproducibility in surface-enhanced Raman scattering (SERS). Because SERS critically depends on molecular adsorption, we investigated how tuning the surface electrochemical potential of AgNPs enables selective and reversible adsorption.

Citrate-stabilized AgNPs (residual citrate ~10^{-3} M) were synthesized using a modified Lee–Meisel method. The redox state of surface Ag was modulated with HNO_3 and $NaBH_4$.

Under acidic conditions, enhanced adsorption of anionic species and a corresponding increase in their SERS intensity were observed. Notably, Ca^{2+} produced a similar effect, with XPS evidence indicating partial Ag^+ formation and a downward shift of the Fermi level, consistent with surface electron depletion. In addition, this effect diminished under oxygen-depleted conditions (Ar purging), supporting a mechanism involving electron transfer from AgNPs to dissolved O_2, leading to Ag^+ formation and enhanced anionic adsorption. Adsorption was reversibly controlled through sequential redox switching: oxidation promoted anionic citrate adsorption, while subsequent $NaBH_4$ addition restored metallic Ag^0 and induced desorption of citrate, resulting in an on/off SERS response.

In contrast, the cationic Nile Blue (10-8 M) was not detected by SERS, even after the addition of 5x10^{-4} M Ca^{2+}, which promoted citrate adsorption. However, the Fermi level increase by 10^{-3} M Cl- through partial charge transfer facilitated the citrate desorption and Nile Blue adsorption, leading to its SERS signal detection.

Ionic species also influenced the adsorption anchoring of histidine. The zwitterionic molecule exhibited distinct SERS spectral changes upon addition of Ca^{2+} or Cl^-, demonstrating shifts in binding orientation through either the carboxylate or ammonium group consistent with electrchemical surface potential modulated by atomic ions.

Overall, the electrochemical surface potential emerges as a practical control parameter for directing molecular adsorption and binding configuration on AgNPs, enabling predictibility in SERS through mechanistic understanding of interfacial molecular processes.

Structure – Defect – Magnetism Correlations in Transition-Metal-Doped Oxide Nanocrystals: Distinguishing Intrinsic and Extrinsic Contributions for Multifunctional Applications

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Transition-metal-doped oxide nanocrystals exhibit complex correlations between crystal structure, defect chemistry, and magnetic behavior that are strongly governed by synthesis conditions and dopant incorporation mechanisms. In this presentation, correlations between structure, lattice disorder, vibrational properties, and magnetism in Fe-, Mn-, and Co-doped ZnO and ZrO_2 nanocrystals will be discussed. These two oxides provide complementary host systems: ZnO is a semiconducting wurtzite oxide with relatively narrow solubility limits for 3d dopants, while ZrO_2 is a polymorphic dielectric in which transition-metal incorporation may stabilize tetragonal or cubic phases.

Experimental studies combining X-ray diffraction, electron microscopy, Raman spectroscopy, Mössbauer spectroscopy, and DC/AC magnetic measurements reveal that magnetic responses in these nanomaterials evolve from diluted paramagnetism at low dopant concentrations toward superparamagnetic or spin-glass-like regimes associated with nanoscale magnetic entities. When apparent solubility limits are exceeded, nanoscopic secondary oxide phases may form and dominate the magnetic response.

Rather than interpreting these materials solely within the framework of semimagnetic semiconductors, a synthesis-driven perspective is adopted. By correlating structural and vibrational characterization, and magnetic dynamics, the analysis enables reliable discrimination between intrinsic dopant-related magnetism and extrinsic contributions arising from defects, clustering, or secondary phases. These insights are important for the rational design of multifunctional oxide nanomaterials for sensing, catalysis, biomedical applications, and electromagnetic interference mitigation.

Recent Approaches to High-Efficiency Intermediate Band Photovoltaics

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Significant developmentshave been made with high-efficiency intermediate band (IB) photovoltaics. Currently, research on IB solar cells using quantum dots (QDSCs) is ongoing in three main axes. The first is to establish methods to fabricate high-density QDs array of low defect density and with long radiative recombination lifetimes. The areal QD density has direct influence on the generation and recombination processes via IB states and for this, we have demonstrated that strain-compensated growth improves the QDs quality and InAs/GaAs QDSC characteristics with QD stacks up to 100 layers in self-organized heteroepitaxy [1]. However, the average QD size prepared by such a dry process is still large and the in-plane density is low, typically limited to the range of 15~20 nm and ~1012 cm-2, respectively. To this end, we have developed a QD-IBSC by using a wet solution process in which colloidal PbS QDs of ~4 nm in size were densely dispersed in a bulk perovskite matrix with a high energy bandgap of 2.4eV [2]. The second challenge is to increase the carrier lifetime in IB states by controlling the recombination rates, and for this purpose, wehave shown thata long lifetime energy-transfer mechanism in rare earth luminescentcenterscontributes directly to the formation of a ratchet type IB [3].Lastly, maximizing the photocurrent generation by 2-step photoabsorption (TSPA) by optimally doping the QDs to realize partially-filled IB states is important to improve the current matching between the valence band (VB) to IB, and IB to conduction band (CB) current production paths. [1] Y. Okada et al, Appl. Phys. Rev.2, 021302 (2015). [2] H. Hosokawa et al, Nature Commun.10, 43 (2019). [3] T. Sogabe et al, Commun. Phys.4, 38 (2021).

Day-1

NanoSeries2026 Technical Session: NS (B)

Nanomaterials for Energy Applications: From Batteries to Solar Cells

Beyond Light Trapping: The Multiple Benefits of Nano- and Micro-Textures in Perovskite Solar Cells

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Perovskite solar cell technologies have undergone rapid improvements over the last decade enabling highest power conversion efficiencies, particularly in the field of perovskite-silicon tandem solar cells. The implementation of nano- and micro-textures has played a major role in this development due to their ability to minimize reflection losses, maximize light trapping, and hence to increase the power conversion efficiency [1,2]. In the slipstream of these optical advances, it has become more and more apparent that these nano- or micro-textures can also have some collateral technological advantages beyond light management: Textures have proven to strongly improve wetting of the perovskite precursor solution during layer fabrication, increasing yield and film homogeneity [2]. Texturing can further lead to an increased carrier collection and enhanced open-circuit voltages [3].Combined opto- electronic simulations indicate that nanotexturing can increase the imbalance between electron and hole densities in the absorber, which reduces non-radiative recombination.Finally, the nanotextures are shown to reduce stress in the solar cell layers, which massively increases the mechanical stability of flexible devices upon bending [4]. The latter property is particularly relevant for flexible perovskite-based solar cells, which are regarded as promising candidates for space applications, mobile energy systems, and portable functional devices, because of their exceptionally high power-to-weight ratios.The results show that nanotextures can be regarded as a holistic strategy enhancing device performance of rigid and flexible opto-electronic devices, such as solar cells, light emitting diodes, and photodetectors.

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Spectral Tailoring and Optical Engineering for Next-Gen Perovskite Photovoltaics

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Harnessing the full spectral potential of sunlight remains a central challenge for photovoltaic technologies. This talk explores the strategic integration of downconversion materialsto enhance the performance and stability of perovskite solar cells (PSCs) - with a special focus on semi-transparent architectures, where current losses are an inherent trade-off.I will introduce the potential of downconversion materials, notably rare-earth-doped systems, to transform ultraviolet photons into visible light, thereby enhancing the photocurrent and suppressing photo-induced degradation. Emphasis is placed on the fundamental mechanisms underpinning downconversion, including intersystem crossing, energy transfer, and population inversion, which enable efficient photon conversion under solar illumination.

I will further present a holistic device strategy addressing the three critical fronts of semi-transparent perovskite solar cell design:(i) Transparent electrode engineering for high optical transmittance and minimal resistive loss, (ii) Absorber layer optimization in terms of thickness- quality balance to preserve transparency while retaining carrier collection efficiency, and (iii) Integration of spectral converters, which not only broaden the spectral response but also contribute to interface passivation and photothermal stability.These findings offer practical insights into tailoring the structure-optical property relationships in perovskite-based systems.

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Nanostructuring The Soft Matter: Molecular Interactions as Designing Rule for Deep Eutectic Solvents for Energy-Related Applications

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Deep eutectic solvents (DESs) represent a novel category of nonconventional solvents notable for their low toxicity, biodegradability and the possibility to tune their structure [1]. They arise from mixtures of a hydrogen bond donor (HBD) and a hydrogen bond acceptor (HBA), whose extensive hydrogen bond network stabilizes the mixture and maintains it in the liquid state. Despite growing applications, the fundamental chemistry of DESs and the specific molecular interactions that govern their behaviour remain under active investigation. The research described throughout, carried out as a collaborative work between Sapienza University of Rome and the University of Turin, focuses on elucidating HBD–HBA interactions and their role in mixture stabilization. This effort relies on a multi technique strategy that integrates electrochemical, spectroscopic and diffraction methods with computational modelling [2]. Improved insight into these interactions has enabled the rational selection, design and engineering of DESs for targeted applications, from electrolytes for sustainable energy storage [3] to catalyst free organic syntheses [4], and from CO_2 sequestration agents to iodine capture materials [5]. Overall, our multidisciplinary research underscores the potential of DESs as versatile molecular platforms for advances in energy, synthetic and environmental technologies, in line with the principles of green chemistry and sustainable development.

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Disordered Versus Ordered Niobates as Electrode Materials for Rechargeable Batteries

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A well-ordered structure with high crystallinity is crucial in various applications, particularly in electrode materials for batteries. The dimensionality and connectivity of the interstitial sites, determined by the crystal structure, inherently influence alkali ions diffusion kinetics. Niobium-based oxides structures are built by the assembly of ReO3-type blocks of specific sizes with metal sites having well defined positions within the crystalline structure. Structural disorder generally disrupts the regular pathways for ion and electron transport, leading to a lower overall conductivity. Here, we report a new anomalous disordered niobium tungsten oxide structure that significantly enhances the Li-ion storage performance compared to the ordered phase. The disordered tetragonal phase consists of corner-shared NbO6 octahedra blocks of varied sizes, including [5x4], [4x4], and [4x3], with a disordered arrangement of the tungsten tetrahedra at the corners of the blocks, together with strong distortion of the WO4 tetrahedra. This structural arrangement is found to be extremely robust during lithiation/delithiation, with a homeostatic local structure evolution during cycling, as determined by operando X-ray diffraction and X-ray absorption spectroscopy. This study highlights the benefits of introducing disorder into niobium tungsten oxide shear structures, through the establishment of clear structure-performance correlations, offering valuable guidelines for designing materials with targeted properties.

Nano-Engineered Cathodes for Lithium and Sodium Ion Batteries: From Disordered Rock Salt Structures to Prussian Blue Analogues

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Batteries arecrucial in the energy transition towards intermittent renewables such as solar and wind, which imply a need for storage. Two of the most important technologies are lithium (LIB) and sodium ion batteries (SIB). However, two issues remain to be addressed: the criticality of battery raw materials, e.g. Li, Co,… and their health risks during processing and recycling.

For LIBs, we have investigated Co-free oxides with a disordered rock-salt structure (DRX). Though DRX have a potentially high energy density, they may suffer from short range order which may form during cooling after hightemperature synthesis. Therefore, we designed solution-based synthesis routes (co-precipitation and solution-gel) and chose Co-free compositionswith Li, Mn and Ti. The effect of synthesis conditions and composition on phase purity was studied, including annealing conditions and fluorination. This way, capacities of >200 mAh/g were achieved.

Because of Na's higher abundance, SIBs are of high interest lately. Prussian Blue Analogues (PBA) cathodesmay contain nocritical raw materials andcould havea very low compositional toxicity. We took a safe-and-sustainable-by-design approach towards PBAs, aiming at the same time for the best possible electrochemical performance and the lowest toxicity, focusing on Fe(II)/Fe(III) ratio and particle size. Rate capability tests and cellular effects (e.g. cytotoxicity) showed that lower Fe(II)/Fe(III) ratios contribute to reduced cytotoxicity, whereas smaller particle size enhances electrochemical performance, but in the limit also may increase toxicity.

Unconventional Semiconductors for Photovoltaics via Physical Vapor Deposition: Transparent Conducting and Photoactive Materials

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Thin-film photovoltaics (PV) are a critical technology for achieving low-cost and environmentally sustainable solar energy conversion and enable applications like indoor photovoltaics and light weight devices. While metal halide perovskites (MHPs) currently lead in thin-film PV performance, issues such as lead toxicity and long-term stability remain significant challenges. This has driven the exploration of alternative, Earth-abundant, and non-toxic semiconductors with complex compositions. However, translating new materials into functional thin films is often limited by fabrication challenges, including volatility mismatches or solvent incompatibilities, which hinder both material quality and integration into devices.

This presentation will discuss how the synergy between mechanochemical synthesis and pulsed laser deposition (PLD) enables the discovery and growth of novel thin-film semiconductors. We will present recent progress on Pb-free perovskites, emerging chalcohalidelight-absorbers and p-type transparent electrodes like S- and Cs-doped CuI. In addition, we will explore how this approach can be extended to the controlled growth of 2D layered materials, which offer tunable optoelectronic properties and opportunities for novel device architectures when integrated with other thin-film systems.

In summary, we highlight how targeted synthesis strategies and advanced deposition methods can accelerate the development of next-generation, efficient, and sustainable materials for thin-film optoelectronic devices.

Perovskite and 2D Materials: A Synergistic Duo for Multi-Purpose Photovoltaic Applications

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Perovskite photovoltaics are rapidly transitioning from record-breaking laboratory curiosities to a versatile, scalable energy platform poised to revolutionize both large-scale outdoor solar generation and low-light indoor power harvesting for the burgeoning Internet-of-Things (IoT) landscape. Achieving this ambitious vision demands a holistic rethinking that goes beyond absorber chemistry: it requires mastery over interfaces, dimensionality, defect dynamics, and processing scalability. Within this paradigm, two-dimensional (2D) design principles emerge as a unifying and transformative strategy—encompassing not only the incorporation of external low-dimensional materials but also the deliberate engineering of layered perovskite phases intrinsic to the absorber. Here we report a comprehensive 2D-enabled approach spanning 3D, 3D/2D and quasi-2D perovskite absorbers. At buried and top interfaces, low-dimensional additives precisely tune work-function alignment, modulate interfacial dipoles, suppress non-radiative recombination, and guide crystallization kinetics. In particular, MXene-based additives for 3D perovskiteenable effective energy-level alignment and defect passivation, which translates from small-area devices to large-area modules and tandem-compatible architectures.[1,2] This strategy has enabled high-efficiency and semi-transparent perovskite top modules (ST-PSMs) exceeding 16%, while maintaining performance upon the integration in tandem panels. Indeed, coupling MXene-based ST-PSMs with commercial silicon heterojunction bifacial cells in a 4-terminal architecture has yielded a 20x20cm2 (45x45 cm2) mini-panels(panels) with over 21% (19.5%) PCE and a power generation density (PGD) exceeding 23 mW/cm², when a typical albedo radiation of 30% from the ground is considered.[3]This approach allows for the optimization and stacking of ST-PSMs without changes to silicon production lines, making it attractive for silicon cell manufacturers.

In 3D/2D heterostructures, the formation of a phase-pure PEA_2PbI_4 overlayer via PEAI:DIO treatment delivers synergistic chemical passivation and electronic reconstruction at the perovskite/charge transport interface.[4] This yields marked improvements in open-circuit voltage and efficiency under both 1-Sun and indoor illumination. Crucially, this strategy scales to large-area modules achieving 15.6% efficiency under standard solar spectra and up to 34% at 1000 lux, alongside a threefold increase in operational stability. Extending beyond hybrid 3D absorbers, we implement 2D concepts in quasi-2D alternating-cation-interlayer perovskites with engineered phase distributions,[5] achieving stable indoor power conversion efficiencies nearing 20% across a wide illuminance range (200–1000 lux). By uniting interfacial 2D materials with dimensional control of absorbers in a single framework, this work positions 2D design principles as a scalable, multifaceted route to stable, efficient, and application-specific perovskite photovoltaics—bridging outdoor solar generation and effective indoor energy harvesting.

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Aging of Carbon Dot Stock Solutions: An Overlooked Parameter Affecting Additive Concentration and Reproducibility in Perovskite Solar Cells

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Carbon dots (CDs) have recently attracted significant attention as multifunctional additives for defect passivation and interface engineering in perovskite solar cells (PSCs). However, the reproducibility of CD-based additive engineering remains challenging, partly due to possible timedependent changes in the stability of stock dispersions.

In this study, we investigate how the aging of a carbon-dot stock solution influences the effective additive concentration introduced into perovskite precursor solutions and the resulting photovoltaic performance. A CD stock solution was prepared by dispersing 5 mg of CDs in 5 mL of dimethyl sulfoxide (DMSO) to obtain a homogeneous dispersion. On the first day after preparation, a portion of the stock solution was filtered and used to prepare perovskite precursor solutions with nominal CD concentrations of 0.007 mg mL^{-1} and 0.014 mg mL^{-1}. Devices fabricated from freshly filtered dispersions exhibited improved photovoltaic performance, whereas devices prepared from one-week-aged stock solutions showed a noticeable decline in device performance.

UV-Vis measurements indicated an increase in the absorbance of the filtered dispersions obtained from the aged stock solution, suggesting a time-dependent increase in dissolved or dispersed carbon species.This behavior is attributed to gradual changes in the dispersion equilibrium of CDs in DMSO, which may lead to the release of smaller carbonaceous species or changes in CD aggregation, thereby altering the effective additive concentration delivered to the perovskite precursor solution.

These results indicate that the effective concentration of carbon-based additives in perovskite precursor solutions can vary significantly depending on the aging time of the stock dispersion. Our findings highlight stock solution aging as a previously overlooked but critical parameter that must be carefully controlled to ensure reproducibility in carbon-based additive engineering for perovskite solar cells.

Carbon Nitride Thin Films for Energy Conversion

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Two-dimensional materials in the carbon nitride family have recently garnered attention for their ability to function as photocatalysts under visible light. However, their application as thin films have been limited due to poor coating homogeneity. We have developed an innovative chemical vapor deposition (CVD) method that enables the deposition of carbon nitride thin films with tuneable thickness and high uniformity.[1] The conformal nature of these CVD-grown films allows integration into microfluidic reactors, where they demonstrate superior performance in the photocatalytic oxidation of benzylic alcohols under flow conditions.[2] Furthermore, the homogeneity of the films facilitates the use of advanced spectroscopic techniques—including NMR, XPS, and XAS—for in-operando analysis of photocatalytic reaction mechanisms.[3,4] Using in-operando XPS and XAS, we explored the mechanism of photocatalytic water splitting, uncovering the crucial role of surface interactions, particularly the formation of hydrogen bonds with water, in activating the carbon nitride surface. Upon illumination we were able to confirm the evolution of hydrogen and oxygen while the spectroscopic features recorded support the proton-coupled electron transfer (PCET) mechanism.4 These insights provide a fundamental understanding of one of the most extensively studied reactions of the past decade. Although the use of thin films in energy conversion applications is still emerging, this work highlights their potential to drive significant progress in photocatalysis, photoelectrocatalysis, and beyond.

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Computational Modeling of New Generation Materials for Photovoltaics and Catalysis

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Hybrid AMX_3 perovskiteshave in the last years revolutionized the scenario of photovoltaic technologies.We developed an effective GW method incorporating spin-orbit coupling [1] which allows us to accurately model the electronic, optical and transport properties of halide perovskites. In parallel, a series of different strategies will be reported to increase the device stability and efficiency.[2]While instability in aqueous environment has long impeded employment of metal halide perovskites for heterogeneous photocatalysis, recent reports have shown that some particular tin halide perovskites (THPs) can be water-stable and active in photocatalytic hydrogen production. To unravel the mechanistic details underlying the photocatalytic activity of THPs, we compare the reactivity of the water-stable and active DMASnBr3 (DMA = dimethylammonium) perovskite against prototypical $MASnI_3$ and $MASnBr_3$ compounds (MA = methylammonium), employing advanced electronic–structure calculations. We find that the binding energy of electron polarons at the surface of THPs, driven by the conduction band energetics, is cardinal for photocatalytic hydrogen reduction.[3] In this framework, the interplay between the A-site cation and halogen is found to play a key role in defining the photoreactivity of the material by tuning the perovskite electronic energy levels. Our study, by elucidating the key steps of the reaction, may assist the development of more stable and efficient materials for photocatalytic hydrogen reduction. We report a report is made on a composite system including a double perovskite, used for solar-driven hydrogen generation and nitrogen reduction, quantified by a rigorous analytical approach. [4] Finally, a new approach for enantioselective synthesis has been reported with chiral perovskite catalyst.

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Development of Micron-Sized Carbon-Coated Porous Si Powders Assembled from Si Nanoparticles for High-Energy-Density Lithium-Ion Batteries

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Silicon (Si) anodes suffer from a critical trade-off: particles larger than100 nm undergo severe pulverization due to volume expansion, while nanoparticles cause excessive solid electrolyte interphase (SEI) formation and electrolyte decomposition due to their large surface area. To address this dilemma, we developed carbon-coated micron-sized porous Si powders assembled from carbon-coated Si nanoparticles. This hierarchical architecture minimizes the exposed surface area to limit SEI formation, while the internal voids and double carbon coating effectively accommodate volume expansion and enhance electrical conductivity. The resulting anode delivers a high reversible specific capacity of up to 2385 mAh g-1with a coulombic efficiency exceeding 92% in half-cells. When paired with an NMC811 cathode (35 wt% Si loading) in full cells, the system achieves a gravimetric energy density of approximately 340 Wh kg-1 and maintains stable cycling performance over 500 cycles. We demonstrate the practical utility of this high-energy chemistry in unmanned aerial vehicle (UAV) applications, where the enhanced battery performance extends flight hovering time from 30 minutes to approximately 50 minutes.

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Day-1

NanoSeries2026 Technical Session: NS (B)

Nano–Bioengineering for Medicine: Therapeutics, Diagnostics, and Regeneration

Rational Design of Bio-Mimicking Nanoparticles as Stimuli-Responsive Nanotheranostic Platform for Cancer Treatment

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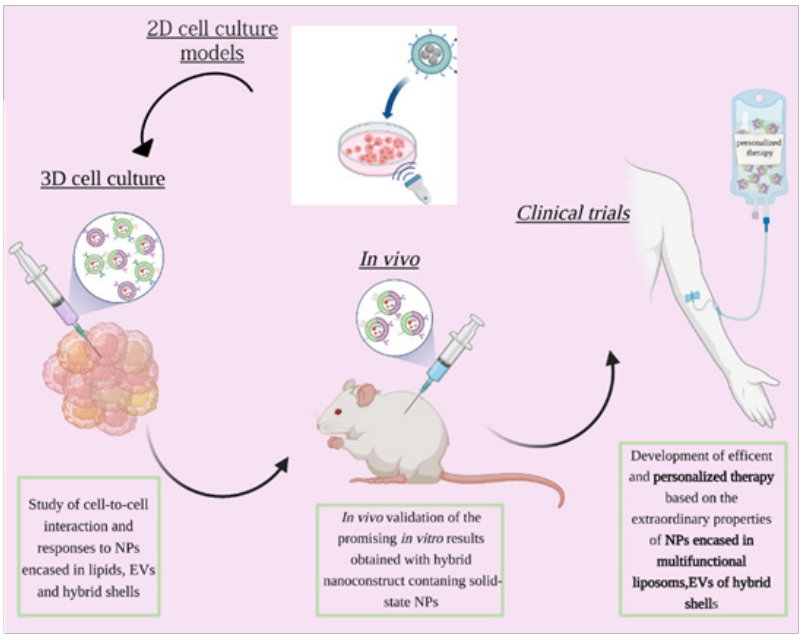
Cancer remains a major global health challenge, heavily requiring the development of multifunctional theranosticsystems that combine precision targeting, robust therapeutic efficacy and diagnosis in a single platform. Here, we describe the preparation of a biomimicking, biocompatible and stimuli-responsivenanoparticle aiming at impairing tumor growth and proliferation.

We developed iron-doped zinc oxide nanocrystals via a wet-chemical method, designed to leverage both diagnostic and therapeutic capabilities. Iron doping imparts biocompatible properties, while the semiconductor nature of ZnOenables the generation of reactive oxygen species (ROS) under external stimulation by acoustic pressure waves, like ultrasound or shock waves, as therapeutic mode of action. Furthermore, these nanocrystals show to greatly reduce the cavitation threshold of ultrasound, allowing to explore also imaging functions. To enhance stability and selectivity, we developed lipidic coatings either inspired to COVID-19 vaccines or biomimicking natural extracellular vesicles. These lipid bilayers include,among others, a functional lipid covalently linked to a targeting peptide or fragmented monoclonal antibodies. These targeting moieties significantly increase nanoparticle uptake by malignant cells both in solid and hematologicaltumors.

The nanoparticles were tested on different tumor models, from hematological cancers, like B-cell and T-cells lymphomas, multiple myelomas, and solid tumors (pancreatic, colorectal, and osteosarcoma ones), starting from two-dimensional (2D) monolayers to physiologically relevant three-dimensional (3D) spheroid models, up to more complex 3D geometries and in vivo mice models, until patients' derived cells. While the 2D cultures offer initial insight into the safe-by-design properties of the NPs, the 3D models provide a more accurate mimic of in vivo conditions and are particularly important for ultrasound-based treatments, where wave propagation in 3D influences therapeutic outcomes.

In the in vivo setting, the therapeutic and imaging effectswere most pronounced in the group receiving NPs with ultrasound stimulation. This combination resulted in a marked decrease in tumor volume, increased immune cell infiltration, enhanced tumor cell apoptosis, extended survival of treated mice, and high contrast signal visualizing the tumor mass.

By combining triggeredtherapy with targeted delivery and imaging capabilities, this nanoplatform represents a promising step forward in the pursuit of more flexible and potent strategies against treatment-resistant malignancies.



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Design of Stimuli-Responsive Nanomaterials as Controllable Carriers and Diagnostic Tools

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The advancements in nanotechnology have opened new opportunities in the biomedical field, offering new strategies to achieve controlled drug delivery and to improve the diagnosis of diseases. The design of sophisticated nano-based responsive nanocarriers is driven by the need to enhance therapeutic efficacy addressing key medical challenges such as on-demand treatment and early diagnosis.

During this presentation, I will walk you through the activities related to the pH- and light-controllable drug delivery systems [1,2] that led me to design the recently started MSCA project, BRAVERY. Within this project, my objective is to improve the brain delivery of neuroactive compounds by developing a responsive nanomaterial that overcomes the major hurdles encountered so far: i) poor brain accumulation, ii) unfavorable drug release, and iii) limited biocompatibility. Such a versatile biocompatible multi-drug nanocarrier will pave the way toward the therapeutic strategy for neurodegenerative disorders (i.e. Alzheimer's and Parkinson's diseases etc.), with a remarkable impact on society and healthcare systems worldwide. I will also present stimuli-responsive nanomaterials specifically designed to improve the diagnosis of bacterial infections, tackling antimicrobial resistance. In particular, I will focus on fluorescent-based indirect approaches to sensitively and selectively detect bacteria (i.e. S. aureus and K. pneumoniae), showing the results achieved with specifically designed nanomaterials enabling the cost-efficient indirect detection of bacteria [3,4].

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Hybrid Biomimetic Nanoparticles: Cutting-edge Strategies for Targeted Early Treatment and Detection in Glioblastoma Multiforme

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Glioblastoma Multiforme (GBM) remains a clinical challenge due to its aggressive invasiveness and the restrictive nature of the Blood-Brain Barrier (BBB), which severely limits the efficacy of standard therapies [1]. While nanomedicineoffers a promising frontier for high-dose drug delivery, its success depends on maintaining stability within complex environments and achieving precise, tumor-specific targeting [2]. However, clinical translation is often hindered by rapid immune clearance and poor accumulation at the target site, a bottleneck particularly critical in CNS disorders where the BBB acts as a formidable gatekeeper [3]. To overcome these barriers, cell membrane-coated NPs (CM-NPs) have emerged as a breakthrough strategy; by mimicking biological entities, these nanocarriers enhance biocompatibility and adopt the functional identity of the source cells to ensure superior therapeutic targeting [4].

In this study, we first engineered Solid Lipid Nanoparticles (SLNs) withtunable mechanical properties by adjusting the ratio of liquid to solid lipids. Our findings revealed that softer lipid cores optimize translocation across the BBB, while increased rigidity enhances cellular internalization. Building on this mechanical foundation, these cores were functionalized with biomimetic coatings, using GBM cell membranes, ensuring colloidal stability and significantly increasing cellular uptake. Notably, this coating actively enhanced BBB permeability in a human in vitro model. This strategy evolved into a hybrid design incorporating human microglia and GBM membranes. This dual-coating approach synergizes 'homotypic targeting' with microglial ligands to interact with BBB receptors, maximizing therapeutic delivery while minimizing neuroimmune activation and inflammation.Comparing four CM-NP systems, hybrid NPs demonstrated superior stability, efficient drug encapsulation, and GBM uptake. These nanocarriers effectively penetrated the CNS and accumulated in tumor regions while significantly minimizing neuroimmune activation.Our findings highlight the potential of merging mechanical tunability with biomimetic engineering to create new platforms that offer improved targeting, CNS penetration, and therapeutic efficacy.

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Glyconanomaterials: Advanced Tools for Precision Cancer Therapy

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Glycoscience, the interdisciplinary study of the structure, function, and biology of carbohydrates (or glycans) and their roles throughout biology, has made significant strides in the past decade, putting in the spotlight the key role of glycans in cancer development. So, glycoscience is now poised for the discovery of a new generation of glycan-based cancer therapeutics.

In this lecture recent developments of glyconanomateirals and their potential in providing new and effective glyco-based strategies to fight cancer will be described. In particular, a specific focus will be dedicated to the development of cellulose-based glyconanomaterials as a new generation of nanoradiosensitizers in precision cancer radiotherapy and as platforms for the development of cancer vaccines

Snowball Effect: A Synergistic Nanotechnology Platform for Precision Radiosensitization of Triple-Negative Breast Cancer

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This strategy addresses the challenge of treating metastatic tumors that are often resistant to conventional therapies, including radiotherapy. Radiotherapy damages cancer cell DNA through ionizing radiation, but its effectiveness is limited by radioresistance. A key cause of radioresistance is tumor hypoxia - regions with very low oxygen levels - which reduces the production of reactive oxygen species (ROS) necessary to amplify radiation-induced damage1. As a result, hypoxic tumor cells survive treatment, promote metastatic progression, and increase the risk of recurrence and therapeutic failure.

Gold nanoparticles (AuNPs) are known to be radiotherapy enhancers due to their high radiation absorption capacity2. However, their clinical translation has been limited by rapid systemic and cellular clearance and the need for high (potentially toxic) doses to achieve sufficient tumor accumulation.

The proposed technology integrates two complementary innovations to create a precision radiotherapy platform designed to enhance therapeutic efficacy, sensitize radioresistant tumors, reduce radiation doses to healthy tissues, and provide tumor-selective treatment. The innovation lies in both its molecular design and its coordinated therapeutic strategy: gold nanoparticles of different sizes and functions were applied for photothermal therapy and for radiosensitization. Circulating endothelial progenitor cells (ECFCs) served as cellular carriers, acting as a "Trojan horse" to transport and accumulate nanoparticles even in hypoxic tumor regions. Moreover, ECFCs improved in vivo biodistribution through natural tumor homing3. Carbohydrate AuNPs coatings, indeed improve nanoparticle stability and promote selective uptake by tumor cells4.

Infrared light activates the gold nanorods, generating localized heat that damages tumor cells and triggers the release of radiosensitizing AuNPs anchored to a cellulose nanocrystal (CNC) platform (CNC-Au-Glc). This construct is engineered with tumor-targeting elements to enhance cellular uptake and retention, overcoming rapid excretion. Subsequent exposure to X-rays increases local radiation dose deposition and ROS production, amplifying the damage initiated by photothermal therapy in a sequential therapeutic cascade.

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Beyond Delivery: Nanoparticles as Active Modulators of Cancer Cell Molecular Architecture

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Metallic nanoparticles (NPs), including silver and gold nanostructures, are traditionally developed as drug carriers, imaging probes, or photothermal agents in oncology. Here, we propose a paradigm shift: metallic nanoparticles act as intrinsic bioactive entities capable of reshaping cancer cell molecular and structural architecture independently of therapeutic cargo.

We investigate how nanoparticle physicochemical parameters—core composition, size, anisotropic shape, surface charge, and interfacial reactivity—govern nano–bio interactions across multiple cellular scales. Owing to their catalytic and redox-active surfaces, metallic NPs perturb intracellular oxidative balance and mechano-sensitive pathways, triggering coordinated remodeling of signaling networks, metabolism, and cellular structure.

Through advanced imaging, transcriptomic profiling, and biophysical analyses, we demonstrate that metallic NP–cell interactions alter intracellular trafficking routes, nuclear organization, chromatin accessibility, and gene expression programs associated with survival, proliferation, invasion, and therapeutic resistance. Using silver nanoparticles (AgNPs) in triple-negative breast cancer (TNBC) cells, we observe dose- and time-dependent cytotoxicity with limited effects on non-tumorigenic endothelial cells, suggesting tumor-selective vulnerability. AgNP exposure increases ROS production, activates p38 MAPK signaling, modulates key metabolic regulators, and destabilizes lipid droplets, indicating disruption of redox–metabolic homeostasis. Complementarily, gold nanorods (AuNRs) induce higher-order chromatin rearrangements and alterations in nuclear organization, accompanied by F-actin cytoskeletal remodeling in melanoma and pancreatic cancer models.

These findings reveal a multiscale nano–bio coupling in which metallic nanoparticles simultaneously influence membrane dynamics, metabolic plasticity, chromatin architecture, and intracellular mechanics. Collectively, our results support a new conceptual framework in which inorganic metallic nanoparticles function as nano-architectural regulators capable of reprogramming cancer cell states through integrated redox, metabolic, and mechanotransductive pathways. This perspective opens new avenues for the rational design of next-generation nanotherapeutics that operate beyond delivery, exploiting the intrinsic physicochemical properties of metallic nanomaterials to modulate tumor cell organization and function.

Lipid Nanoparticle-Based Delivery of CRISPR/Cas9 Machinery Configured for Site-Specific Integration of CFTR Enables Cystic Fibrosis Mutation Agnostic Disease Rescue

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Lipid nanoparticles (LNPs) configured to transport CRISPR/Cas9-based gene editing reagents have enabled the direct engineering of stem and progenitor cell populations targeted for emerging gene and cell-based therapies. Here we design LNPs capable of packaging editing components required for homology directed repair (HDR)-mediated site-specific insertion of a full-length copy of the cystic fibrosis transmembrane conductance regulator (CFTR) gene to correct cystic fibrosis (CF) in diseased airway epithelium. Nanoparticle formulations were screened by adjusting ratios of Cas9-encoding mRNA, single guide RNAs (sgRNAs), and large (>5 kb) linear double-stranded DNA (ldsDNA) donor templates to optimize gene editing using human bronchial epithelial cells (16HBE14o-) harboring a CF-causing mutation (G542X). This mutation was selected as a model for our studies because it is responsible for causing CF in roughly 4.5% of patients and individuals with this mutation cannot benefit from existing CFTR modulator therapies. Populations of G542X-16HBE14o- cells edited via LNP delivery of codon-optimized CFTR donors achieved 3 – 3.5% gene integration and yielded CFTR protein expression comparable to normal 16HBE14ocontrols. These edited populations exhibit restoration of CFTR-dependent Cl- current to ca. 80% of values measured in normal 16HBE14o- cell monolayers. The capability for transporting large gene editing reagents to airway epithelial cells demonstrated by this LNP platform enables genomic integration of the entire CFTR gene coding sequence at its endogenous locus, enabling therapeutic solutions that achieve correction of any CF-causing mutation.

CEACAM5 Biomarker Characterization and Fluorescent Detection Tool for Image-Guided Gastric Cancer Surgery

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Gastric cancer (GC) is the third leading cause of cancer-related mortality worldwide, with approximately one million new cases diagnosed annually. Although surgery remains the primary treatment, the lack of specific intraoperative tools to distinguish malignant from healthy tissue and to accurately identify metastatic lymph nodes necessitates indiscriminate lymph node resection, increasing surgical risk. Near-infrared (NIR, ~800 nm) fluorescent contrast agents such as indocyanine green (ICG) enable real-time visualization during laparoscopic and robotic procedures; however, their limited tumor specificity highlights the urgent need for biomarker-targeted fluorescent probes [1]. Accordingly, this study aims to develop a novel fluorescence-based tool for real-time surgical use to improve metastatic mapping in gastrectomy procedures.

We evaluated the expression of candidate GC markers, including carcinoembryonic antigen-related cell adhesion molecule 5 (CEACAM5), in GC cell lines by western blotting. CEACAM5 expression was further assessed by immunohistochemistry (IHC) in tumor and matched healthy tissues from 35 GC patients who underwent partial gastrectomy at the Digestive System Surgery Unit, Florence. CEACAM5 was significantly expressed in tumor samples but absent or minimally present in healthy mucosa ($p = 0.0018$), confirming its tumor specificity. This specificity was further validated in patient-derived organoids. We are developing a novel tool targeting CEACAM5 and fluorescent in the NIR range to selectively label GC cell surfaces. The binding properties of this tool will be evaluated by western blotting in GC cell lines and in patient-derived tumor and healthy mucosal tissue slices.

Moving forward, this system represents a strong candidate for in vivo validation and clinical translation in precision gastrectomy, with potential applicability extending beyond gastric cancer to a broad range of CEACAM5-overexpressing malignancies.

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Design of Versatile Multimodal Nanocarriers toward Cancer Therapeutic and Diagnostic Platforms

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The development of nanotechnology-drivencancer therapeutics and diagnostics requires substantial effort to translate promising concepts into improved clinical outcomes. Effective nanocarriers must combine biocompatibility, prolonged circulation, targeted delivery, and high stability to address current challenges in the field.Our strategy to enhance these properties involves tailoring biopolymers as stabilizing and shell-forming materials to design versatile nanocarriers with multiple capabilities. In my talk, I will first present the design of hyaluronic acid nanocapsulesfor pH-responsivedelivery of doxorubicin [1].We also utilize hyaluronic acid in combination with albumin to coat diverselipid nanoparticles and gold nanorods using our previously developed protocols [2,3]offering potential targeting capability toward breast cancer cells for selective drug delivery and photothermal therapy.The resulting nanocapsules and hybrid nanoparticles exhibit high physicochemical stability, good cytocompatibility, and stimuli-responsivebehavior, highlighting their potential for the development of multimodal nanoplatforms in cancer therapy and diagnosis.

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Computational Design of Heterogeneous Coatings to Modulate Macrophage Uptake of Gold Nanoparticles

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Self-assembled monolayers (SAMs) on gold nanoparticles (AuNPs) enable the rational tuning of surface properties, which is of central importance for nanomedicine applications.[1,2] However, establishing direct relationships between SAM structure and nanoparticle behavior remains experimentally challenging, requiring complementary computational approaches. In this talk, I will present an integrated experimental–computational study combining differential centrifugal sedimentation and electrophoretic light scattering with coarse-grained simulations to extract structural information on mixed SAMs with varying degrees of disorder at their hydrophilic, solvent-exposed interface.[3] We propose a design strategy to control disorder in the hydrophilic region of negatively charged SAMs that extends beyond standard thiolated ethylene glycol oligomers. Our results show that SAM coatings with higher chain-length heterogeneity exhibit increased hydration and form a more diffuse electric double layer. This subtle nanostructure heterogeneity, which emerge only through the integration of experiments and simulations, significantly affect nanoparticle internalization by macrophages. Overall, this work elucidates a structure–function relationship and provides a general framework for optimizing SAM composition on nanoparticles for nanomedicine applications.

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Nanozyme Engineering Strategies for Controlled and Enhanced Functionalities

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Nanozymes (catalytic nanomaterials that can mimic the activity of natural enzymes) are raising interest for various applications in different fields including nanomedicine, diagnostics, sensing, and pollutant degradation owing to their versatility, stability, and low cost [1]. It has been recently shown that Platinum Nanozymes (PtNZs) present multi-enzymatic oxidoreductase-like activity outperforming catalytic activity of the most employed nanozymes in the field [2]. PtNZ can perform Oxidase (OX), Peroxidase (POD), Catalase (CAT), and Superoxide Dismutase (SOD) activities all together but exerting CAT in a much more efficient way in the biological context. Indeed, by mimicking CAT and SOD activities, PtNZs have been shown to counteract oxidative stress in vitro and in vivo, providing effective protection even in central nervous system dysfunctions models [3,4]. In view of future therapeutical applications, the implementation of a specially designed surface ligand-shell is necessary to provide PtNZs targeting ability (minimizing biomolecular corona) and allow them to selectively perform their antioxidant functions. In this study we analyzed the PtNZ engineering process facing a peculiar situation. We observed that the multi-enzymatic behavior of PtNZ could also hamper the commonly employed functionalization strategies for nanoparticles. Interestingly, thiol-ligands, conventionally employed for metal nanoparticles [5], were unsuitable for PtNZ as they were susceptible to its OX-like activity. We therefore implemented a different strategy involving an oxidation-resistant, carbene-based ligand. This approach: (i) provided a long-lasting ligand shell with high stability in complex biological media; (ii) reduced non-specific protein adsorption; and (iii) offered flexibility for further functionalization and targeting applications. Overall, a general conclusion from this study is the need for extra care when characterizing the NZ-ligand shell, as intrinsic catalytic activity can lead to a 'chemistry of conflict' that fundamentally alters NP-ligand interactions.

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Functionalized Silica Nanoparticles with MnO_2 for H_2O_2-based wound Management

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Chronic wounds affect up to 2% of the world population, impacting the quality of life of the patient and presenting a socioeconomic burden to the patient and healthcare [1]. Currently, wound assessment relies on visual inspection, whereas wound biomarkers such as H_2O_2 could improve diagnostic accuracy, as its concentration increases in chronic wounds (>250 µM)[2, 3]. Interest in wearable Point-of-Care (POC) devices for non-invasive diagnostics has grown over the last decade, with optical sensors being a promising approach for wearable POC device[4]that align with the ASSURED criteria [5], improving wound management.

Here, we present a wearable H_2O_2-based colorimetric wound dressing for wound assessment. The probe was synthesized through the Stöber method, loading manganese dioxide (MnO_2) nanoparticles in silica nanoparticles (MnSNP), adjusting a previous protocol[6], and embedded in agarose hydrogel to achieve the final wound dressing. When in contact with H_2O_2, MnO_2 is reduced from Mn4+to Mn2+, resulting in a color change from brownish to colorless, which allowsa qualitative analysis with the naked eye, and a quantitative analysis through a smartphone-based RGB analysis. MnSNP was tested against H_2O_2 at various concentrations, with MnSNP at 5 mg/mL and 6 mg/mL yielding the best results, with a limit of quantification (LOQ) of 64 µM and 117 µM, respectively, indicating its suitability for detecting H_2O_2 in chronic wound diagnosis. MnSNP was incorporated into the wound dressing at different concentrations and tested against H_2O_2, demonstrating a responsive color change detectable through RGB analysis.

The wound dressing showed promising results for the development of a simple, affordable, and sensitive wearable colorimetric POC for wound assessment. Such awound dressing could help decentralize patient care, decreasing the burden on the healthcare system and improving patient compliance and quality of life.The probe also demonstrated potential for diverse H_2O_2-based detection applications.

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Prussian Blue Nanoparticles (PBNPs) as Biocompatible Photothermal Antibacterial Agents

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Prussian Blue (PB) is an iron-based coordination polymer that has been known since the 18th century. Recently, growing attention has been focused on its nanometric form for potential biomedical applications: particularly in imaging and therapeutic fields. PB is already approved by the FDA as an antidote for Tl^+ and Cs^+ intoxication. Prussian Blue nanoparticles (PBNPs) exhibit strong photothermal properties and can be employed in cancer photothermal therapy as well as in antibacterial photothermal treatments.[1] PBNPs also show a very good biocompatibility, as does the bulk material. [2]

PBNPs grafted on a surface can impart an effective photothermal antibacterial effect against both planktonic bacteria and biofilms and can be combined with intrinsically active antibacterial nanomaterials like silver.[3]

The quantity of PBNP grafted on a surface can be easily tuned with a layer-by-layer approach, and the use of a multilayer can help increase the local hyperthermia. Multiple layers of PBNP can be grafted on a surface using biocompatible poly-L-lysine as the grafting layer. The morphology and composition of the functionalized glass surfaces were extensively investigated using UV-Vis spectroscopy, surface zeta potential measurements, SEM imaging, and photothermal effect study following 808 nm NIR laser light irradiation.

PBNPs multilayersgrafted on glass show a good photothermal antibiofilm activity against Staphylococcus aureus ATCC25923. The antibiofilm effect was evaluated with quantitative measurements and Confocal Laser Microscopy imaging. ROS generation and synergic interactions with a traditional antibiotic therapy were also evaluated.

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Deep Tech Translation in Nanotechnology: Scientific, Regulatory, and Industrial Bottlenecks

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The global transition toward Deep Tech represents a paradigm shift where frontier science is leveraged to solve complex, high-value problems. However, the journey from laboratory to market for nanotechnological innovations is characterized by a series of structural challenges. This workshop explores the critical bottlenecks that define this trajectory, focusing on three foundational pillars: Scientific, Regulatory, and Industrial.Scientific bottlenecks are often rooted in the inherent uncertainty of frontier knowledge. Nanotechnology requires a deep understanding of material behaviour, where traditional models may should be adapted, leading to unpredictability in biological interactions and long-term stability. Regulatory bottlenecks arise from the gap between rapid technological advancement and existing legal frameworks. Strict or slow-moving regulations—as seen historically in other deep tech sectors—can hinder global competitiveness and limit the adoption of innovations. Finally, industrial bottlenecks center on the difficulty of scaling. Transitioning from a controlled laboratory environment to mass production involves complex engineering and supply chain hurdles, where even minor process variations can compromise the integrity of the nanomaterial.By repositioning researchers as scientific entrepreneurs, this workshop aims to discuss how these barriers can be navigated to ensure that nanotechnology moves beyond theory into tangible, society-altering applications.

Day-1

NanoSeries2026 Technical Session: NS (D)

Hierarchical Assembly of Functional Nanomaterials

Bioinspired Multiscale Pore/Channel Systems

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"Pore" and "Channel" are everywhere, e.g., from small biological ion channels to large oil pipelines. The difference between pore and channel is the relationship between its diameter and its depth. If the diameter is greater than its depth, it is referred to as Pore, otherwise, Channel. Both "Pore" and "Channel" have a wide range of significant applications on different scales. For example, pipelines which are commonly used in the chemical industry, food industry, agriculture, and energy-petroleum transportation, can be treated as macro-scale channels. The problems with such channels center on energy-saving, anti-fouling, anticorrosion, and anti-block. Another example of micro-scale pores is "liquid gating technology", which has a great impact in the areas of chemical synthesis, biological analysis, optics and information technology, etc. It utilizes the capillary-stabilized functional liquid as a pressure-driven, reversible, and reconfigurable gate to fill and seal the pores in the closed state and create completely liquid-lined pores in the open state under pressure changes. Recently, it has already become a reality by design of various smart materials by responsive design of the porous solid phase and dynamic liquid phase, which expand the basic scientific issues of the traditional membrane materials from the solid-liquid/gas interface to the solidliquid-liquid/gas interface and have found applications in chemistry, energy, environmental, and biomedical related interdisciplinary fields. For nano-scale systems, we design and prepare smart symmetric/asymmetric nanochannels by physicochemical design of responsive porous materials and realize the regulation of mass transport in the nanoconfined spaces and focus the new research directions on bioinspired nanofluidic iontronics.

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Controllable Electrical Doping of Inorganic–Organic Hybrid Perovskite Semiconductors for High-Performance Photovoltaic Devices

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Doping is one of the most important topic in semiconductor science. Due to the unique character of organic-inorganic hybrid perovskite semiconductorswith dative bonds and soft lattice, it's almost impossible to realize such ionic doping in the perovskite lattices as in silicon. On the other hand, surface transfer doping mechanism offers us an alternative route to realize doping in perovskites, which was firstly reported on the diamond by Ristein Jurgen in 2004. [1]In 2018, we reported the surface transfer doping for p-NiO via F6TCNNQ molecule, in which the electron transfer from NiO to F6TCNNQ was revealed for the first time by surface probe microscopy. [2] One year later, we enhanced n-doping of SnO2 by triphenylphosphine oxide. [3] In 2023, we designed DMAcPA molecule and successfully realized p-doping of CsFAMA mixed-cations perovskite via the surface charge transfer occurred at grain boundaries.[4] Depending on that doping, a well matchedp-perovskite/ITO contact were obtained, along with a power conversion efficiency of 25.86%. Moreover, that dative complex of DMAcPA molecules also passivate well all-round grain boundaries, realized by so called molecule-extrusion process. Currently, we pushed the device conversion efficiency to over 27% through the top surface modulation of perovskite film.[5]

Keywords: Hybrid perovskite semiconductors; surface transfer doping; perovskite solar cells; grain boundaries; charge transfer.

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Self-Assembly of PEGylated Carbon Nanodots into Solid-State Emissive Superparticles

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Carbon nanodots (CDs) are a fascinating class of fluorescent carbon-based nanoparticles, exhibiting excitation-dependent luminescence and low toxicity, which make them attractive for cost-effective and biocompatible photonic applications. However, their implementation into solid-state optoelectronic devices is severely limited by luminescence quenching in the aggregated state [1, 2]. Controlled assembly provides a promising strategy to engineer collective physicochemical properties arising from interparticle coupling while mitigating aggregation-induced quenching [3].

In this work, we investigate whether the hierarchical organization of CDs into superparticles can be capitalized to enable bright and stable solid-state emission [4].

Carbon nanodot superstructures are fabricated via a controlled emulsion-templated assembly approach, where spontaneous aggregation within confined microdroplet templates yields well-defined superparticles composed of either bare or surface-functionalized CDs. Interparticle coupling is modulated through surface functionalization with polyethylene glycol (PEG) chains of different molecular weights (PEG400 and PEG3000).

TEM and SEM imaging confirm the spherical morphology of the superstructures, with diameters ranging from ~150 nm to a few micrometres. Their optical properties are investigated through steady-state and time-resolved photoluminescence spectroscopy in the ps-ns time domain at the level of individual superparticles.

Notably, the emissive behaviour of both bare and PEGylated CDs is preserved in the assembled state despite nanoparticle aggregation, with all superstructures exhibiting an emission band centred at 510 nm. PEGylation suppresses fast non-radiative decay channels, modulating recombination kinetics within the superparticle and resulting in increased excited state lifetimes and enhanced photoluminescence quantum yield.

Environmental humidity significantly affects the emission stability of the superparticles. PEGylation preserves structural integrity and mitigates moisture-induced photoluminescence degradation by slowing photobleaching dynamics associated with water penetration and disruption of the super-architecture.

This work demonstrates that controlled assembly is an effective strategy to overcome aggregation-induced quenching in CDs and establishes PEGylation as a key encapsulation strategy to protect the integrity of the superstructure toward real-world applications.

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Reversible Assembly of Iron Oxide Nanoparticles on Gold Nanorods for Magnetic Alignment and Plasmonic Control

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Overcoating gold nanorods (GNRs) with plasmonic or magnetic satellite nanoparticles (NPs) can modify the longitudinal and transverse localized surface plasmon resonance (LSPR and TSPR) through coupling with the satellite NPs. We report use of electrostatic interactions to reversibly assemble different types and amounts of satellite NPs on GNR cores, which allows coupling with and manipulation of the LSPR and TSPR of the GNR core. Cationic Fe3O4 NPs and spherical gold NPs (GNPs) functionalized with polyethylenimine (PEI) assemble on the surface of anionic GNRs functionalized with bovine serum albumin (BSA), yielding MagGNRs.Magnetic alignment of MagGNRs arising from magnetic dipolar interactions on the anisotropic gold nanorod core is comprehensively characterized, including enhancement (suppression) of the LSPR and suppression (enhancement) of the TSPR for light polarized parallel (orthogonal) to the magnetic field.[1]The distinct optical extinction spectra of Fe3O4 NPs and GNRs make possible straightforward quantification of the loading of satellite NPs. Successive overcoatings on GNRs with GNPs followed by Fe3O4 NPs are also demonstrated. pH is a useful lever for controlling assembly and the loading of satellite NPs because the charge on PEI- and BSA-functionalized NPs strongly depends on pH. Stable assemblies are obtained at pH between the isoelectric points (pHI) of BSA ($pH_I \approx 5$) and PEI ($pH_I \approx 11$), wherethe core and satellite NPs have opposite charges. At lower or higher pH, the core and satellite NPs have like charges, which inhibits assembly. Adjusting the pH to values outside of this window drives disassembly. As a demonstration of the effect of disassembly, diattenuation of transmitted light is observed when GNRs coated with Fe3O4 NPs align in a magnetic field but vanishes when the Fe3O4 NPs are removed and the orientations of the GNRs randomize.

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Designer Metacrystals

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High-quality monocrystalline materials and nanostructures are key to high-efficiency optoelectronic devices, plasmonic materials and metasurfaces. A large variety of materials can be synthesized at low temperature in solution as colloidal single crystals, combining the advantages of high-quality material and low-cost fabrication, but the potential for large area integration into nanophotonic and plasmonic devices via nanoparticle assembly techniques still remain elusive. The two major bottleneck are:

-Difficulty to achieve defect-free colloids self-assembly in truly arbitrary patterns;

-Poor optical and electronic properties resulting from the discreetness of individual building blocks.

In this invited talk I will present recent breakthroughs from our team tackling both challenges with a new approach that we have introduced based on nanocube assembly and epitaxy. In the first part I will focus on advances on templated-assembly. I will show the fabrication of complex and truly arbitrary organisation of nanocubes on a large surface, with a single nanocube resolution. Examples includes 1D linear assembly1, 2D nanocube grid arrays for transparent electrodes2,3, highly dense split-ring resonator absorbers and Pancharatnam–Berry metasurfaces4. Then, I will focus on advances on metal nanocube epitaxy, showing a general methodology to transform an arbitrary assembly of nanocubes into defect-free continuous nanostructures and operando mechanistic insights5,6. This approach enables to obtain monocrystalline plasmonic and nanophotonic surfaces that can be readily printed on any substrate (flat, microstructured), but also to make nanocrystals with unconventional (à la carte) geometries, that can be used as colloids to go beyond Platonic solids, or into continuous nanostructured grids with record conductivity.

Finally, I will present recent results on a new paradigm on gap-selective crystal growth. In these context, growth takes place in sub-nanometer gaps, enabling to obtain unconventional monocristalline nanostructures.

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Effects of Doping on the Self-Assembly of $CsPbX_3$ Perovskite Supercrystals

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Metal halideperovskite nanocrystals, specifically cesium lead halide (CsPbX3), have emerged as a versatile class of semiconductor materials due to their tunable optoelectronic properties and high photoluminescence quantum yields. Supercrystal formation, afforded by the self-assembly of CsPbX3 perovskite nanocrystals, has been a phenomenon of interest due to the high degree of three-dimensional structural order required and the resulting emergent properties. This high structural order is influenced by the surface chemistry and particle morphology of the starting nanocrystal building blocks. Ion doping (e.g., Mn2+) into metal halide perovskite nanocrystals has also been separately investigated as these dopants can modulate physical and structural properties while also imparting other characteristics not present in the parent metal halide perovskites. In this work, we investigate the structural effects of Mn2+ doping on metal halide perovskite supercrystals through the predictive multilayer diffraction phenomenon observed in powder X-ray diffraction and confirm it through electron microscopy. The photophysical effects of the dopants are investigated through absorbance and photoluminescence spectroscopies, photoluminescence quantum yield measurements, and time-resolved photoluminescence. Specifically, we demonstrate that the degree of doping influences the final morphology and dimensionality of the resulting self-assembled micron-sized supercrystals.1,2

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Hierarchically Engineered Electrochemical Interfaces on Laser-Induced Graphene for Molecular Sensing

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Laser-induced graphene (LIG) has emerged as a promising platform for rapid manufacturing of porous carbon electrodes, offering scalable fabrication, high surface area, and direct patterning capabilities[1]. However, despite these advantages, LIG electrodes often suffer from intrinsic heterogeneity, uncontrolled surface chemistry, and mass-transport limitations that can hinder their analytical performance in electrochemical sensing.

Here, we present straightforward, multiscale surface engineering strategies for tailoring LIG properties. Metal or other catalytically active nanoparticles introduce active sites that allow signal amplification [2].Conductive polymer layers provide electroactive matrices via controlled electropolymerization [3],meanwhile, functional hydrogel layers regulate diffusion within the porous architecture, introducing electrostatic interactions and promoting analyte preconcentration [4]. Beyond catalytic enhancement, these surface engineering protocols also mitigate key challenges associated with LIG electrodes, including surface heterogeneity, signal stability, batch-to-batch variability, and susceptibility to biofouling. Importantly, they enable rational control over charge transfer and mass transport phenomena, which are critical for achieving reliable sensing performance in complex environments.

Proposed engineered interfaces transform LIG into a customizable and cheap electrochemical platform, opening new opportunities for the development of high-performance programmable multielectrode sensor arrays capable of multiplexed detection and advanced electroanalytical applications in complex biological and environmental systems.

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Electrical Versus Mechanical Network in Conductive, Liquid Nanocomposites

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Electrofluids (EFs)—conductive particles dispersed in non-conductive liquids—exhibit two interacting, yet partially decoupled, networks: an electrical network formed by transient particle contacts and a mechanical (colloidal gel) network that governs flow and deformation. Here, we map how particle morphology, concentration, and particle–solvent interactions tune this electrical–mechanical interplay and, in turn, the mechano-electrical responses relevant to soft and stretchable devices. Using multi-walled carbon nanotube (MWCNT) in glycerol, we combine four-point I–V measurements with small-amplitude rheology to locate the onsets of electrical and mechanical network formation. Electrical percolation emerges at 0.04 wt%, while the mechanical gel point appears at 0.16 wt%, revealing a concentration window, in which EFs are electrically continuous yet mechanically fluid-like.We distinguish three regimes—below electrical percolation, between electrical and mechanical percolation, and above both—each displaying distinct electromechanical signatures under strain and shear. The sequence of these regimes can be altered by using MWCNTs functionalizedwith carboxyl-groups (MWCNTs-COOH) as filler particles in a mixture of glycerol and water (50:50) as the liquid matrix.Encapsulation in elastomeric conduits enables tensile tests that link network architecture to in-situ resistance evolution; in the intermediate regime, resistance relaxes under strain due to CNT rearrangements, whereas in solid-like EFs, the electrical pathway is retained. Flow curves further show conductivity remains stable up to ~50 s^{-1}, evidencing partial independence of the electrical and mechanical networks under shear. Extending to formulation design, we illustrate how solvent polarity/viscosity and particle shape (e.g., Carbon Black vs. MWCNTs) control agglomeration, percolation thresholds, and sensitivity, enabling bespoke EFs for interconnects and sensors. We demonstrate fluidic conductive interconnects in metal ball joints with ~80% reduction in resistance fluctuations during motion compared to empty joints.Altogether, our results delineate design rules to decouple and exploit electrical versus mechanical networks in conductive, liquid nanocomposites for robust, deformable electronics.

Polymer Nanoparticle Assemblies for Structural Coloration

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While the color of conventional dyes and pigments results from the absorption of light (and inevitably fades with time by photodegradation), the structural color of photonic pigments involves wavelength-selective light scattering by nanostructures with a periodic variation of the refractive index, and thus have much better resistance to color fading. Also, their color depends mostly on the structure, not the composition of the material, so that photonic pigments with bright and saturated colors can be obtained from virtually any material, holding enormous potential for developing sustainable dye-free color coatings, stimuli-responsive coloring, dye-free colorimetric sensors, reflective displays, etc.

We have developed spherical colloidal photonic pigments by self-assembling of polymer nanoparticles (PNPs). By changing the size of the PNPs, the periodicity of the structure changes, producing colors across the entire visible spectra. [1,2] The order of the PNP arrangement can be directly evaluated using multi-wavelength reflective confocal microscopy, [3] and was found to correlate with the saturation and angle-dependence (iridescence) of the colors (Figure). The structural pigments can be incorporated in water-borne polymer films to produce dye-free coatings. [4]

Keywords: polymer photonic pigments, structural color, waterborne polymer coatings

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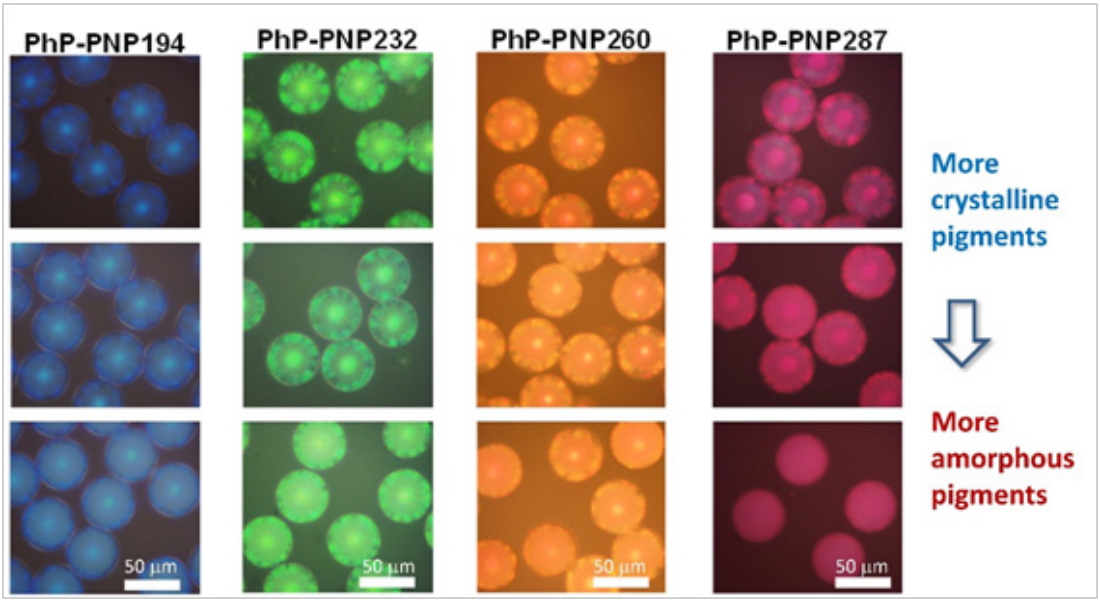

Figure: Photonic pigments obtained from assembling polymer nanoparticles with different diameters (left to right: 194 nm, 232 nm, 260 nm and 287 nm), with increasing disorder (top to bottom).

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MSNC-Enabled DLP 3D Printing of Hierarchical porous MOF@SiO_2 Monoliths for CO_2 Capture

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The integration of advanced nanomaterials into additive manufacturing remains a key challenge in expanding the functional scope of 3D printing beyond conventional polymers. In this work, we introduce methacrylate-functionalized silica nanocages (MSNCs) as a versatile platform for digital light processing (DLP) printing of fully inorganic, hierarchical porous structures. These photo-cross-linkable MSNC inks enable the direct fabrication of mesoporous silica monoliths without the need for organic binders or post-synthetic calcination, preserving structural integrity and porosity. The approach further allows the post-printing incorporation of compounds enabling spatially controlled multifunctionality within printed architectures.Furthermore, we demonstrate the integration of metal–organic frameworks (MOFs), specifically HKUST-1, to create composite monoliths with multiscale porosity. The resulting MOF@SiO_2 structures combine intrinsic MOF microporosity with silica mesoporosity and 3D-printed macroporosity by embedding MOFs within the MSNC-derived silica matrix or promoting their in situ growth. This hierarchical organization ensures high accessibility to active sites while maintaining MOF functionality, overcoming limitations of traditional binder-based printing approaches. The printed materials exhibit high CO_2 affinity and are suitable for flow-based applications, including catalytic processes and gas capture. Overall, this strategy demonstrates the potential of MSNC-enabled DLP printing in the design of next-generation, MOF-based monolithic reactors with customizable architecture, hierarchical porosity, and improved performance.

Keywords: Digital Light Processing, Hierarchical porosity, Mesoporous Silica Nanocages, Metal Organic Frameworks, CO2 capture.

Multifunctional Porous Organic Polymer-Alginate Composites for Sustained Antibiotic Delivery and Wound Healing Applications

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The rise of antibiotic-contaminated wastewater and the persistence of bacterial infections in clinical settings necessitate the development of multifunctional materials capable of both environmental remediation and controlled therapeutic delivery. This study presents Porous Organic Polymers (POPs) as a versatile platform for the sensing, capture, and subsequent medical repurposing of Tetracycline (TC).While POPs exhibit exceptional efficacy in detecting and sequestering TC from aqueous media, their application in biological environments requires enhanced biocompatibility and release control. To address the limitations of conventional wound dressings, such as poor moisture retention and the “burst release” effect of directly loaded drugs, we integrated TC-loaded POPs into alginate hydrogels.The resulting POP–alginate composites combine the soft, oxygen-permeable, and hydrated nature of hydrogels with the high drug-retention capabilities of porous frameworks. Our results demonstrate that the framework chemistry and host-guest interactions within the POP pores govern a temperature-dependent, sustained release of TC, successfully preventing the initial burst release that often leads to cytotoxicity. Furthermore, the TC released from these frameworks preserved its structural integrity and antibacterial activity against E. coli.By transitioning from environmental capture to localized, sustained delivery under physiological and wound-relevant conditions, these materials offer a dual-purpose strategy for mitigating environmental risks while advancing the next generation of antimicrobial wound dressings.

Hierarchical Self-Assembly of $CuWO_4$ Heterostructures for Selective Photocatalytic Glycerol Oxidation

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$CuWO_4$ is a promising photoactive oxide for solar-driven chemical transformations, yet its performance is often constrained by interfacial charge recombination and poorly optimized surface reaction pathways[1-2]. Here we present a hierarchical self-assembly strategy to engineer $CuWO_4$-based heterostructures with enhanced charge separation and improved photocatalytic activity toward glycerol oxidation. Using Fe(III) as a self-assembly mediator rather than a dopant, the material undergoes a controlled structural reorganization that promotes the formation of local CuO/WO_3 heterojunctions together with metallic Cu nanoinclusions [3]. Comprehensive structural and spectroscopic characterization (XRD, TEM, EPR) confirms that Fe is not incorporated into the final lattice, but instead transiently directs phase segregation and the emergence of interfacial nano-domains that act as efficient charge-transfer junctions. This self-assembled hierarchical architecture results in a pronounced enhancement of photoresponse and operational stability compared to pristine $CuWO_4$. Under mild photocatalytic conditions, the engineered heterostructures exhibit markedly increased glycerol oxidation rates with high selectivity toward formate, underscoring the key role of the heterointerface in steering reaction pathways. Importantly, we show that photocatalytic performance is strongly governed by WO_3 polymorphism: heterostructures enriched in monoclinic WO_3 display superior activity, whereas hexagonal or hydrated WO_3 phases lead to diminished performance, consistent with less favorable electronic coupling across the interface. These findings establish hierarchical self-assembly and polymorph control as effective design principles for $CuWO_4$-based photocatalysts targeting biomass-derived molecule valorization. Ongoing modelling efforts aim to rationalize molecule–surface interactions at the $CuWO_4/CuO/WO_3$ interfaces.

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Nanoengineered Electrospun Smart Bandages Integrating Photoresponsive Copper Silicate Nanosheets for Controlled Wound Regeneration

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Introduction and Objective: The development of multifunctional wound materials requires the integration of structural biomimicry with active, externally controllable functionalities. Conventional dressings act as passive barriers and lack the ability to dynamically modulate the wound microenvironment. In this work, we engineered a nanoarchitecturedelectrospun platform combining extracellular matrix (ECM)-mimicking polymeric nanofibers with photoactive 2D copper silicate nanosheets (cuprorivaite, $CaCuSi_4O_{10}$)[1]. The objective was to establish a scalable nanoengineering strategy in which fiber morphology, nano-interface integration, and photothermal (PTT) responsiveness synergistically regulate cellular behavior, antibacterial performance, and tissue regeneration.

Methodology: PLGA nanofibrous were fabricated via electrospinning, optimizing parameters to achieve uniform nanometric fibers with high porosity and interconnected architecture.[2] Exfoliated cuprorivaite nanosheets were incorporated within the polymer matrix to generate a hybrid nanocomposite interface.Comprehensive physicochemical characterization was performed through SEM (morphology and fiber uniformity), XRD (structural integrity), FTIR-ATR (chemical interactions), UV–Vis spectroscopy (optical properties), DSC and TGA (thermal stability). Mechanical behavior and scaffold stability under physiological conditions were assessed. PTT efficiency was evaluated under NIR-irradiation. Biological performance was investigated through *in vitro* cytocompatibilityand antibacterial testing against representative Gram+/- strains. Finally, *in vivo* regenerative performance was evaluated in a full-thickness skin wound model to assess tissue integration, re-epithelialization, collagen organization, and inflammatory response.

Results: Electrospinning yielded homogeneous nanofibrous architectures characterized by high surface-to-volume ratio and nanoscale topographical cues. The incorporation of 2D nanosheets generated a stable multifunctional nano-interface. Under NIR stimulation, the hybrid scaffold produced controlled mild hyperthermia, enabling spatially confined thermal modulation.The combined effects of nano-topography and photothermal activation significantly enhanced wound healing. Antibacterial assays demonstrated reduced bacterial proliferation due to synergic effect of PLGA, copper and PTT. *In vivo* analysis revealed improved tissue integration, accelerated wound closure, and more organized collagen deposition, confirming the regenerative potential of the engineered nanocomposite system.

Conclusions: This work demonstrates a rational materials engineering approach for integrating electrospun nanofibers with photoactive/antibacterial 2D nanomaterials into a single multifunctional platform.Such hybrid nanointerfaces represent a promising strategy for next-generation regenerative materials and smart wound technologies.

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Force-Activated Molecular Systems for Nanoscale Sensing and Functional Soft Matter

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At the nanoscale, mechanical forces can reshape energy landscapes and unlock reaction pathways inaccessible through conventional stimuli. This ability to use force as a molecular level input opens new possibilities for sensing, adaptive materials, and mechanically gated chemical function. However, realizing these opportunities requires the discovery of molecular systems in which force reactivity relationships are predictable, tunable, and compatible with soft matter environments.

In this presentation, I will showcase triarylmethane and diarylmethane mechanophores as highly tunable molecular units that transduce mechanical stress into optical and electronic outputs. These systems provide rare examples of force activated radical and ionic species in the solid state and enable nanoscale readout through full visible range mechanochromism, environment dependent optical signatures, and tunable activation thresholds. I will discuss how mechanophore architecture, electronic design, and nano engineered polymer environments collectively determine reaction pathways, enabling mechano optical probes that report on local polarity, hydrogen bonding density, and force distribution with molecular precision. Overall, the talk will underline how force-responsive molecular designs can expand the chemical toolbox available for nanotechnology, offering new avenues for responsive and adaptive materials.

Day-1

NanoSeries2026 Technical Session:NS (E)

2D Materials Research: Graphene and Beyond

Low-Dimensional Materials: A Computational Journey Into OptoelectronicProperties

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In recent years, a plethora of material systems have been designed and prepared to increase the performance of light harvesting and light-emitting technologies, and to develop new and attractive applications. Limitations of state-of-the-art devices based on organics (both conjugated polymers or small molecules/oligomers) derive largely from material stability issues after prolonged operation. This challenge could be tackled by leveraging the enhanced stability of carbon nanostructures (CNSs, including carbon nanotubes and the large family of graphene-based materials) in carefully designed nano-hybrid or nano-composite architectures to be integrated within photo-active layers, paving the way to the exploitation of these materials in contexts in which their potential has not been yet fully revealed. In this talk, I will discuss the theoretical background behind CNSs hybridization with other low dimensional materials, focusing on different assemblies: 0D/2D and 2D/2D assemblies, in which we can follow the evolution of both charge and energy transfer, providing an overview of new optoelectronic and transfer properties arising from the assembly of low dimensional materials, that allow to forecast interesting future perspectives for use in real devices and molecular physics and chemistry, opening up new research directions and opportunities for collaboration.

Precise Engineering of Wafer-Scale 2D Semiconductors and Dielectrics

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This work reports on recent advances in the precise engineering of two-dimensional semiconductors (2dSEM) and 2d oxides (2dO). The mechanical exfoliation of bulk crystals generally produces only small-area flakes; most importantly, physical properties associated with specific compositions, crystal structures, doping and size are difficult to control by exfoliation. Using a bespoke facility (EPI2SEM) for the integration of epitaxial growth of 2dSEM with advanced studies by scanning probe microscopy and electron spectroscopy in ultra-high vacuum, we push the limits of what can be created, probed and exploited at the atomic scale.

This work focuses on 2dSEM based on metal chalcogenides with a unique electronic band structure, including inverted “Mexican hat” valence bands tuneable by composition and layer thickness. The interest in this band is motivated by the possibility to create and manipulate new forms of charge, magnetic, and superconducting order driven by electron correlations. Furthermore, this work introduces a research network in the UK (NEED2D) that will develop prototype low-energy-consumption electronics and optoelectronics with 2dSEM and 2dO beyond traditional systems. Recent applications include the use of 2dSEM and 2dO in free-space optical communication and deep-UV sensing.

Surface Oxidation of 2D Layered Materials for Device Processing

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2D materials obtained by exfoliating layered crystals exhibit chemically inert surfaces owing to the absence of dangling bonds on their basal planes. This inertness presents a fundamental challenge for integrating 2D materials into various device architectures. Surface activation through controlled oxidation—which increases surface energy and reactivity—offers a promising pathway to overcome this limitation. In this talk, we will discuss innovative device-processing approaches that strategically exploit the surface oxidation of 2D materials.

(i) Resist-Free Patterning of 2D Semiconductors: The atomic thickness and ultrasmall heat capacity of 2D materials render them particularly vulnerable to conventional patterning techniques. Resist-based lithography often results in severe surface scattering caused by resist residues that are difficult to remove completely, whereas laser ablation induces significant thermal damage to the ultrathin films.For the 2D semiconductor GeS2, we demonstrate a resist-free and environmentally benign patterning method that combines low-power laser-induced photo-oxidation with the subsequent wet etching of the formed oxide layer in water [1]. This approach avoids both resist contamination and thermal degradation.

(ii) Integration of Ultrathin Dielectrics without Damaging Surface Treatment: The fabrication of ultrascaled transistors and quantum devices, such as tunnel junctions, demands ultrathin, high-quality insulating layers. Atomic layer deposition (ALD) is a well-established technique for forming such ultrathin dielectrics with atomic-level precision. However, achieving uniform and conformal ALD film growth on the inert surfaces of pristine 2D materials typically requires aggressive surface activation treatments—such as plasma oxidation or chemical functionalization—which inevitably introduce defects and degrade the intrinsic properties of the 2D materials. Our results reveal that on 2D oxides and on 2D materials that naturally form a native oxide layer, conformal ALD growth can be achieved without any additional surface oxidation treatment [2], thereby preserving the high quality of the underlying 2D material while enabling the seamless integration of ultrathin dielectrics.

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Computational Study on Iron-Mediated Direct Amination of Graphene-Based Materials With Hydroxylamine-Derived Reagent

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Graphene is a prominent 2D nanomaterial in applied material science due to its extraordinary properties, such as high flexibility, strength, and electrical and thermal conductivity [1]. However, it is not easily modified with molecular functional groups. Direct functionalization of graphene Nanoplates (GNPs) can be performed through both non-covalent and covalent approaches [2-3]. In the former approach, only weak π-π stacking interactions between aromatic molecules and the layers of GNPs can be established without altering their extended conjugation. Conversely, in the latter, chemical derivatization increases the number of defects affecting the overall properties of the pristine nanomaterial.

This work presents the computational study of a novel and one-pot functionalization of graphene with -NH2 groups using a hydroxylamine-derived reagent, such as [MsONH3]+[4], in the presence of ferrocene in a polar medium. This reaction affords GNPs rich in amino-groups localized both at the edges and basal plane of the layers,where the -NH2group is directly bound to the graphene sheet without the need of a molecular spacer. The functionalization reaction has been theoretically modelled via DFT calculations, scaling the modelling from benzene to bigger carbon clusters, such as coronene (24 carbon atoms), to clarify the interaction that occurs between the aminating reagent, Fe-base species, and the substrate. We enlighten the propagative radical course of the reaction that leads to both aromatic and aliphatic amines, adding more insights to a mechanism that is still debated and not so clear in the recent literature [5]. All this computational study corroborates the experimental data of amine-rich GNPs, that has been characterized by several spectroscopic techniques. Functionalization of GNPs with amino-groups increases the dispersibility of this material in polar medium such as water, paving the way to the preparation of novel carbon-based nanoassemblies based on covalent chemistry.

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2D Materials in the BCN Triangle Prepared on Transition Metals

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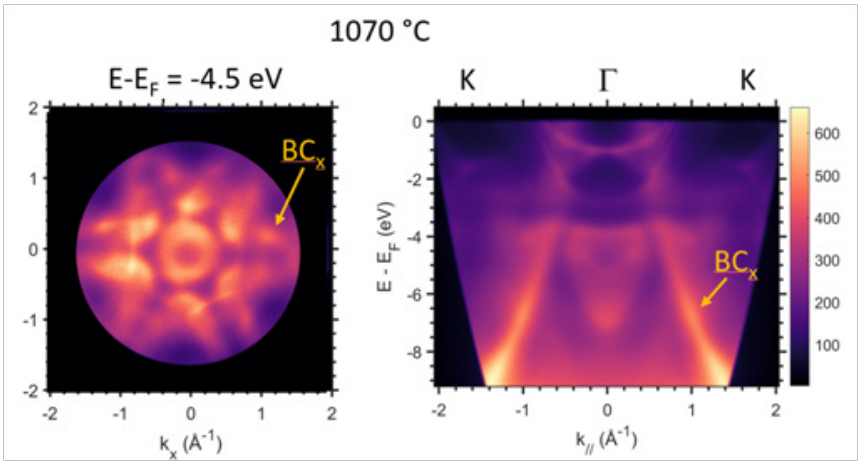
While graphene is a semimetal, hexagonal boron nitride (h-BN) is an insulator, which has stimulated intense research into preparing mixed B, C, and N-containing 2D materials to tune electronic properties. However, alloying these three elements is difficult because there is a strong energetic driving force for phase separation into graphene and h-BN. Here, we applied a single precursor (bis-BN cyclohexane, B2C2N2H12) with all three elements already mixed in its six-membered ring, and decomposed it on a catalytically active Ir(111) single crystal to obtain 2D monolayers. Theiratomic structure was analyzed using low-energy electron diffraction (LEED), while their chemical coordination and band structure were revealed by XPS and momentum microscopy, respectively. The energetics behind the observed processes were disclosed by DFT calculations.It turned out that the mixed molecular ring is not a significant advantage for the preparation of mixed BCN layers, as the ring breaks down already at 275 °C. Accordingly, separated graphene and h-BN domains have been identified up to 740 °C. However, further increasing the substrate temperature during preparation, from 980 °C, smaller and smaller h-BN domains formed, and the average composition became increasingly N-deficient. The very small (~1 nm) h-BN domains are energetically stabilized by having exclusively B atoms at their perimeters. Moreover,the remaining extra boron atoms are alloyed in graphene, forming 2D boron carbide, characterized by a new band.The elevation of temperaturealso facilitates entropy effects,favoring mixing. At the optimal temperature of 1070 °C, an intimately mixed BCN layer with very small h-BN nanodomains in a boron carbide environment is formed. The results will be discussed in the context of recent publications on 2D BCN layers on transition metals from our and other laboratories [1-3].



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From Exfoliation to Printed Devices: Controlling 2D Nanomaterial Morphology for Flexible Electronics

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Liquid-phase exfoliation has become one of the most versatile and scalable approaches for producing two-dimensional nanomaterials. The method enables solution processing and printing of nanomaterial thin films, making it particularly attractive for applications in flexible electronics such as thin-film transistors and chemical sensors. Despite its widespread use, controlling the morphology of exfoliated nanosheets, especially their thickness and lateral aspect ratio, remains a major challenge. These structural parameters strongly influence charge and energy transport within printed films and therefore directly affect device performance.

In this contribution, I will discuss recent progress toward understanding and controlling the mechanisms governing liquid-phase exfoliation. I will focus on how intercalation-based strategies can be used to promote more efficient exfoliation and produce ultrathin nanosheets with high lateral aspect ratios. In addition, I will highlight approaches to control nanosheet organization during thin-film deposition,[1] enabling improved film morphology and connectivity in printed devices.[2] Together, these insights provide new opportunities to rationally tailor nanomaterial dispersions and deposition processes for high-performance solution-processed flexible devices.[3]

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Darkness in Electronic States: Based on True Events in Cr and 2H-TaS_2

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Quantum materials hosting charge and spin density waves often exhibit complex photoemission signatures. These signatures are shaped not only by the materials' intrinsic electronic structures, but also by interference effects coming from the symmetry properties of the lattices. In this talk, it will be shown the angle-resolved photoemission spectroscopy (ARPES) study of two systems: elemental chromium, which has prototypical incommensurate spin and charge density waves (SDW and CDW) [1], and the layered dichalcogenide 2H-TaS_2, in which hidden electronic states emerge due to interlayer quantum interference [2]. Regarding chromium, it will be demonstrated that the interplay between SDW/CDW order and multiple scattering in the final states of photoemission requires a sophisticated theoretical approach to align with experimental data. For 2H-TaS_2, it will be identified the phase-dependent spectral features tied to the CDW transition. In addition, it will be demonstrated how interference between wave functions from nonequivalent layers can suppress or reveal specific electronic states. These findings underline the necessity of moving beyond simplistic models when interpreting ARPES spectra and provide deeper insight into the interconnected roles of electronic correlations, structural periodicity, and final-state effects in complex materials.

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Accurate Quantum Mechanics for slab calculations of semiconductor surfaces. The elusive case of the Si (111)-7x7 Surface

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Understanding and controlling the formation of surfaces and interfaces arenecessary for the design and development of new2-D materials with specific opticalproperties and chemical reactivityespecially as more complex materials are considered.The

Si(111) 7x7 surface represents a complex large unit cell 2-D material whose nature and structure are widely accepted to be the DAS (dimer adatom stacking fault) structure [1] and as a result has become a testing ground to develop machine learning approaches to define new materials.[2] However, our understanding of the Si (111)-7x7 surface has been questioned due to the failures of all DFT calculations to describe a wide range of properties of this system.[3],[4]

In the present study,new Density Functional calculations of Si(111)-7x7 surfaces using (mainly) hybrid B3LYP-functionaland more realistic surface slab terminations revealthe sensitivity of the DASstructure to subtle surface charge rearrangements arising from more accurate exchangecorrelation. This produces a new, more stable7x7 structure that alters its geometric andelectronic structure to improve its agreement with two measured properties: the adatomheights and insulating surface bands at low temperatures. This more accurate treatmentof exchange correlationand localization inherent in our calculations differentiates the forces that change the adlayer structure onthe two sides of the surface unit cell that results in these new properties of the widelyaccepted DAS structure.

Beyond the present case, our findings may constitute relevant groundwork towards a better understanding of novel 2-D systems.

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Probing Molecular Conformation and Charge Transfer in Graphene-Based Nanohybrids at the Nanoscale

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The functionalization of graphene-based materials with photoactive molecules represents a powerful strategy for engineering two-dimensional systems with tailored properties. In these nanohybrids, molecular conformation plays a critical role and therefore requires detailed characterization at the nanoscale. Here, we investigate individual flakes of graphene–porphyrin hybrids dispersed on inert substrates using co-localized nanospectroscopy that combines scanning probe microscopy, photoluminescence (PL) mapping, and tip-enhanced Raman scattering. The experimental results are supported by molecular dynamics simulations.

On graphene, π–π stacking stabilizes dense planar assemblies of porphyrin molecules, enabling efficient photoinduced electron transfer, as evidenced by strong PL quenching and a pronounced surface photovoltage. In contrast, graphene oxide (GO) anchors porphyrins through electrostatic interactions with oxygen-containing functional groups, inducing distortions of the macrocycle and modifying the porphyrin emission spectrum.

These findings demonstrate how nanoscale molecular organization governs conformation and charge transfer in graphene–molecule nanohybrids, providing a framework for the rational design of graphene-based systems for light harvesting, optoelectronics, and photodynamic therapy.

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Molecular Precursor Strategy for Scalable Growth of 2D Metal Sulfides for Memristive and Neuromorphic Electronics

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Two-dimensional layered metal chalcogenides have attracted increasing interest for next-generation electronic and neuromorphic systems owing to their tunable electronic properties and compatibility with emerging device architectures.1 However, achieving phase-pure materials through scalable and low-temperature processing routes remains a significant challenge. In this work, we report a solution-processed strategy2 for the controlled growth of layered metal chalcogenide thin films using a tailored molecular precursor that enables in-situ thin film growth under mild solvothermal conditions. The precursor chemistry was systematically designed and verified through spectroscopic techniques, confirming its suitability as a single-source precursor for delivering both metal and chalcogen during film growth. Structural and compositional analyses revealed the formation of highly crystalline layered films with well-defined morphology and phase purity. Optical characterization further indicated a suitable bandgap for electronic device applications. Furthermore, a memristive device3 fabricated from these solution-grown films exhibits electroforming-free bipolar resistive switching at low operating voltages, along with stable endurance characteristics. Beyond digital switching, the devices demonstrate analogue conductance modulation and key synaptic functions, enabling the emulation of biological learning behavior. When incorporated into a hardware-aware neural network framework, the experimentally obtained conductance states enable efficient pattern recognition tasks with high classification accuracy on benchmark datasets. Overall, this work highlights the potential of precursor-enabled solution processing as a scalable pathway for engineering layered chalcogenide materials for future memory and neuromorphic computing technologies.

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Scalable 2D Material Laminates for Selective Ion Transport and Emerging Iontronics

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Global challenges in water purification, energy conversion, and ion-based information processing are pushing membrane science beyond passive filtration, toward materials that regulate ionic flux, generate electrical output, and process ionic signals. Under Å-scale confinement, ions no longer behave as bulk hydrated species: their mobility reflects hydration-shell deformation, ion–surface friction, and the competition between geometric restriction and electrostatic coupling. Seminal work on nanofluidic devices with atomically defined slits mapped these phenomena quantitatively, showing that hydrated diameter alone cannot predict transport under extreme confinement [1]. Graphene oxide membranes translated part of this physics into laminar materials, revealing anomalous water permeation and size-selective ion sieving, while exposing the swelling and stability limits of oxidized graphene in water [2–4]. Bringing comparable control into scalable and low-costmembranes remains a crucial challenge.Here, we use liquid-phase-exfoliated two-dimensional (2D) materials to build scalable laminate nanochannels for selective ion transport and nanofiltration. Graphene flakes exfoliated in green solvents form robust µm-thick membranes that retain structural stability in water while combining high permeance with hydrated-size-dependent sieving, preferential anion transport, and organic-contaminant rejection [5]. $Ti_3C_2T_x$ MXene laminates extend the platform to a chemically distinct, hydrophilic, and negatively charged channel system, where surface terminations, hydration, and stacking order strongly affect ion transport [6]. Moving beyond size exclusion as a single design rule, our current work focuses on how surface charge, channel spacing, and transport-path geometry govern ion transport in graphene and MXene laminates. These features can be tuned via flake-size selection, lamellar assembly, and chemical functionalization to target ion rejection, conductance, and cation/anion mobility ratios. Engineered 2D nanochannels can also be designed for functions beyond separation. Gated vermiculite capillaries demonstrate giant electrostatic modulation of ion flux at high salt concentration, while phase-engineered MoS_2 laminates show hydrovoltaic energy generation controlled by channel structure [7,8]. Together, these studies trace a path from passive nanofiltration toward innovative iontronic concepts.

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UHV Exfoliation and Chemical Modification of 2D Materials

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Two-dimensional (2D) materials represent the ultimate limit of vertical miniaturization, enabling access to a range of otherwise inaccessible quantum phenomena. This has generated significant interest across both fundamental and applied research. However, the scalable production of monolayer materials remains a major challenge due to the lack of suitable synthesis and manipulation techniques.Here, we report a facile approach for obtaining bulk-crystal-sized 2D monolayers with near 100% yield under ultra high vacuum (UHV) conditions. Using MoS_2 exfoliated onto different metal substrates as model systems, spectroscopic measurements reveal a strong interaction between the metal substrate and MoS_2. This interaction induces a substantial strain field in the topmost layer of the bulk crystal, which is significantly relaxed in the underlying layers. The resulting vertically inhomogeneous strain distribution weakens the interlayer van der Waals coupling, thereby enabling highly selective monolayer exfoliation. Beyond scalable monolayer production, this method also offers a pathway to isolating 2D materials that are unstable under ambient conditions. Furthermore, the properties of 2D materials can be tailored via chemical functionalization. However, such processes are typically incompatible with ultra-clean environments such as UHV. Strategies to overcome this challenge and enable controlled functionalization under UHV conditions will be also discussed.

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Day-1

NanoSeries2026 Technical Session: NS (F) & NS (C1)

Next–Generation Light–Matter Interactions at the Nanoscale: Photonics and Optoelectronics

Bionanosensors and Bioelectronics: In Vitro and In Vivo Applications

Theme: Nanophotonics, Optical Sensing & Semiconductor Interfaces

Semiconductor Nanocrystals: From Energy Conversion to Polaron Formation

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Semiconductor nanocrystal systems can be designed with tailored properties, which favour microscopic processes relevant for energy conversion. Time-resolved optical spectroscopy provides information on relaxation, recombination and reaction pathways of photocreated charge carriers. Based on these insights, wellchosen chemical and geometrical structures can lead to tailored carrier pathways and thus to efficient energy conversion processes. It turns out that pure electronic mechanisms often fall short in explaining important spectroscopic results. Coupling effects between electronic excitations and the lattice must be taken into account.

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Colloidal InAs Quantum Dots for Short-Wave Infrared Light Sources

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Short-wave infrared (SWIR) light sources are fundamental components of various optoelectronic sensing systems, including machine vision and light detection and ranging (LIDAR). SWIR light-emitting diodes (LEDs) are typically produced using single-crystal III-V semiconductors (mostly In1-x GaxAs grown on InP). However, th e multi-step epitaxial growth and processing of these semiconductors limit their use in consumer electronics products. Alternative SWIR light-sources are colloidal quantum dots (QDs),1 a class of nanomaterials that can be synthesized cheaply and have tunable optical properties thanks to their size, shape, and composition. Due to their solution-processing nature, QDs are fully compatible with well-established, inexpensive complementary metal-oxide-semiconductor (CMOS) technologies. While red, green, and blue (RGB) emitting QDs have been commercially successful in displays, SWIR emitting QDs have not yet reached the consumer market due to the difficulty of achieving high efficiency for emissions beyond 1100 nm while complying with European Restriction of Hazardous Substances (RoHS) directives. In fact, state-of-theart SWIR QD-LEDs mainly use toxic Pb- and Hg-chalcogenide QDs thanks to their wellestablished chemical synthesis. Progress on indium arsenide (InAs) QDs, however, has been hindered by the limited number of available precursors (leading to low photoluminescence quantum yield), size dispersion challenges, and electroluminescence limited to wavelengths below 1100 nm. In this talk, I will present our recent findings on the synthesis of indium arsenide (InAs) quantum dots (QDs) via an amino-As precursor2-4 and their application in light-emitting diodes (LEDs).5, 6 I will focus on indium arsenide/zinc selenide (InAs/ZnSe) core/shell QDs and respective LEDs that deliver photoluminescence/electrolumin escence beyond 1100 nm.

Keywords: InAs, Quantum Dots, Nanocrystals, light-emitting diodes, SWIR

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Photon Management in Advanced Semiconductors for Light Emission and Energy Conversion

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Controlling the interaction of light with semiconductor materials is a central challenge in modern optoelectronics. Beyond the intrinsic properties of the active layers, device performance is increasingly shaped by how photons are generated, confined, extracted, recycled, or harvested through materials design, nanostructuring, and optical engineering. In this talk, I will present an overview of our recent work on photon management across advanced semiconductor platforms, with emphasis on GaN-based materials, and plasmonically enhanced perovskite emitters and tandem solar cells.

I will first discuss our work on the optical response of GaN-based systems [1], including Fe-doped GaN, n-GaN, and porous GaN, highlighting the importance of accurate optical parameterization for understanding light propagation and enabling modelling and photonic design. I will then move to hybrid perovskite light emitters [2], where coupling to plasmonic nanostructures provides new opportunities to tailor the local optical environment, enhance radiative processes, and improve light-emission performance. Finally, I will address photovoltaic devices, showing how optical modelling and light-management strategies can be used to optimize absorption, reduce parasitic losses, and guide the development of more efficient tandem solar cells [3].

By connecting material-level optical response, light-emission engineering, and photovoltaic design under a common framework, this talk highlights photon management as a unifying concept for the development of next-generation semiconductor technologies for sustainable optoelectronics.

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Photonic Platforms by 4D Printing Technologies on Nano-Doped Hybrid Materials

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The incorporation of functional and stimuli-responsive molecules and nanomaterials into complex three-dimensional (3D) architectures offers a powerful route for improving device performance. These strategies have found application in areas including optoelectronics, soft robotics, energy harvesting, and droplet microfluidics [1–3]. In fact, devices fabricated using standard approaches (such as photolithography, micromachining, milling, etc.) can remain limited in their geometric complexity and in the practicability of integration of functional and smart materials. Additive manufacturing has stably emerged as a powerful set of fabrication technologies enabling, among others, the realization of microfluidic devices with complex and customizable geometries [3]. While 3D printing allows for fast prototyping and scalable device production, the emergence of four-dimensional (4D) printing technologies further expand the design capabilities by enabling printed components that can evolve over time, with time-varying physical properties that can respond to external stimuli.

The work ongoing in our group on the development of photo-controlled 4D-printed platforms is here presented. Exemplary photoresponsive, nano-doped architectured are reviewed, that are processed via UV photopolymerization-based additive manufacturing, and their potential applications for all-optical data processing are discussed [3]. The dynamic control of the transmitted light by means of sequences of incoming signals, leads to evidence robust photoswitching, effective local information storage, and can be exploited for motion control as well as all-optical arithmetic and logic processing. Overall, these results open new opportunities for applications ranging from all-optical computing to light harvesting, sensing and actuation, and light-emitting devices.

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Plasmonic Light–Matter Interactions at the Nanoscale: An Atomistic Perspective

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The optical response of plasmonic nanostructures can be tuned by varying their shape, size, and chemical composition [1]. Peculiar phenomena arise when a molecular system is adsorbed on the surface of plasmonic materials, ranging from surface-enhanced spectroscopies to photocatalysis [2]. The accurate description of the optical properties of the plasmonic substrates is thus crucial for an understanding of the physical phenomena occurring at the plasmon resonance frequency. Here, we present an atomistic, yet classical, approach to predict the plasmon properties of nanostructures of complex shapes. The method is general enough to describe any plasmonic material, including noble metal nanoparticles (Ag and Au) [3] and metal alloys [4]. The approach is also coupled to a quantum mechanical (QM) description of the molecular system adsorbed on the nanostructure surface [5]. The resulting mixed QM/classical method is then extended to various spectral signals, from surface-enhanced Raman scattering to surface-enhanced fluorescence.

We show that our classical approach for plasmonics can correctly reproduce reference ab initio data [3], and experimental trends [3-4], and can be applied to large-scale nanoplasmonic simulations (more than 1 million atoms). By properly accounting for the atomistic discretization of matter, we can accurately describe the nanoplasmonics of systems dominated by quantum effects, such as subnanometer junctions [3,6], and geometrical defects, such as picocavities [7]. Finally, we discuss the current challenges in the prediction of the light-driven phenomena at plasmonic interfaces by means of atomistic approaches, ranging from surface-enhanced spectroscopies to photocatalysis.

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Continuous Monitoring Biosensing at Femtomolar Concentrations Using Plasmon-Enhanced Single-Molecule Detection

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Biomolecular sensing is fundamental to our understanding of disease mechanisms, and to develop platforms toward diagnostics. Detection of low concentrations remains extremely challenging, particularly in complex biological fluids. In this talk, I will present a novel plasmonic sensing platform for the fluorescence-free detection of single molecules at femtomolar concentrations directly in undiluted blood serum.

The sensor is based on a nanoparticle-on-film platform that exploits the coupling between the propagating plasmon on a metallic film and the localized plasmon on a gold nanoparticle for single-molecule detection. I will discuss the fundamental signal generation mechanisms through simulations and single-particle spectroscopy. Next, I will describe how we exploit low affinity (reversible) interactions to enable the continuous monitoring of biomarkers with a 200 fM limit-of-detection and a response time of 10 minutes in undiluted serum. This platform holds great promise to monitor lowly abundant analytes in complex media, expanding the scope of continuous monitoring biosensing.

Functionalized Carbon Nanoparticles as a Versatile Class of SupraNanoSensors

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Sensing is one of the most impactful areas where chemists, engineers, and materials scientists converge to translate molecular recognition into practical devices capable of detecting chemical and biological targets. In this context, fluorescence sensing is particularly attractive because the analyte can be revealed through a measurable change in emission intensity and/or color, enabling straightforward optical readout.[1] Carbon nanoparticles represent an intriguing class of nanomaterials thanks to their robust photophysical properties and, most importantly, the possibility to tailor their external shell through covalent functionalization.[2] This feature allows the integration of well-defined recognition motifs that operate through supramolecular (non-covalent) interactions, converting binding events into reliable optical responses.

In this contribution, we describe the use of functionalized carbon nanoparticles—also obtainable from natural sources—as fluorescent SupraNanoSensors for the detection of relevant analytes, including chemical warfare agents,[3] catecholamines,[4] and formaldehyde.[5] The sensing mechanism is driven by selective host–guest interactions and interfacial effects at the nanoparticle surface, resulting in efficient signal transduction even in complex environments. Notably, the emission changes can be monitored using a simple smartphone-based detector, supporting compact and low-cost point-of-care/field-deployable implementations suitable for real-life applications.

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Engineering Gating in Nanopores: A Biomimetic Approach

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Nanopore technologies have ushered a new era in DNA sequencing and single molecule detection [1]. The key inspiration, and often the core of this technology, are biological nanopores whose controlled (sub)nanoscale aperture enables the controlled translocation of molecules. The most popular biological nanopores that have been used in this context are derived from toxins, due to their simplicity and robustness. However, their functionalities are limited. In this talk, it is suggested that a leap forward in the capabilities and scope of nanopore technologies can be achieved by drawing inspiration from ion channels that have more sophisticated biological functions. The key feature that will be considered in detail is gating, i.e., the capacity of ion channels to switch on or off in response to external stimuli. Gating is at the basis of advanced biological functions such as signal transmission and processing in the form of action potentials, in addition to sensing of diverse environmental signals. How can such disruptive capabilities be effectively implemented in nanopore technologies? An approach based on hydrophobic gating is proposed [2], in which nanoscale bubbles,which form where the nanopore lumen is sufficiently narrow and hydrophobic, are used to switch off ionic currents across nanopores. To achieve control over this gating mechanism, i.e., to realize a voltage-sensitive nanopore, electrowetting can be used to re-establish a conductive pore by polarizing water within the nanopore [3]. Bidirectional control can be further implemented leveraging the new concept of electrodrying [4], by which the gating nanoscale bubble can be restored by applying a voltage. This electro-wetting/drying strategy relies on phase transitions that require no moving parts, avoiding the intricacy of the gating machinery of biological ion channels. Molecular dynamics simulations, continuum models, and electrophysiological experiments demonstrate the feasibility of this bioinspired gating strategy, establishing simple design rules [3,4]. EngineeredFraCand CytKnanoporessuccessfully replicate the voltage gating of ion channels, enabling simple synaptic devices capable of learning and forgetting. In summary, gating can confer new bioinspired capabilities to nanopores, opening new scenariosfor applications at the interface with biology.

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A SERS-Active Plasmonic Nanosensor-Chemometrics Platform Reveals a Biphasic Zinc Switch That Controls Breast-Cancer Metastasis

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Labile Zn2+ is emerging as a quantitative driver, not just a biomarker, of metastasis, yet rapid, second-resolved intracellular measurement remains elusive. Here we engineer terpyridine-functionalised, hollow Au@SiO2 nanocapsules (NCs@TPY) and couple their SERS signal to cell-specific partial-least-squares (PLS) chemometrics, yielding an 8-log dynamic range (10-12 – 10-4 M), a low-nanomolar detection limit and ≤4.5 % cross-validated error while rejecting Ca2+ / Mg2+ interference. Applying this platform to four breast-cancer lines reveals that basal cytosolic Zn2+ forms a "ladder" paralleling metastatic aggressiveness (MCF-7 25 pM < MDA 430 pM < LM2 4.7 nM < BrM2 51 nM). Manipulating extracellular zinc uncovers a biphasic switch: migration, invasion and proliferation all peak when intracellular Zn2+ rises into the nanomolar band (~ 10 – 560 nM) and collapse once it exceeds ~5–70 µM (line-specific). Primary-tumour-derived MDA cells are hypersensitive, reaching maximal metastatic traits at ~0.6 µM Zn2+, whereas lung- and brain-tropic variants show partial resistance, indicating micro-environmental adaptation. The NCs@TPY-PLS assay thus provides the first tool to track intracellular zinc across eight orders of magnitude in situ and demonstrates that tightly regulated Zn2+ dyshomeostasis controls metastatic behaviour. Because the Raman ligand is exchangeable, the capsule architecture is readily extendable to multiplex ion or redox sensing, and the identified "functional window" positions zinc transporters as actionable targets for anti-metastatic therapy.

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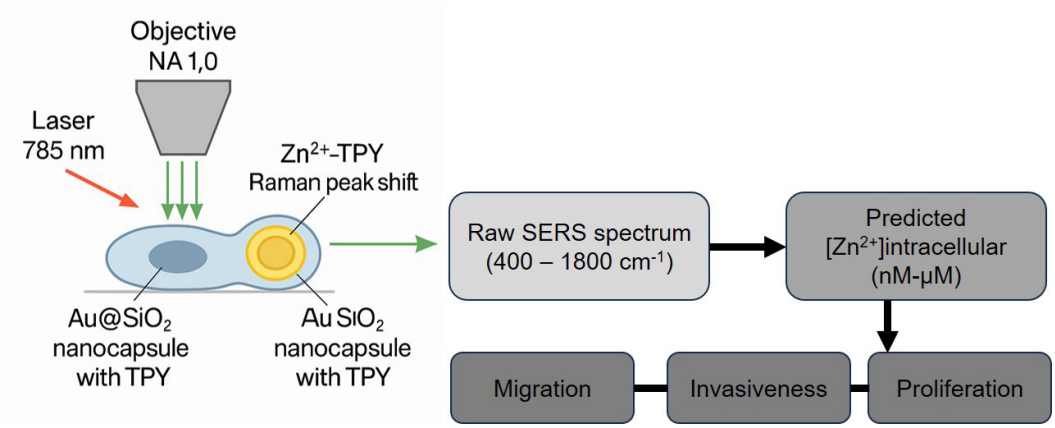

Figure 1: Data analysis pipeline for intracellular Zn2+ quantification.

Solid-State Nanopores as Ion Channels for Single-Molecule Detection and Ionic Gating

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Artificial intelligence is rapidly permeating modern technology, but its growth is increasingly constrained by the costs of delivering power and removing heat. Neural computation offers a striking counterpoint, for it achieves sophisticated information processing at exceptionally low energy by exploiting ionic flows and adaptive conductance. Inspired by the Hodgkin-Huxley view that function emerges from ion-transport dynamics, recent work has begun to implement memory and learning directly in fluids, where ions simultaneously carry signals and encode internal device state. Here I will present some recent results on the use of solid-state nanofluidics to realize devices able to work as gates and memristors towards the development of artificial bio-inspired iontronics.

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Scaling Up In Vitro Real-Time Cell Monitoring Through Large-Area Printing of PEDOT:PSS OECTs

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Poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS) is a promising semiconducting material in bioelectronic and biomedical application due to its ability to conduct both ions and electrons, biocompatibility, high conductivity, and reversible electrochemical properties in acqueous environment.

Our group developed PEDOT:PSS-based Organic Electrochemical Transistors (OECTs) for the electrical, continuous monitoring of in vitro cell viability, providing fast and real-time outputs which overcome standard optical-based techniques, without the need of toxic substance staining or highly specialized operators.

Here, we present our first prototype of the sensing platform, named TECH-OECT (Tissue Engineering Cell Holder for Organic Electrochemical Transistor), allowed the quantitative, real-time, electronic readout of up to six (6-well) different cell cultures:[1] it was demonstrated to efficiently detect viral infections,[2] quantify neutralizing antibodies,[3] and evaluate patient response (lymphocytes activation) during immunotherapy. Moreover, we show a preliminary prototype platform scale up, using printing facilities aiming at saving material and cost-effective depositions, while maintaining the requested resolution and device performances. This step towards a pre-industrial, large area, fabrication pilot line proves the prototype scalability, for the realization of a 48-well sensorized platform.

This PEDOT:PSS-based TECH-OECT represents a scalable biosensor for versatile monitoring of cell culture stress response, paving the way for high throughput drug discovery screening, toxicology evaluations, serum neutralization assays, and vaccine development.

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Designing Catalytic and Magnetic Micromotors as Mobile Sensors for Next-Generation Bioanalytical Applications

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Self-propelled micromotors and microrobots have emerged as disruptive analytical platforms for next generation biosensing. Their active motion throughout the sample volume generates enhanced mass transport and mixing effects, significantly improving target–receptor interactions and consequently increasing the sensitivity and speed of bioassays. These unique features have opened new opportunities for bioanalysis, particularly when dealing with limited sample volumes and complex biological matrices. This presentation will discuss recent advances in the design and engineering of catalytic and magnetically guided micromotors and microrobots for precision biosensing. Special emphasis will be placed on tubular micromotors and Janus-type architectures incorporating functional nanomaterials and molecular recognition elements, enabling autonomous propulsion, controlled navigation, and highly selective target recognition. The integration of advanced nanostructures with electrochemical and optical transduction strategies has led to sensitive and reliable analytical systems for clinically relevant biomarkers. Selected examples will illustrate the application of these mobile sensing platforms to challenging biomedical scenarios. In these applications, micromotor-assisted bioassays provide rapid analysis, enhanced analytical performance, and the capability to operate with microliter-scale sample volumes. The talk will highlight how active matter concepts are transforming conventional biosensing approaches and paving the way toward future autonomous analytical microsystems for precision diagnostics and personalized healthcare.

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Day-1

NanoSeries2026 Technical Workshop: NSAW1

“Nanoengineering for Advanced Sensing Applications” (Workshop Code:NSAW1)

Supramolecular Sensor Devices based on Organic Field-effect Transistors

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Supramolecular materials have the potential to be applied to analytical tools owing to their fascinating functions. However, these materials have not been satisfactorily used for practical sensor devices. In this presentation, we propose an approach for the development of supramolecular sensor devices based on organic field-effect transistors (OFETs) [1]. OFETs are electronic devices whose switching characteristics are controlled by applying a gate voltage. The device characteristics are governed by the assembly of organic semiconducting molecules; therefore, OFETs can be referred to as supramolecular devices. Owing to their beneficial device properties, OFETs functionalized with appropriate molecular recognition materials can offer advantages in sensitive detection compared with conventional electrochemical sensing methods. In receptor design, biological materials such as enzymes and antibodies have been employed because of their favorable specificity toward analytes based on the lock-and-key recognition principle. However, the range of detectable analytes is limited by the available library of biological recognition materials. Thus, the use of synthetic receptors based on molecular recognition chemistry is a promising approach for designing recognition sites. In this study, molecularly imprinted polymers (MIPs)were applied as recognition materials for selective detection. MIPs provide three-dimensional recognition sites for specific analytes, as pre-organized structures consisting of a template and functional monomers can be optimized using quantum chemical calculations. Such optimized MIP structures contribute to selective detection even in the presence of interferents [2]. In contrast, the inherent cross-reactivity of supramolecular receptors can be applied to simultaneous detection using pattern recognition methods [3].This presentation will highlight the potential of this approach for the realization of supramolecular sensor devices based on the integration of organic electronics, molecular recognition chemistry, and polymer chemistry.

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A Self-Assembled Colorimetric Chemosensor Array for Pattern-Recognition-Driven Detection of Steroid Hormones

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Steroid hormones are essential biomarkers playing significant roles, such as sexual functions in the human body; thus, their simultaneous detection is required in many research fields.Chemosensor arrays are powerful optical analytical tools that enable visualization of multiple types of chemical information corresponding to the types and concentrations of analytes, in combination with pattern recognition techniques [1]. In this regard, the discriminatory power of chemosensor arrays relies on the cross- reactivities of each sensor element [2]. In other words, chemosensor designs are significant, especially for the quantitative detection in mixtures of similar structural targets in the presence of interferents. Herein, the presenter proposes a self-assembly approach to easily obtain colorimetric chemosensors for the discrimination of various steroid hormones [3]. The target steroid hormones (H1−H15) possess unique structural features with differences in molecular geometries and hydrophobicity, which are crucial factors in their discrimination based on pattern recognition. In this study, cucurbit[8]uril (CB[8]) was employed as a macrocyclic receptor owing to its encapsulation capability for azo dyes (1−3) and target steroid hormones (H1−H15). The colorimetric ensembles made of azo dyes and CB[8] provide various colorimetric recovery by adding analytes, according to an indicator-displacement fashion. The variation of colorimetric responses depends on competitive interactions among azo dyes, CB[8], and analytes. Indeed, the self-assembled chemosensors successfully discriminated 15 types of steroid hormones and semi-quantitatively detected similar structural analytes (i.e., testosterone (H2) and 17-β-estradiol (H7)) in their mixtures with high accuracy. More importantly, the applicability of the analytical method to a real-sample analysis was revealed by a regression analysis of progesterone (H13) in human saliva. The presenter will introduce the strategy of chemosensor designs and the performance of chemosensor arrays based on pattern recognition.

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Tunable SERS Sensing Hydrogel for In-Situ Analysis and Diagnostics

Pietro Strobbia

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Our lab research is largely directed towards bridging the gap between current state-of-the-art sensing technologies and the actual requirements for their application in clinical settings or in the field. Emerging infectious diseases and global food security are arising as major societal challenges due to climate change and other shifting conditions. We believe surface-enhanced Raman scattering (SERS)-based technology can play a key role in tackling global challenges, including early surveillance of infectious diseases and advancing precision agriculture. Our goal is to advance the state-of-the-art of SERS biosensors developing solutions designed to meet these global challenges.

Within this effort, our lab has been working on the translation of SERS biosensors for real-world applications. Specifically, we have been focused on designing a SERS sensing platform for agricultural settings. We have developed SERS-sensing hydrogels for the detection of viral infections directly in plants. This sensing platform integrates reagentless sensors in a hydrogel matrix. The hydrogel materials are optimized for the extraction of viral and genetic material from the plant interstitial fluid. The hydrogels also function as an optimal matrix for the sensors to respond to target genetic material without additional processing steps. Our current research focus is on tuning polymeric hydrogel material for the extraction of specific analytes and understand its relation to sensing performance.

Electroactive Imprinted Nanoparticles Towards Mass Production of Chemosensors

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Molecularly imprinted polymers (MIPs) represent an excellent example of synthetic systems that mimic the recognition encountered in nature [1]. MIPs are synthetic materials prepared by co-polymerization, in a porogenic solvent, with functional and cross-linking monomers in the presence of a template. This template can be similar to the target substance or be the target itself- the analyte - that the polymer should subsequently selectively recognize. This templating induces three-dimensional binding sites in the polymer that are complementary to the template in size, shape, and chemical functionality.

The preparation of imprinted polymer in the form of nanoparticles has received much consideration because of their excellent binding efficiency compared to a polymer synthesized in film or bulk. Moreover, the mass production of nanoparticles can enable large-scale fabrication of chemosensors.During my talk, I will presentour efforts in the synthesis and application of electrochemically active imprinted nanoparticles (NPs) prepared by soft molds.

One such effort describes the large-scale production of fully inkjet-printed electrodes for the sensitive and selective determination of duloxetine (DUX), a commonly prescribed antidepressant. This intriguing approach involves inkjet printing (IJP) graphene layers onto Kapton, followed by NP printing, to fabricate a chemosensor. This sheds light on an innovative method for preparing a chemosensor recognition unit based on MIP NP. Electrochemical impedance spectroscopy with a redox probe was selected as the signal transduction method to indirectly determine DUX concentration [2].The fabricated chemosensordetected DUX over a concentration range of 1 - 482 nM, with a limit of detection (LOD) of 2.2 nM.The chemosensor's selectivity and detectability were satisfactory. Inkjet-printed electrodes were characterized by long shelf life without performance depletion.

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Electropolymerized Organic Mixed Conductors as Tunable Surfaces for Organic Electrochemical Transistor Biosensors

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Organic Electrochemical Transistors (OECTs) have gained significant research interest for applications as chemical/biological sensors and in neuromorphic circuits due to their high transconductance, efficient electron-ion coupling, compatibility with aqueous solutions, conformability, and low voltage operation. These advantages stem from organic mixed ionic-electronic conductors (OMIECs) that enable simultaneous transport of electronic charges and ionic species, which can be direct processed via electropolymerization. This technique offers precise control over polymer film thickness and morphology, facilitating the formation of nanostructures and enabling selective patterning on individual channels without complex photolithography, simplifying OECT fabrication and integration. In this talk, I will discuss the performance of OECTs using various electropolymerized channel materials, starting with PEDOT for dopamine detection, followed PEDOT:N3[1], a clickable OMIEC variant whose threshold voltage can be finely tuned through control of the electropolymerization parameters, and finally P-tri-DPA for zinc ion detection, achieving low limits of detection and high specificity for Zn^{2+} ions[2]. These findings highlight the potential of electropolymerization and OMIEC materials engineering in developing advanced bioelectronic devices.

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Edible Polydopamine–Alginate Hydrogel Electrodes for Gastrointestinal Glucose Monitoring

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Postprandial glucose absorption in the small intestine is an increasingly important therapeutic target in type 2 diabetes and related metabolic disorders, yet current monitoring approaches are invasive and cannot resolve local glucose fluctuations during digestion. Ingestible biosensors offer a route to real-time, site-specific analysis within the gastrointestinal tract, but their translation is limited by the use of non-degradable materials, risk of retention, and the need for device retrieval.[1] Here, we report a novel self-standing edible polydopamine-based alginate hydrogel electrode that integrates intrinsic ionic and electronic conductivity, enabling a new architecture for transient ingestible bioelectronics. The platform is fabricated from Ca2+-crosslinked alginate (3.5% w/v) plasticized with glycerol (5% w/v) and reinforced with polydopamine, silver nanoparticles, and food-grade glucose oxidase. The optimized formulation exhibits an electroactive surface area of 1.99 ± 0.07 cm2, a double-layer capacitance of 10.1 ± 0.3 µF, and a charge-transfer resistance of 7.7 ± 0.6 kΩ. Morphological and structural analyses by SEM, TEM, AFM, WAXS, and FTIR confirm homogeneous AgNP dispersion, formation of conductive polydopamine domains, and stable enzyme incorporation within the hydrogel matrix. Rheology and dynamic mechanical analysis reveal enhanced viscoelastic behavior, tensile strength of 14 MPa, and a Young's modulus of 65 MPa, supporting robust mechanical performance under physiologically relevant conditions. Configured as a first-generation glucose biosensor in USP simulated intestinal fluid (pH 6.8), the edible electrode shows a linear response from 50 µM to 1.0 mM, a detection limit of 10.4 ± 0.8 µM, and an apparent KMapp of 0.35 ± 0.08 mM. The biosensor retains at least 95% activity over 20 h of continuous operation and 90% after 30 days of storage, with negligible interference from physiological species. This platform provides a sustainable strategy for non-invasive gastrointestinal glucose monitoring and future closed-loop edible therapeutic systems. It highlights personalized, transient diagnostic and therapeutic opportunities ahead.[2].

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Fluorimetric Detection of Micro- and Nanoplastics for Environmental Monitoring Purposes

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The continuous growth of environmental pollution due to the intensive industrial, agriculture and urban emissions became nowadays a serious problem negatively influencing the quality of life and health of modern society. The decrease of pollutingemissions not only from industrial processes, but also the waste production and release by society itself, would improve the ecology and serious legislation efforts are afforded in this direction on international level [1]. Plastics constitute12% of total waste, and annualy more than 350 million tonnes of plastic waste are generated, only ca.10% is recycled, while around 70% of produced plastic is indiscriminately wasted in the environment [2]. Among wasted plastics, the most dangerous forms for biota and human health are micro- and nanoplastics (MNPs), being ubiquitous and more bioavailable. Their detection and monitoring are complicated, since existing protocols are unsatisfactory, limited by high cost, complex instrumentation, necessity of sampling, transportation and impossibility of rapid on-site analysis [3].The development of effective, low-cost, time-saving portable devices forMNPs environmental pollution detection is an important and challenging task.

Optical sensors are easy to handle, fast, non-expensive and portable technology characterized by sensitivity comparable with standard instrumental methods, and low detection limits[4,5]. Here we have tested on-paper based disposable fluorescent chemical sensors prepared with hyaluronic acid functionalized with Nile Red (HA-NR) and with rhodamine B (HA-RB) for screening and quantitative assessment of six MNPs: PVC, PMMA, PE, PP, PS, PET, and their mixtures in distilled and tap water. The possibility to discriminate MNPs with HA-NRoptodes, as well as the possibility to detect MNPs in tap water background in a range from 1 µM to 0.1 mM with the lowest detection limit of 1.7 µM and R2 of 0.995 through HA-RB sensor was shown. The detailed discussion of these results will be provided in our presentation.

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Nanomaterials Integration and Engineered Interfaces for Advanced Chemical and Biosensing Platforms

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The rapid evolution of chemical and biosensing technologies relies on the rational design of nanomaterials and the precise engineering of their interfaces with microelectronic platforms. This work presents a comprehensive approach to the integration of graphene, metal oxides, organic semiconductors, and hybrid nanostructures into scalable sensing architectures, highlighting strategies that bridge materials science and device engineering. Innovative graphene transfer and patterning techniques, including hot embossing-assisted transfer [1]and lift-off lithography[2], enable the fabrication of high-quality, few-layer graphene on flexible and rigid substrates, preserving electrical performance while ensuring compatibility with large-area processing. These approaches facilitate the development of flexible electronics and highly sensitive transducers. Complementarily, the integration of ZnO nano-tetrapods onto MEMS micro-hotplates demonstrates a scalable route for metal oxide gas sensors, combining high surface-to-volume ratios with low power consumption and wafer-levelmanufacturability[3].Advances in CMOS-compatible platforms further enable the seamless incorporation of nanoscale sensing elements into multipurpose electronic systems, supporting signal conditioning and multiplexed detection[4]. The miniaturization of organic electrochemical transistors (OECTs) down to nanosized channels significantly enhances transconductance and sensitivity, opening new opportunities for label-free biosensing in physiological environments[5]. Additionally, layered double hydroxides and electrospun nanofibers expand the materials toolbox, offering room-temperature VOC detection and bioelectrochemical functionality through engineered porosity and tailored surface chemistry[6],[7].Central to these developments is the control of material–interface interactions, which governs charge transport, analyte adsorption, and long-term device stability. By combining scalable fabrication techniques with interface-aware design, these integrated platforms demonstrate improved sensitivity, selectivity, flexibility, and system-level compatibility. The convergence of nanomaterial synthesis, microfabrication, and CMOS integration thus provides a robust pathway toward next-generation, low-cost, and high-performance chemical and biosensing systems for environmental monitoring, healthcare, and wearable applications.

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Porous Organic and Metal–Organic Cages: Adaptive Platforms for Sensing and Separation Processes

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Porous organic cages (POCs) and metal–organic cages (MOCs) have emerged as complementary classes of discrete, three-dimensional architectures with significant potential in advanced functional applications. POCs, typically assembled via dynamic covalent chemistry, combine intrinsic porosity, structural tunability, and solution processability. In parallel, MOCs, formed through coordination-driven self-assembly of metal ions and organic ligands, offer well-defined geometries, dynamic behavior, and tunable cavity environments. Together, these systems represent a versatile platform for the design of adaptive materials.

In this invited contribution, we highlight recent advances in the application of POCs and MOCs to sensing. Both platforms exploit selective host–guest interactions that can be transduced into optical or electronic signals, enabling the detection of pollutants and biologically relevant analytes in complex aqueous media.

We further discuss their growing role in gas separation technologies. Their well-defined cavities and tunable pore environments enable precise molecular discrimination based on size, shape, and chemical functionality. In addition, their solution processability and film-forming ability facilitate integration into membranes and mixed-matrix materials, resulting in promising performance in CO2 capture and, more broadly, in gas separation processes.

Overall, this contribution emphasizes the convergence of POCs and MOCs as multifunctional platforms and outlines future directions toward advanced materials for next-generation sensing and separation technologies.

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Molecular Simulation to Autonomous Materials Discovery: AI-Guided Design of Carbon Nanostructures and Hybrid Perovskites

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AI, molecular simulation, and automated experimentation are rapidly transforming the discovery of nanostructured materials. This presentation discusses recent advances toward AI-guided and autonomous materials discovery using reactive molecular simulation, graph neural networks, machine learning, and robotic experimentation.

First, we introduce machine learning frameworks for predicting the mechanical and failure properties of graphitic carbon nanostructures, including carbon nanotube bundles, fiber cross-sections, and nanotube junctions. A database of more than 2,000 reactive molecular dynamics simulations generated using the reactive INTERFACE force field (IFF-R) enables hierarchical spatial graph neural networks (HS-GNNs) to predict elastic and failure properties with mean relative errors below 5% and accelerations up to 10,000× relative to molecular dynamics simulations. The models provide insight into defect engineering, transferability outside the training range, and scalable design of lightweight structural nanomaterials.

Second, we present integrated workflows for the accelerated discovery of hybrid organic-inorganic perovskites and related nanomaterials. Machine learning, molecular dynamics simulation, crystallographic databases, and robotic synthesis are combined to predict structural dimensionality, stability, and structure formation across large compositional spaces relevant to LEDs, solar cells, and optoelectronic devices. Recent advances include AI-assisted dimensionality prediction, molecular simulation-guided stability ranking, and automated growth and characterization of low-dimensional metal-halide structures.

The presentation highlights broader opportunities for interpretable and experimentally validated AI workflows that combine molecular simulation, graph learning, and autonomous experimentation to accelerate nanomaterials discovery from atoms to functional systems.

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Memristive Devices and Systems Based on Nanowires for Brain-Inspired Computing

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In a technological landscape marked by the rapid advancement of artificial intelligence, memristive devices have emerged as promising building blocks for brain-inspired computing systems that move beyond conventional von Neumann architectures. Here, we investigate memristive devices based on single nanowires as model systems for studying resistive switching phenomena [1], and nanowire network–based memristive systems for the emulation of synaptic functionalities [2] and the implementation of unconventional neuromorphic computing architectures [3]. Through a combined experimental and theoretical approach, we further demonstrate that single nanowire memristive devices provide a powerful platform for exploring quantum conductance effects in air at room temperature [4]. We have recently shown that this phenomenon can be harnessed to realize a novel quantum-based standard of resistance [5]. At the network level, we show that the intrinsic dynamics and signal-processing capabilities of nanowire-based memristive networks can be exploited within the reservoir computing framework to perform a wide range of computational tasks, including time-series prediction, speech recognition, and pattern recognition [3,6].

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Synaptic Functionalities and In-Materia Reservoir Computing in Azopolymeric Compounds

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Understanding and emulating fundamental functions of biological systems has gained increasing significance in modern science and technology, driven by the remarkable efficiency of neural systems in handling complex tasks such as classification, pattern recognition and motion perception. Neuromorphic computing, inspired by biological neural networks, offers a novel approach in which data processing and memory functions occur within the same structure, rather than in separate units, as in conventional systems. This paradigm aims to replicate key features of neuronal and synaptic activity, such as their non-linear and dynamic responses to external stimuli. These features, including potentiation and relaxation, underlie fundamental learning mechanisms in biological systems.

Intelligent matter, understood as a material capable of responding to external stimuli by changing its state and adapting to the external environment through learning from previous stimuli, could pave the way for a new class of hardware for neuromorphic computing. Adaptive materials responsive to light stimuli open up exciting possibilities, including the perception, memorization, and processing of visual information, which emulates the basic functions of the human retina.

A well-known class of light-responsive materials are azobenzene-containing molecular compounds, known for their strong light responsivity that may result in light-induced birefringence or light-driven mass migration, phenomena that have been extensively studied in the context of optical memories.

In this work, we explore the properties of a water-soluble and biocompatible azopolymer known as PAZO (poly[1-[4-(3-carboxy-4-hydroxyphenylazo) benzenesulfonamido]-1,2-ethanediyl, sodium salt]). We focus on its optically induced birefringence and examine how the system's spontaneous relaxation can be leveraged to store and process spatial and temporal signals.

In addition, we provide a modeling framework based on a rate-balance equation to predict the material's internal state and allow for *in silico* testing of unconventional computing architectures that exploit intrinsic material dynamics. By correlating model parameters and physical quantities (temperature, light power density) we also provide insights into the driving and restoring mechanisms underlying the light induced birefringence.

In the final part of the paper, we extend these findings to demonstrate spatio-temporal data processing capabilities. This work underscores the potential of PAZO as a key material for developing intelligent, adaptive devices that mimic the complex processing abilities of biological systems.

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Day-1

NanoSeries2026 Technical Workshop: NSAW2

Single–Molecule Electronics: From Fundamental Quantum Transport to Emerging Applications

Physics and Chemistry of Single-Molecule Circuits

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Thepast decade has seen tremendous progress in realizing molecular analogues of macroscale electronic components, such as resistors, diodes, switches or transistors, where the molecular circuit property is determined by the chemical structure and physical properties of the metal-molecule-metal junction. This progress has been enabled by the scanning tun neling microscope (STM)-based break-junction technique that my group has pioneered, which facilitates reliable and reproducible measurements of single-molecule devices. In this talk, I will first describe how we developed this technique to probe fundamental properties of circuit elements created with organic molecules and then give you an exam ple of how we created long and highly conducting molecular wires using one-dimensional molecular analogs of topological insulators.

Decorating Surfaces with Molecular Spin Qubits and Molecular Quantum Logic Gates

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Chemical tunability and processability make molecular spins an attractive platform for the physical realization of qubits [1]. Typical examples of molecular spin qubits are coordination complexes based on S=1/2 metal ions with long coherence times [2]. Molecules are ideal candidates for implementing quantum logic gates by designing bimetallic paramagnetic complexes where two S=1/2 centers are interacting via exchange coupling interaction [3]. Controlling the individual qubits orientation of the magnetic anisotropic tensors permits single spin addressability in these systems in diluted solutions. Next step is the organization of these objects as addressable ordered arrays of single objects intactly physisorbed on surfaces.

Here we report on our efforts of organizing on surfaces archetypal molecular spin qubits [4-6] that accommodate paramagnetic metal ions in rigid scaffolds and is maintained paramagnetic on ad hoc selected surfaces including graphene as well as their combination in more complex dimeric and polymeric units [6,7] that can be arranged on surface controlling their interactions thus opening to their use as quantum logic gates to be operated either by light irradiation [8] or via an electrical current flowing through them [9].

At this preliminary stage x-ray photoelectron spectroscopies and X-ray absorption spectroscopies are key tools for the investigation of the orientation and the organization of these systems on surfaces. They shed light on the strength of the interaction between these molecular systems and the selected surfaces, thus allowing us to evaluate if the magnetic structure of these objects is preserved on surfaces and their evolution when organized into arrays achieving a crucial advance toward the development of a molecular spin-based quantum technology.

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Electron Transport Through Long Molecules: From Wires to Nanoribbons, Coherent to Ballistic Conductance

Edmund Leary

IMDEA Nanociencia

The search for long molecular wires that can transport charge with maximum efficiency over many nanometers has driven molecular electronics since its inception. Single-molecule conductance at low bias voltages normally decays significantly with length and is typically far below the theoretical limit of G0 (77.5 μS, the conductance of a “fully-open” quantum channel). Indeed, this is the behaviourwe observe for monoatomic polyyne chains, all the way up to a length of at least 5 nm.1Some systems, such as cumulenes,2 cyanine dyes,3 and extended-indenofluorenes4 show either zero or slightly positive conductance decay with length, but there conductance values are still significantly below G0. On the other hand, edge-fused porphyrin ribbons display quite different behaviour. We have tested ribbons up to 7 nm in length. The low-bias conductance is high and fairly constant across the series, although still below 1 G0.5By pulsing with a larger bias, however, we can increase the low-bias conductance up to 1 G0 (corresponding to a current of 20 μA) even for the longest compound. We will discuss a potential mechanism for this.These results lay the foundations for long, perfectly-transmissive, molecular wires.

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Room-Temperature Quantum Transport: Instrumentation , AI, and Single Molecule Glycerol Junctions

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Room-temperature molecular electronics is fundamental for the future generation of nanodevices, but its study using Break Junctions (BJ) lacks *in situ* calibration methods with subatomic precision. To solve this problem, we propose using the formation of 1- to 3-atom-thick gold structures as a reference standard [1]. This allows for the precise calibration of the system at room temperature and the evaluation of electrode sharpness during mechanical stretching. These experimental findings, supported by Molecular Dynamics (MD) simulations and ab *initio* transport calculations, are complemented by an in-depth review of the instrumentation, highlighting a comparison of and advance in different current-voltage (I-V) amplifier architectures [2].

Finally, we will integrate these innovations into the study of gold contacts immersed in glycerol. By applying Machine Learning algorithms (DBSCAN clustering and neural networks) combined with BJ measurements and MD/DFT calculations, we will unveil the complex relationship between the molecule and the contact geometry, revealing intriguing questions about this medium [3].

These results not only resolve historical technical limitations but also establish a standard that guarantees the integrity of the quantum signal for the next generation of nanoscale technologies.

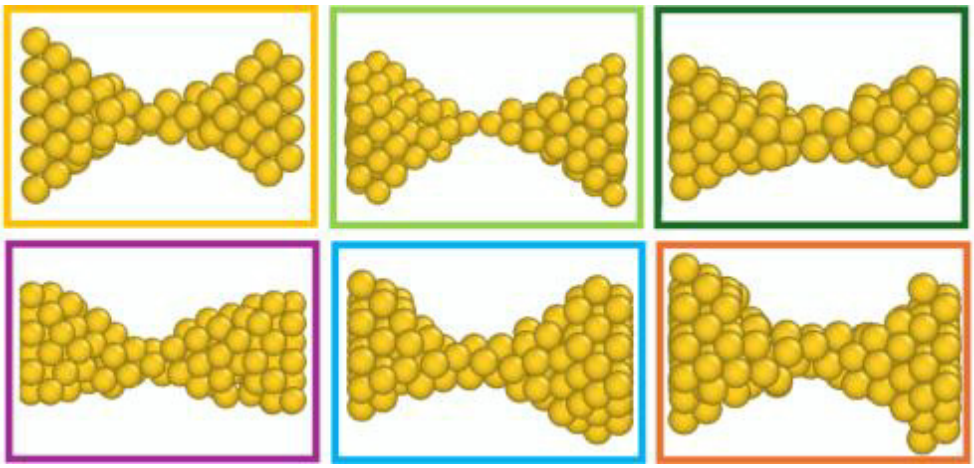

Figure 1: Illustrations of the atomic structures obta ined by CMD during the stretching process of the atomic contacts

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Spin-Dependent Charge Transport in Single-Molecule Junctions of α-Helical Peptide Sequences

Ismael Díez-Pérez[1], Albert C. Aragonés[2], Wenzhu Kuang[1], Qiankun Wang[1], Mario Galante[3], Vladimiro Mujica[3], Qing-Feng Sun[4]

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In this contribution, we will present our latest experimental results on spin-dependence charge transport through single-molecule electrical contacts made with chiral alpha-helical peptide backbones. We synthesize a series of α-helical peptides sequences of varying lengths, i.e., from 6 to 22 amino acids and their two corresponding D- and L-optical isomer, all bearing the repeating pattern (H2N-Cys(Acm)-(Glu-Ala-Ala-Ala-Lys)n-NH-CH2-CH2-SH). The peptide is flanked by two axial thiol groups; an Acm (acetamidomethyl)-protected Cys(-SH) residue and an alkanethiol terminal group. The chosen specific sequence presents an α-helix favored conformation in the working polar water:TFE (trifluoroethanol) mixture. We use a magnetic STM break-junction approach we have previously exploited to measure magnetoresistance in various single-molecule contacts[1,2]. This approach allows us to trap individual α-helical peptide between two metal beads (namely, a Au and a ferromagnetic Ni electrode) oriented along the main helix axis though the two side thiol groups specifically binding to the two metal electrodes. We are then able to inject spin-polarized electrons from the ferromagnetic Ni to individual α-helical chiral structures and measure the conductance as a function of the Ni magnetization direction. The analysis of the single-peptide charge transport results provides an intuitive picture combining both CISS and spinterface effects that has enough flexibility to accommodate the description of the observed differences in magnetoresistance as a function of the peptide chirality[3]. The latter picture is then studied as a function of well-known structural drivers of the CISS/Spinterface manifestation such as the electric dipole direction of the helical structure[4], the molecular length and the secondary structure[5]. We hope our work demonstrates the feasibility of our single-molecule platform to study fundamental mechanisms of spin-dependent transport in chiral biomolecular motifs and proposes to expand the studies to more complex metalloproteins with redox-dependent functions where the electron spin might play a key quantum biological role.

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In Situ Tunnel Junction Assembly of Organometallic Molecular Wires Displaying Aurophilicity

Masha Kamenetska

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I will report on recent progress in assembling, characterizing, and controlling electronic properties of quasi 1D molecular materials containing transition metal atoms at the junc- tionoftwometalelectrodes.Briefly,Iwill-describejunctionsformedwithimidazolate ionswhichcanbeelongatedthroughtip-sampledisplacementtoincorpo-ratesilveror gold atoms.Next, I will show that cyanide ligands can also assemble in the junction and elongateinto-extendedchainsbetweenthetipandsubstrateelectrodes.Wefindthat metallophilic interactions between adjacent metal sites result in increased coupling and formationofmolecularmaterialswithnovelelectronicproperties.

Probing Interfacial Electrochemical Dynamics with Single-Molecule Junctions

Roberto Listo

University of Pavia, Italy

We present a novel approach to probe the electric double layer (EDL) at electrochemical interfacesusingsingle-moleculejunctions(SMJs)asultrasensitiveprobes.Focusingon the inner Helmholtz plane (IHP), we employ the scanning tunnelling microscope break- junction(STMBJ)techniquetomeasurecurrentresponsesundersquare-wavebiasin differentsolventenvironments.Thelinearresponseiscapturedbyamolecular-level equivalent circuit model, revealing clear correlations between solvent properties and in- terfacial dynamics.

Exploiting Quantum Interference in Open- and Closed-Shell Junctions for Functional Molecular Electronics

Sara Sangtaras

University of Warwick, United Kingdom

Understanding how quantum interference (QI) controls charge transport through metal–molecule–metal junctions is central to the progress of molecular electronics. At this length scale, electron transport is governed by the laws of quantum mechanics; specifically, the wave nature of electrons gives rise to QI effects that dictate overall conductance.

In this talk, I will discuss the strategic design of molecular junctions to harness both constructive and destructive QI. By precisely engineering a molecule's chemical structure, utilising both open- and closed-shell organic molecules, we can design interference landscapes to create functional electronic components. We demonstrate how chemical topology and substituent placement can be tuned to provide precise control over electron transmission. By suppressing conductance through destructive interference or enhancing it via constructive pathways, we can achieve high-performance molecular switches and logic gates.

Furthermore, we explore how the sharp transmission features induced by QI can be exploited for thermoelectric energy harvesting, by significantly enhancing the Seebeck coefficient, and for highly sensitive molecular sensors capable of detecting analytes through interference-pattern shifts. Ultimately, the realisation of these junctions offers the potential to revolutionise low-power computing, waste-heat recoveryand molecular-scale circuitry.

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Plasmonic Activation of Molecular Transitions in STM-Tip Cavities: Role of Higher-Order Effects in Near and Far-Fields

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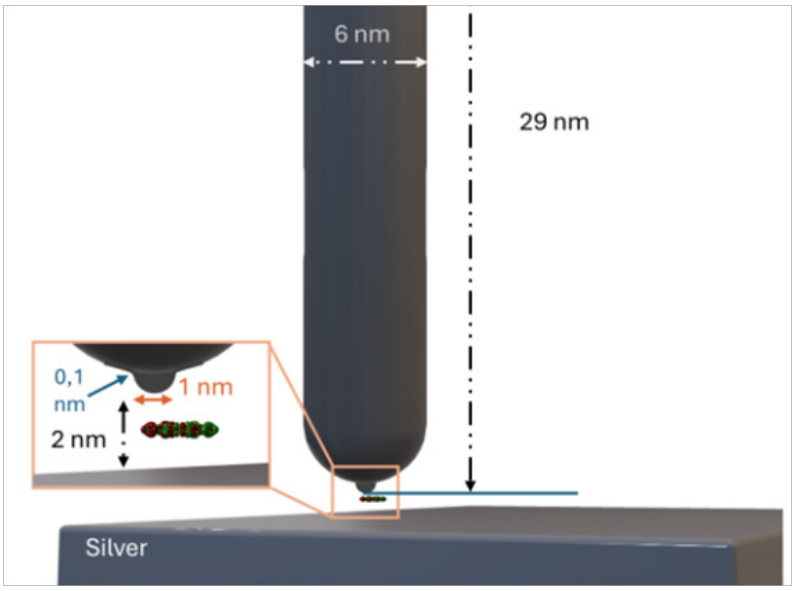
Recent experiments showed that light emission from a molecule can be triggered by inelastic electron tunnelling through a molecular device. The electronic current promotes the molecule in an excited state, and further deexcitation process leads to photon emission.[1] Very interestingly, the metallic tip is a plasmonic nanostructure. Those specific environments are known to strongly enhance the light emission rate, which is named as the Purcell effect in literature. This strong enhancement effect enables optical detection of single molecule fluorescence or the well-known surface-enhancement effect in Raman spectroscopy.

Light emission from a molecule is usually approximated as being emitted from an oscillating point-dipole, with the transition dipole moment as a key-property. Advancements in the field of nanophotonics and plasmonics have shown that light emission from a quantum emitter can be largely enhanced when this emitter is placed near nanoplasmonic structures (Purcell effect). More recently, it has been shown that those structures may also confine light to effective wavelengths within the sub-molecular scale. Consequently, the question of whether the standard description of a molecular emitter as a point-dipole arises. Effects beyond dipole, such as quadrupolar or octupolar contributions, are usually named as 'higher-order effects' and commonly neglected.

In Mons, we address the theoretical modelling of those effects for molecules placed in those nanoplasmonicenvironments.[2-4] We introduce theoretical frameworks to explore the higher-order contributions and limits of the standard point-dipole description. It allows us to calculate the fluorescence emission rate of molecular quantum emitters, described at the TD-DFT level, within nanoplasmonic environments, described by solving Maxwell equations. First, dipole-allowed conjugated emitters are considered: (i) an H2Pc molecule in a tip-on-mirror nanogap and (ii) oligothiophenes of different chain lengths near gold nanospheres. We show that significant deviations from the point-dipole approximation are predicted due to excitonic delocalization. Second, we consider dipole-forbidden molecular emitters within a tip-on-mirror nanoplasmonic structure. We observe a very strong plasmonic activation, with rates essentially equivalent to dipole-allowed emitters, related to a strong quadrupolar contribution. Finally, our framework allows us to evaluate the rate in the far-field and we show that a significant amount of light actually radiates in the far-field for dipole-forbidden molecular emitters in cavities.



Molecule in anSTM-junction cavity

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Quasi-Ballistic Transport in 1D Carbon Chains

AndreaVezzoli

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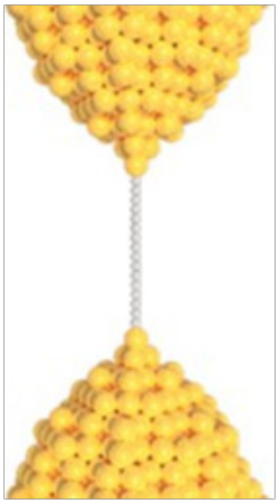
Carbyne promises extraordinary electronic properties.We devised a novel strategy to access stable, uncapped metal-(CC)n-metal junctions exploiting in-situ transmetalla- tion.While shorter chains display typical attenuation, chains exceeding 10 C atoms ex- hibit a transition to cumulenic electronic equalization. This shift unlocks quasi-ballistic, distance-independent transport with conductance enabling currents in excess of 40 µA through a single carbon chain.



Day-2 Plenary

From Ensemble Binding to Single-Molecule Statistics in Surface Plasmon Resonance Immunosensing

Luisa Torsi

Università degli Studi di Bari A.Moro

Surface plasmon resonance (SPR) has long been established as a powerful label-free platform for immunodetection; however, when operated without signal amplification, its analytical sensitivity has remained largely restricted to nanomolar concentrations. In this lecture, we disuss a comprehensive interpretative framework that reveals the coexistence of two qualitatively different sensing regimes governing SPR immunoassays over an exceptionally broad dynamic range, extending from nanomolar to zeptomolar concentrations. Through systematic investigation of centimeter-scale SPR sensing surfaces densely functionalized with pH-conditioned recognition layers, we show that detection at ultralow analyte levels is no longer governed by ensemble-averaged affinity interactions. Instead, the response is dictated by Poisson statistics associated with stochastic single- and few-molecule capture events on large-area interfaces. In this ultradilute regime, individual binding events induce a pH-mediated dielectric reorganization of the capturing layer, generating a measurable plasmonic signal that enables direct, label-free detection at concentrations as low as 10–100 zM with a statistical confidence of 99%, while maintaining false-positive and false-negative rates below 1%. As analyte concentration increases, the sensing behavior progressively shifts toward a classical Maxwell–Boltzmann framework characterized by conventional binding isotherms. By explicitly accounting for instrumental noise, uncertainty propagation, and statistically robust decision criteria, and by modeling the full binding curves, we extract equilibrium parameters in both regimes, including an apparent binding constant unique to the ultralow-concentration limit. These results clarify the physical and statistical mechanisms underlying extreme sensitivity in large-area SPR immunoassays and provide a general foundation for the rational design and interpretation of single-molecule plasmonic sensors operating without labels or amplification strategies.

New photodetection in 2D materials

Yoshi Iwasa

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Over the past two decades, research on 2D materials has provided us with an extremely rich set of concepts in physics and materials science. Today, I am going to discuss optical responses, in particular, photovoltaic effects of 2D materials and their related nanostructures from both fundamental and application viewpoints. Since many 2D semiconductors composed of transition metal dichaocogenides (TMD) have band gapsof near infrared and visible region, they form a rich platform of optical functionalities. In particular, new paradigms are emerging regarding potential ultrafast photo-responses, on which I am going to discuss today.

First, I will introduce a relatively conventional approach; an interface of MoS_2 and GaN for high-speed visible-light detection, developed mainly in Nichia Corporation [1].In this heterostructure, visible light is only absorbed in MoS2 and GaN plays a role of electron carrier collection layer, forming a uni-carrier-traveling photodetector (UCT-PD) [1].

Second, a new fundamental concept named shift current, which is a quantum mechanical mechanism of photovoltaic effect. So called bulk photovoltaic effect is a photovoltaic effect without interfaces such as p-n junctions. It is known that bulk photovoltaic effect appears in noncentrosymmetric semiconductors, and most importantly, the theoretical representation of the shift current mechanism is expressed by the band-structure-driven geometrical quantity, Berry connection, and does not include scattering time. This means that the shift current has nothing to do with impurities and thus the response time maybe ultrafast. I will explain our investigation on the shift current in TMD based nanostructures [2-4].

Finally, I will touch on the observation of pure magnetic injection current, which is governed by another band-structure driven geometrical quantity, quantum metric [5], in contrast to the Berry connection driven shift current. With these explanations, I would like to convince audience that the photoresponse of 2D materials is a plat form not only the device application but also for the modern condensed matter physics.

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Putting Nanomaterials to Work for Biomedical Applications

Younan Xia

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Nanomaterials have found widespread use in many applications, including those related to photonics, electronics, catalysis, energy conversion, sensing, imaging, and biomedicine. Chemistry plays a central role in all these developments. For almost three decades, my group has been working diligently to develop chemical methods for synthesizing and/or fabricating nanomaterials with well-controlled properties. In this talk, I will briefly discuss some of the most recent developments, with a focus on the rational,deterministic, and controllable synthesis/fabrication of various types of nanomaterials for applications in drug delivery,controlled release, and cancer theranostics. At the end, I willalso discuss how to scale up the synthesis or fabrication without losing control to produce nanomaterials with the quality, quantity, and reproducibility needed for a systematic study of their fundamental properties as a function of size, shape, and internal structure, as well as for the exploration of industrial and translationalapplications.

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Strong Light-Matter Coupling in Nanostructured Optical Cavities

Hernán Míguez

Consejo Superior de Investigaciones Científicas Instituto de Ciencia de Materiales de Sevilla

In recent years, high optical quality (i.e., negligible diffuse scattering) nano and mesostructured films displaying intense excitonic bands have been integrated into Fabry-Pérot resonators, giving rise to strong light-matter coupling effects involving nanomaterials that had been so far reluctant to enter this challenging field. Under this regime, the electronic and photonic structure of the system undergoes a reconfiguration that gives rise to new hybrid light-matter states known as exciton-polaritons, which determine the new absorption and emission properties of the ensemble.These advances have yielded significant milestones, like the first observation of room-temperature Bose-Einstein condensation in a quantum dot solid or the first example of fine tuning of the coupling strength by means of reticular materials such as MOFs.

In this talk, we will review these recent findings and describe an alternative approach to achieve strong light-matter coupling using nanoporous optical cavities. , We will show that mesoporous scaffolds presenting a narrow nanopore size distribution provide unique opportunities both to (i) control the quality and purity of the low dimensional perovskite materials synthesized within them, featuring large transition dipole moments, and (ii) achieve intense and spectrally tunable cavity resonances, hence favoring the precise design of exciton-polaritons. Fine control of the cavity size, achieved by means of the precise controlled of the scaffold thickness, permits to accurately determined the absorption and emission properties of the ensemble, which displays absorption and emission properties fully controlled by the exciton-polariton dispersion relation.

The results presentedin this talk has been obtained in the framework of projects funded by the Spanish Ministry of Science and Innovation under grant PID2023-149344OB-100 (MCIN/AEI/10.13039/501100011033 and FEDER/UE) and Junta de Andalucía under grant DGP_PIDI_2024_00821.

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Day-2

NanoSeries2026 Technical Session: NS (A)

Synthesis and Advanced Characterization of Nanomaterials & Nanostructures

XPS at the Nanoscale: A Key to Surface Chemistry in Energy Conversion and Storage

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The development of advanced materials for energy conversion and storage relies on a detailed understanding of surface and interfacial phenomena, which often determine device efficiency, stability, and lifetime. Since many of the key processes involved in batteries, fuel cells, electrolyzers, and photocatalytic systems occur within the first few nanometres of a material, surface-sensitive analytical techniques are essential for elucidating the underlying chemical mechanisms.

X-ray Photoelectron Spectroscopy (XPS) has established itself as one of the most powerful tools for probing surface chemistry, providing quantitative information on elemental composition, chemical states, and electronic structure. Recent technological advances, including chemical imaging, depth profiling, and operando or near-ambient pressure measurements, have significantly expanded the range of materials and processes that can be investigated.

This presentation will highlight the role of XPS in addressing fundamental challenges in energy research through selected examples spanning both energy storage and energy conversion technologies. Case studies on battery electrodes [1-2] will demonstrate how XPS can unravel surface evolution, interfacial reactions, and degradation mechanisms occurring during electrochemical cycling, providing insights into performance limitations and long-term stability. Complementary examples involving platinum-group-metal-free catalysts for the oxygen reduction reaction (ORR) [3-4] will illustrate how XPS enables the identification of active surface species, the characterization of dopant environments, and the investigation of structure–property relationships governing catalytic activity and durability.

By correlating local chemical environments with macroscopic functional properties, XPS provides a critical link between material design and performance. The examples discussed will showcase how surface analysis contributes to the development of more efficient, durable, and sustainable energy technologies, while highlighting emerging opportunities for advanced XPS methodologies in next-generation energy materials.

This work was supported by the European Research Council (ERC) under the European Union's ERC Starting Grant agreement "CO2CAP" (Grant No. 949916). The author also acknowledges financial support from the Italian National Recovery and Resilience Plan (PNRR) project iENTRANCE for the acquisition and development of the NAP-XPS instrumentation.

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Defect-Engineered Nanocatalysts for Sustainable Electrochemical Energy Systems

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The defect engineering of nanostructured materials has garnered significant research interest due to its utility in exploring high-performance energy-functional materials. The introduction of crystal vacancies into nanostructured material is found to be quite effective not only in tailoring the electronic and local structures but also in increasing the electrochemical activity. Since crystal defects can serve as efficient adsorption/reaction sites for ions, electrolytes, and catalysis reactants, the defect engineering can provide a versatile means to optimize the electrocatalyst functionalities of nanostructured materials. In this talk, I will present diverse examples of defect-engineered nanostructures along with the correlation between chemical bonding nature and energy functionalities. The various roles of crystal vacancies in optimizing the catalyst performances will be highlighted based on combined in situ/ex situ spectroscopic analyses.

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Sub-Surface Patterning of Polymers With Inorganics by Area-Selective Vapor Phase Infiltration

Silvia Mirallas García*[1,2], Gabriele Botta[1], Ivan Pavlov[1], Christopher Tollan[1], Evgeny Modin[1] and Mato Knez[1,3]

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Polymers are attractive for their flexibility and ease of processing, yet they often lack the intrinsic electrical properties required for flexible electronics.[1] To address this, hybrid materials are developed as alternative to polymers. By combining organics and inorganics, the resulting hybrids introduce electrical or other physical and chemical properties, while remaining mechanically flexible. The application fields of hybrid materials are very broad, including energy storage, biomedical devices, and flexible electronics.

Derived from Atomic Layer Deposition (ALD), Vapor Phase Infiltration (VPI) was developed as a versatile strategy for polymer functionalization. Unlike standard ALD, VPI adds a critical dwell phase in the process, allowing extended interaction time in which precursors diffuse into the polymeric matrices and react with functional sites within the bulk material. This creates a hybrid subsurface where the infiltrate and matrix coexist and often show synergies due to chemical or physical interactions.[2]

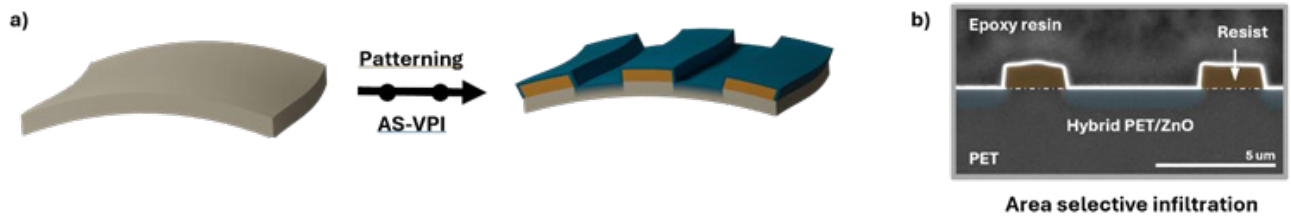

Figure 1. a) Schematic of the workflow of the sample fabrication: bare PET used as substrate in grey and an ilustration of area-selectively infiltrated PET (in orange: resist and in blue: ZnO). b) Scanning electron microsocopy (SEM) image of a sample with infiltrated area and resist artificallycolored.

This work focuses on the infiltration of ZnO into a lithographically patterned PET matrix (Fig. 1a) transferring the pattern into the polymer subsurface (Fig. 1b). Following our approach of area selective-VPI, not only can the regions for infiltration be chosen, but also the depth of it is controllable, even to the micrometer scale. To prove the applicability, anisotropic electrical conductivity is induced using our process, showing a difference in electrical resistance of more than seven orders of magnitude between directions parallel and perpendicular to the infiltrated pattern. The importance of using VPI to embed zinc oxide within the polymeric matrix, rather than simply coating the surface, is demonstrated by the preservation of electrical resistance after bending and deliberate scratching, as conductive pathways formed by infiltration maintain current flow.

This study successfully demonstrates area-selective infiltration and its potential application for the first time, representing a foundational step toward device design and fabrication based on selectively embedded inorganic materials within polymers.

Keywords: Hybrid Materials, Thin Films, Vapor Phase Infiltration, Functional Polymers, Atomic Layer Deposition

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Charge-Carrier Transport and Recombination Mechanisms in Emerging Low-Dimensional Semiconductors

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In the last decade, metal halide semiconductors have emerged as promising materials for solar cell applications. While lead halide semiconductors have achieved remarkable power conversion efficiencies, now exceeding 26%, Pb(II) toxicity and stability issues have raised the urgency of developing stable and environmentally friendly alternatives. As a result, a catalogue of emerging metal halide semiconductors (e.g., 2D perovskites, double perovskites, rudorffites, and others) has been the subject of intense investigation. However, record power conversion efficiencies for this new class of materials currently lag behind those of traditional metal halide perovskites, prompting new research efforts to explore and eliminate current performancelimitations. In this talk, I will discuss the impact of electronic and structural dimensionality on charge-carrier transport and recombination in these materials.

I will start by discussing the impact of low (<3D) electronic dimensionality on charge-carrier transport in emerging perovskite-inspired materials. Focusing on the archetypal silver-bismuth-based perovskite-inspired materials (PIMs),I will examine how rapid decays in terahertz photoconductivity and their temperature dependence reveal an ultrafast localisation of free chargecarriers to a small polaronic state.[3,4]Examples related to several structural and chemical features of PIMs, such as cation disorder, cation vacancies, and structural dimensionality, will be given.

I will proceed in discussing how the peculiar electronic structure of PIMs, and in cases, the presence of localised states, contribute to determining the charge-carrier recombination dynamics of these materials. In particular, I will focus on quasi-1D bismuth-based semiconductors.I will illustrate how temperature-dependent terahertz photoconductivity can disentangle different contributions to overall recombination, and demonstrate how the resulting mechanism can be investigated by comparing the temperature-dependent absorption coefficientwith the terahertz photoconductivity through the van Roosbroeck-Shockley equation.

Overall, achieving efficient charge-carrier transport and slow charge-carrier recombination remains a formidable challenge for low-dimensional electronic and structural materials and their use in renewable energy. The findings presented in this talk explore the underlying causes of thesechallenges,thus tracing a clear path towards tackling them.

Modification of Photoanodes for Photoelectrocatalytic Reactions in Aqueous System

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The development of efficient and stable photoanodes is essential for advancing photoelectrocatalytic (PEC) reactions in aqueous systems for solar energy conversion. In processes such as hydrogen evolution and CO_2 reduction, the overall efficiency of PEC systems is significantly constrained by the intrinsically sluggish kinetics of the anodic oxygen evolution reaction (OER). This kinetic bottleneck has stimulated extensive efforts toward the design and optimization of high-performance photoanode materials. Among the various candidates, BiOI and $BiVO_4$ have emerged as promising anodic semiconductors due to their good chemical stability in mildly aqueous environments, suitable band gaps for visible-light absorption, facile synthesis, and favorable valence band positions for driving OER. In this work, BiOI- and $BiVO_4$-based photoanodes were synthesized using a combination of automated fabrication methods to ensure reproducibility and scalability. Surface modification was carried out by introducing different types of coating layers, and it was found that amorphous oxide coatings significantly enhance PEC efficiency and operational stability. The improved performance is attributed to enhanced charge separation, suppressed surface recombination, and accelerated interfacial charge transfer kinetics. These findings demonstrate the potential of automated photoelectrode production and highlight the importance of rational surface engineering in improving both the efficiency and durability of photoanodes for aqueous PEC applications.

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Quantum Sensing of Hydroxyl Radical Neutralization by Defect-Engineered Nanoceria

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Hydroxyl radicals (•OH) are classified as one of the most aggressive reactive oxygen species, driving oxidative damage. Their transient nature andhigh reactivity make reliable detection challenging and necessitate effective strategies to control their formation. Cerium oxide (CeO2) nanoparticles are able to quench free radicals, yet the underlying mechanism linking nanoparticle structure to hydroxyl radical scavenging activity remains insufficiently defined.

Here, we investigate how defect engineering via lanthanum doping modifies the capability of hydrothermally-synthesized cerium oxide nanocubes to eliminate •OH. Using an advanced quantum sensing method along with a variety of physicochemical approaches, including X-ray diffraction, X-ray photoelectron spectroscopy, Raman spectroscopy, UV-Vis spectroscopy, inductively coupled plasma mass spectrometry, transmission electron microscopy, and atomic force microscopy, we correlated structural features of the nanomaterial with its tendency to neutralize hydroxyl radicals.

Real-time measurements using a nanodiamond-based quantum sensing method indicated that CeO2 efficiently reduced •OH formed under Fenton reaction conditions. Moreover, the incorporation of lanthanum into the ceria crystal lattice led to superior free radical scavenging. La doping increased defect density, resulting in altered kinetics of hydroxyl radical neutralization. In fact, while microscopy examinations revealed minimal morphological differences between the analyzed nanomaterials, spectroscopic studies indicated a richer defect chemistry in La-doped nanoceria that governed the ability to eliminate hydroxyl radicals. In addition, preliminary studies in macrophages showed that defect-engineered CeO2 was able to rescue cells from intracellular oxidative stress associated with •OH generation, highlighting the potential biological relevance of nanoceria and its derivatives.

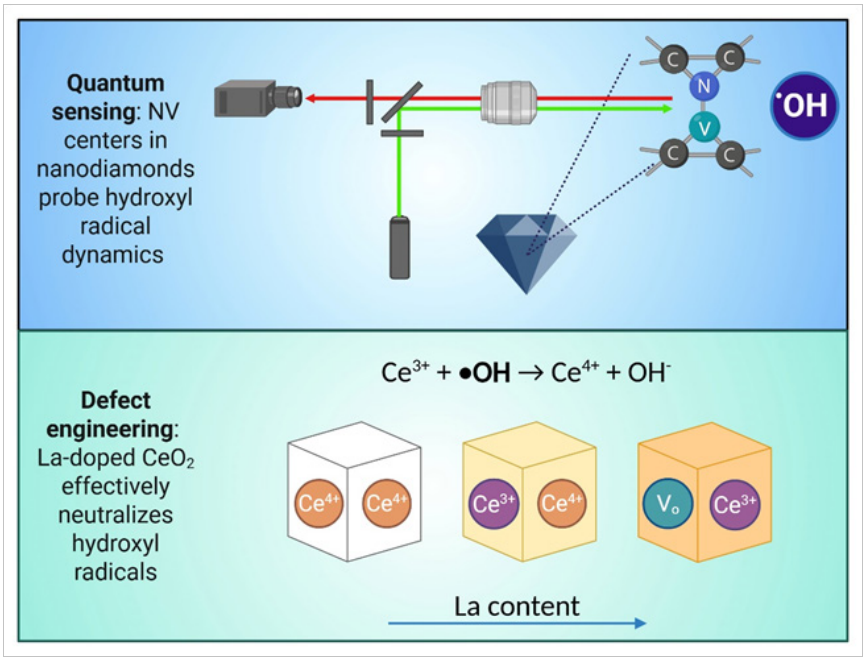

Figure 1. Nanodiamond-based quantum sensing enables real-time detection of hydroxyl radicals (top), revealing defect-dependent •OH quenching by cerium oxide nanoparticles (bottom).

Overall, this study links defect structure to free radical neutralization efficiency and demonstrates quantum sensing as a highly sensitive method for probing the dynamics of short-lived radical species. The results pave the way for the rational design of nanomaterials for controlled redox modulation in both chemical and biological environments.

Keywords: reactive oxygen species, oxidative stress, cerium oxide, reactive oxygen species-scavenging nanomaterials, nanodiamond-based quantum sensing

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Thermally Stable, Symmetric Gold Nanostars for Shell-Isolated Nanoparticle-Enhanced Raman Spectroscopy

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Anisotropic noble metal nanoparticles are attractive for surface-enhanced Raman scattering (SERS). Electromagnetic field enhancement is highest near tip-shaped structures, so nanostars are used as SERS substrates. These structures often have randomly distributed tip lengths, numbers, and orientations, leading to poor reproducibility. Reliable results require particles with defined tips, symmetry, and uniform shape, which symmetrical gold nanostars provide. To produce these nanostars, icosahedral nanoparticles are first formed via a polyol process. The structural quality of these seeds governs nanostar quality. The roles of different polyols, impurities, and halides on their formation were evaluated. Subsequently, gold nanostars are obtained by growing 20 tips per nanoparticle in a polyvinylpyrrolidone/dimethylformamide mixture.

To study catalytic reactions using SERS, chemical interactions between plasmonic nanostructures and analytes must be avoided. Shell-isolated nanoparticle-enhanced Raman spectroscopy (SHINERS) overcomes this by separating the catalyst from the plasmonic surface by adielectric shell. Therefore, smooth, pinhole-free silica shells of a few nm thickness are directly grown onto the goldnanostars. However, catalytic reactions often take place at elevated temperatures, but symmetrical gold nanostars undergo shape changes due to surface diffusion of gold atoms, causing significant degradation of the nanotips above 200 °C and severe reduction in Raman activity, a phenomenon typical of metal nanoparticles with tip-like structures. Coating gold nanoparticles with platinum can enhance their thermal stability. Approaches for synthesizing platinum shells, minimizing interference with Raman enhancement of gold nanostructures, while ensuring temperature stability, were investigated. Reacting gold nanostarswith H2PtCl6 and tetrabutylammonium borohydride yields thin platinum shells. This enhances the thermal stability of gold nanostars, enabling them to maintain their shape and SERS activity up to 400 °C. The Pt-Au nanostars are coated with a thin silica shell,decoupling their surfaces from analytes, enabling SHINERS. Finally, their effectiveness as SERS substrates is evaluated in Raman measurements with model molecules.

Green Solvent for the Synthesis of Halide Perovskite Nanocrystals

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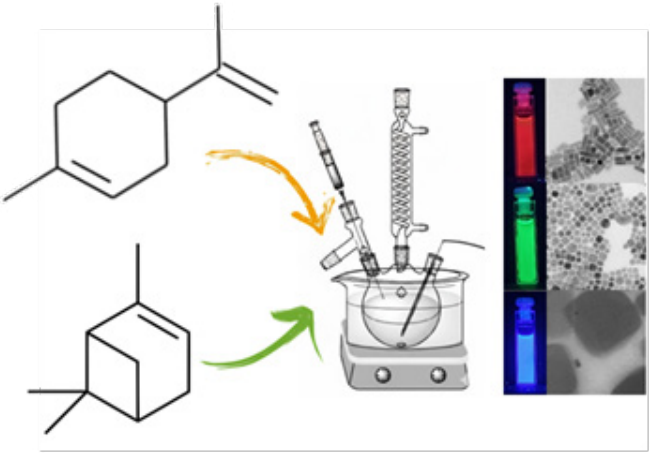
Hot-injection is a benchmark technique for producing highly crystalline nanomaterials; yet it is accompanied by significant environmental drawbacks due to the large quantities of petroleum-based solvents required. Addressing this limitation is essential for improving the sustainability of nanocrystal synthesis.

Here, we introduce naturally derived molecules as eco-friendly solvent systems for the preparation of halide perovskite nanocrystals [1,2]. The monoterpenes limonene (R- and S-), α-pinene (1R- and 1S-), and β-pinene (1S-) were selected for their favorable physicochemical properties, including high boiling points, robustness under reaction conditions, and renewable origin. These solvents enable the synthesis of $CsPbX_3$ (X = Cl, Br, I) nanocrystals with nanocubes, nanoplates, and nanorods morphology, and the methodology was successfully expanded to double perovskite compositions.

Comprehensive structural and optical characterization demonstrates that nanocrystals obtained in green solvents are comparable from those produced using standard high-boiling solvents such as 1-octadecene. In addition, the intrinsic volatility of monoterpenes under reduced pressure allows for their efficient removal from the final products, minimizing post-synthetic purification steps. The spent reaction mixtures can be readily distilled to recover high-purity solvent, which can be directly reused, highlighting the potential of this approach to significantly reduce chemical waste in nanocrystal synthesis.



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FLIM Guided Nanomedicine: PLGA Nanoparticles for Controlled Baricitinib Delivery

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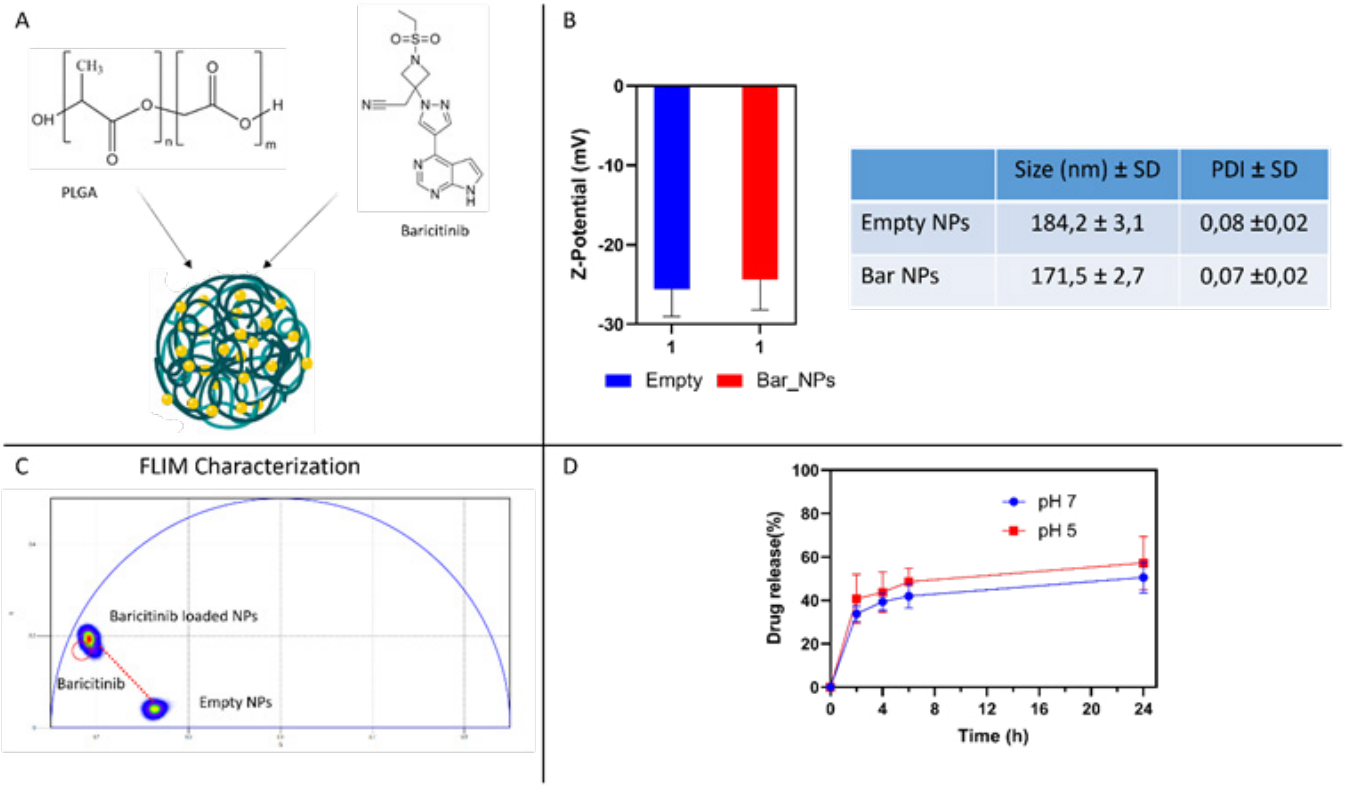
Diabetes is a metabolic disorder in which progressive β-cell dysfunction impairs insulin secretion. Given the role of chronic inflammation and JAK–STAT signaling in β-cell stress, selective immunomodulation represents a promising strategy to preserve β-cell function1. In this context, Baricitinib, a selective JAK1/2 inhibitor, may protect β cells and modulate pathological signaling pathways by mitigating inflammation-driven cellular stress2. Encapsulation in nanoparticles (NPs) can enhance drug solubility, control release kinetics, and improve delivery to target tissues. Poly(lactic-co-glycolic acid) (PLGA) NPs provide a biodegradable platform for controlled and sustained drug release. However, conventional analytical techniques often fail to provide information on the internal organization of encapsulated drugs. Advanced optical approaches such as Fluorescence Lifetime Imaging Microscopy (FLIM) enable non-invasive characterization of luminescent compounds within NPs, allowing distinction between free and encapsulated drug and providing insights into supramolecular organization and stability without chemical labeling or extensive sample preparation3. In this study, we developed FLIM-guided PLGA NPs for controlled Baricitinib encapsulation, using fluorescence lifetime analysis to optimize formulation and characterize the internal structural organization of the drug within the nanocarriers. During formulation optimization, UV–Vis and FLIM were used in parallel: spectrophotometry provided quantitative measurements of EE% and DL%, whereas FLIM enabled visualization of fluorescence lifetime signatures and drug distribution within individual nanoparticles. The optimized formulation produced PLGA nanoparticles with a hydrodynamic diameter of 171.5 ± 2.7 nm and a low PDI of 0.07 ± 0.02, indicating good colloidal stability. Encapsulation efficiency was 45.4 ± 4.1%, with drug loading of 3.20 ± 0.5%. FLIM analysis allowed visualization of baricitinib distribution within nanoparticles, distinguishing encapsulated from non-encapsulated drug and supporting formulation refinement. This study demonstrates the development of PLGA NPs for Bar encapsulation using a FLIM-guided approach, providing a robust framework for designing well-characterized drug-loaded nanocarriers for advanced nanomedicine applications.



	Size (nm) ± SD	PDI ± SD
Empty NPs	184,2 ± 3,1	0,08 ±0,02
Bar NPs	171,5 ± 2,7	0,07 ±0,02

Figure showphysicochemical characterizationof baricitinib-loaded PLGA nanoparticles.(A) Schematic representation of the nanoparticle formulation showing the chemical structures of PLGA and baricitinib, and a graphical illustration of drug encapsulation within the polymeric nanoparticle matrix.(B) Physicochemical characterization of empty nanoparticles (Empty NPs) and baricitinib-loaded nanoparticles (Bar NPs), including ζ-potential, hydrodynamic diameter, and polydispersity index (PDI) measured by dynamic light scattering (DLS).(C) FLIM phasor plot analysis showing the fluorescence lifetime distribution of free baricitinib, empty nanoparticles, and baricitinib-loaded nanoparticles. The shift observed for Bar NPs indicates the different microenvironment experienced by the drug upon encapsulation within the polymeric matrix. The red circle represents the fluorescence lifetime of free baricitinib.(D) In vitro release profile of baricitinib from PLGA nanoparticles at pH 7 and pH 5, reported as cumulative percentage of drug released over time.All data are reported as mean ± standard deviation (SD), n = 3.

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Non-Spherical Fe_3O_4 Nanoparticles with Tunable Morphology and Magnetic Properties: From the Synthesis to their Theranostic Properties

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Most of the research performed in maghemite/magnetite nanoparticles has been carried out on isotropic spherical particles. [1] However, during the latest years, non-spherical morphologies such as nanorods and nanocubes have attracted the attention of the scientific community working on magnetic iron oxides due to their anisotropic properties and the potential wide range of applications. Here we present a rationally designed synthesis pathway based on the thermal decomposition to obtain high quality nanocubes [2] and on solvothermal strategies to reach magnetic iron oxide nanorods, both over a wide range of sizes. The nanocubes with an edge length below 17 nm show a great colloidal stability (Figure 1), even after transferring them to water. Moreover, the 17 nm nanocubes exhibit an excellent magnetic hyperthermia and NMR relaxivity performance (better than their spherical counterparts), making them excellent candidates for potential applications in nanotheranostics. In addition, the Fe3O4 nanocubes are outstanding heat mediators for photothermia in the near infrared biological windows (680-1350 nm), with heating efficiencies similar to, or better than, the best photothermal agents [3]. On the other hand, structural and magnetic properties of elongated IONPs between 25 and 400 nm (length) and aspect ratios between 4 and 8 are presented (figure 2). The magnetic nanorods were synthesized by the solvothermal method using iron organic precursors. Different strategies for their transfer to water have been addressed. We will correlate their magnetic properties with the performance in hyperthermia and MRI applications as a function of the structural and colloidal properties, compared to their spherical equivalents.

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Structural and Thermal Stabilization of $CsPbI_3$ Quantum Dots via Lattice-Surface Co-Engineering

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Introduction: All-inorganic $CsPbI_3$ quantum dots (QDs) exhibit excellent optoelectronic properties but suffer from structural instability due to lattice distortion, intrinsic defects, and surface trap states. These issues arise from the metastable α-phase and high density of halide vacancies, leading to nonradiative recombination and phase degradation.Although strategies such as cation doping and surface passivation have been explored, they are typically applied independently and fail to address both lattice and surface instabilities simultaneously. Here, we introduce a lattice-surface co-engineering strategy, combining Pb-site substitution (Ag^+ or $Co2^+$) with halide passivation (Cl^-/I^-), to achieve simultaneous control over crystal structure and defect chemistry in $CsPbI_3$ QDs [1,2].

Experimental Study: $CsPbI_3$ QDs were synthesized using a modified hot-injection method with controlled incorporation of dopants via AgCl/AgI and $CoCl_2/CoI_2$ precursor systems. Structural and compositional properties were characterized by XRD, TEM, and XPS. Optical properties and recombination dynamics were analyzed using PL, UV-Vis absorption, and TRPL.

Results and Discussion: Structural analysis confirms successful incorporation of dopants into the perovskite lattice without secondary phase formation.Optically, halide passivation effectively reduces surface defect density by mitigating iodide vacancies, leading to suppressed trap-assisted recombination and improved emission properties. This is supported by photoluminescence and TRPL measurements, which reveal enhanced radiative recombination and a significant reduction in nonradiative decay pathways (Δk_{nr}).Together, these lattice and surface modifications establish a structure-driven improvement in electronic quality and excitonic behavior. Temperature-dependent measurements further confirm that the structurally stabilized QDs retain their crystal integrity and optical response under thermal stress, exhibiting reduced lattice dilation compared to pristine QDs. These results highlight a synergistic lattice-surface mechanism, where structural stabilization governs defect suppression and optical performance, while thermal resilience emerges as a direct consequence of the improved crystal framework.

Conclusion: We demonstrate that lattice-surface co-engineering enables simultaneous control over crystal structure and defect chemistry in $CsPbI_3$QDs, leading to enhanced structural stability and improved optical performance. By combining Pb-site substitution with halide passivation, defect formation is effectively suppressed and nonradiative recombination is reduced. The resulting materials exhibit stable emission characteristics, while their thermal resilience arises as a direct consequence of the improved structural integrity. This work establishes a structure-driven framework for designing stable and defect-tolerant perovskite nanomaterials.

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Day-2

NanoSeries2026 Technical Session: NS (B)

Nanomaterials for Energy Applications: From Batteries to Solar Cells

Metal Halide Perovskite-Based Photocatalysis: Materials Development and Mechanistic Features

Lorenzo Malavasi

University of Pavia, Italy

3D and 2D metal halide perovskites (MHPs) and related derivatives have recently emerged as highly promising materials for solar-driven photocatalysis, complementing their established role in photovoltaics and optoelectronics. Their tunable and narrow band gap, long carrier lifetimes, high mobilities, and strong defect tolerance make them particularly attractive for reduction reactions such as H_2 evolution and CO_2 conversion, as well as selected oxidation processes. In this contribution, we present our group's ongoing research aimed at engineering MHPs for solar fuel production through rational materials design. By tailoring composition, dimensionality, morphology, and band alignment, and by implementing heterojunction strategies, we demonstrate enhanced photocatalytic performance. A combined experimental and computational approach further provides mechanistic insight into hydrogen photogeneration and nitrogen fixation pathways, highlighting the potential of MHPs as versatile platforms for sustainable solar-driven chemistry.

From Bulk to Quantum: Engineering Perovskite Optoelectronics

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Metal-halide perovskites (MHPs) have rapidly evolved into a versatile platform for both high-performance optoelectronics and emerging quantum devices, owing to their tunable electronic structure and strong light–matter interaction.[1–2] In this talk, I will present our advances in thermally evaporated perovskites as a scalable and highly controllable route toward next-generation devices. We demonstrate a sixfold increase in deposition rate while preserving film quality and power conversion efficiency, enabling an annealing-free, high-throughput co-evaporation process for perovskite solar cells.[3] Fully vacuum-processed architectures, including soft-sputtered transparent electrodes, further enable ultrathin and stable devices.[4]

Beyond photovoltaics, nanometer-scale thickness control allows the realization of perovskite-based Multiple Quantum Wells (MQWs), where carrier confinement and excitonic coupling can be precisely engineered.[5–6] These structures open access to quantum-confined regimes and tunable emission phenomena not attainable in bulk systems. Together, these results illustrate how thermal evaporation bridges scalable manufacturing with quantum-enabled optoelectronic functionalities.

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Harnessing Light for Hydrogen Production: Bismuth-Based Perovskite-Inspired Materials

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Currently, clean energy production represents one of the most pressing challenges for the scientific community, industry, and policy makers. Organic-inorganic hybrid halide perovskites have emerged as potential semiconductors not only for photovoltaic applications but also for photocatalysis, including H2 production, CO2 reduction, and water remediation. In particular, bismuth-based perovskite-inspired materials exhibit attractive photophysical properties, along with low toxicity and enhanced air stability [1]. However, these materials typically suffer from poor stability in aqueous environments, being stable only in organic solvents or hydrohalic acid solutions. Therefore, the development of robust and water-stable perovskite materials remains a significant challenge.

Herein, we present novel bismuth-based perovskite-inspired materials (IEF-15, IEF-16, IEF-17 and IEF-19; where IEF stands for IMDEA Energy Framework) containing hydrophobic organic cations (i.e., dimethylpyrazolium, triazolium and 1,5-diammonium naphthalene). Moreover, a facile solvothermal method has been developed to obtain water-stable perovskites, involving the alkylation of the bulky diammonium cation (1,5-diammonium naphthalene) and resulting in 3 novel materials (IEF-19-X, X = Me, Et and Pr, containing the alkylated cations by methyl, ethyl and propyl groups, respectively). Their photocatalytic performance has been evaluated in overall water splitting (OWS), demonstrating the evolution of both H2 and O2. In addition, these materials can act as interlayers to induce band bending in perovskite architectures [3], enabling fine-tuning of energy level alignment at device interfaces, thus paving the way for future optoelectronic applications.

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Capacitive Photocharging in Plasmon-Dirven Catalysis

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Light can charge plasmonic nanoparticles via photochemical processes, significantly modifying their optical and chemical properties [1]. However, photocharging is largely overlooked in plasmon-driven chemistry, because it is experimentally difficult to identify and a suitable descriptive framework has been missing. In our work, we investigate the charging of gold nanoparticles during the light-induced oxidation of hole scavengers, such as ethanol, driven by interband excitation of 5d-band holes. Exploiting the sensitivity of the longitudinal plasmon resonance of gold nanorods to surface charge density allows us to track charge accumulation in situ. By introducing a new framework that treats the particle as ananocapacitor, allows us to connect the charging and the accompanying Fermi-level shift to theillumination intensity[2]. Crucially, the electrostatic potential of the accumulated surface charges raises the entire band structure, not only the Fermi level. Our measurements indicatethat the nanoparticles possess a very high capacitance of 2.7×10^{-15} F per particle (294 µF cm^{-2}). To subsequently investigatethe influence of the charging process on a full photo-redox reaction, including oxidation and reduction half-reactions, we extend the nanocapacitor model to an equivalent circuit framework. As predicted by this model, we were able to demonstratethe adjustment of the charge state of a gold nanoparticle during photoinduced reduction of ferricyanide. These results lay the groundwork for the rational engineering of dynamic charge accumulation in plasmon-driven photocatalysis.

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Photocatalytic-Radical Chain Concerted Reaction for Highly Efficient Hydrogen Peroxide Production With an External Quantum Yield of Almost 500%

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Hydrogen peroxide (H_2O_2) is of extremely importance because it is not only a clean oxidant but also a promising fuel for (photo-)fuel cells. Thus, the development of green methods for H_2O_2 production is indispensable as an alternative to the conventional anthraquinone method. Among the candidates, photocatalytic H_2O_2 production has recently attracted much interest.However, the external quantum yield (ϕ_{ex}) of H2O2 production by inorganic photocatalysis remains below 20% in most studies. In this study, we have clarified that a nanohybrid photocatalyst consisting of antimony-doped SnO_2 and ZnO can produce H2O2 with a ϕ_{ex} of ~500% from O_2-saturated ethanol aqueous solution under UV-light irradiation. The photoelectrochemical measurements and the reactions using isotope and radical scavenger clarified that the incredible highϕ_{ex} is originated from the photocatalytic and radical chain concerted reaction [1]. In the photochemical reactions, the quantum yield is usually far below unity (< 100%) due to the rapid recombination of photogenerated charge carriers. Breaking through this limit will be expect to pave the way for the practical application.

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Excited-State Thermodynamics of Photocatalytic Reactions on Nanostructured Surfaces

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Nanostructured materials play a central role in emerging energy technologies, including photocatalysis, solar fuel generation, and photoelectrochemical conversion. Computational modeling based on density functional theory (DFT) is widely used to analyze reaction thermodynamics on catalytic surfaces through Gibbs free energy diagrams. However, these approaches typically rely on ground-state electronic structure, whereas photocatalytic processes occur under illumination and involve electronically excited states.

This contribution discusses a computational framework for incorporating excited-state contributions into thermodynamic reaction profiles within a DFT-based workflow. The approach extends conventional free energy diagrams by introducing excitation energies obtained from electronic structure calculations, enabling the evaluation of reaction energetics under photoexcited conditions. By retaining the structure of established ground-state methodologies, the framework provides a practical route for studying light-driven surface reactions while maintaining compatibility with widely used computational tools.

The methodology allows systematic comparison of different approximations for representing photoexcitation and their influence on the predicted stability of reaction intermediates and the energetic barriers of elementary steps. Including excited-state effects can substantially modify the relative energetics of catalytic pathways, which in turn affects predicted reaction selectivity and thermodynamic feasibility.

These developments contribute to the broader effort to improve theoretical descriptions of photoactivated processes in nanomaterials relevant to energy conversion. Integrating excited-state effects into thermodynamic analyses provides new opportunities for interpreting experimental observations and for guiding the design of catalytic materials for solar energy applications.

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Sustainable Photoabsorbers for Solar Fuels Generation and Waste Valorization: Addressing Stability and Activity Barriers

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Photoelectrochemical systems serve as prototype of artificial photosynthesis devices to produce sustainable fuels and chemicals from abundant and waste feedstocks. However, they are far from their practical utilization due to instabilityin aqueous environments and poor selectivity towards specific redox conversion reactions. Thetalkwill focus on the main question, i.e., Do we have “PV-grade” semiconductors that have intrinsic stability, and offer surface activity for PEC reactions? (ii) explore an ideal integrated tandem PEC system for standalone operation.

I will introducechalcogenideCu(In,Ga)S2photocathodesthat are interesting due to their bandgap tunability and defect-rich surface chemistry. Our results show that PEC CO2R can be directly facilitated on bare CIGS surface producing CO and HCOO-without any transport layer or co-catalyst. Mechanisticanalyses and atomistic simulations reveal the role of surface composition to be critical for stability and activity towards CO2R.Additionally, the aqueous stabilityand defect-rich surfaceof CIGSalso present PEC activity towards nitrate (NO3-) to ammonia (NH3) conversion.

Our work highlights the discovery of a compositionally rich and stable system active for different redox reactions. The findings are useful to design highly stable and active photocathodes for driving photoelectrochemical reactions. I will finish my talk highlighting the opportunities and challenges ahead in realizing a standalone artificial leaf-like devices from emerging chalcogenide-silicon tandems.

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Beyond Halide Perovskites: Powering a Sustainable IoT Era

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The rapid expansion of the Internet of Things (IoT) is driving the need for sustainable energy solutions capable of powering distributed, low-power electronics under ambient conditions.[1] Indoor photovoltaics have emerged as a promising approach, but conventional materials, particularly lead halide perovskites, face challenges related to long-term stability, toxicity, and deployment at scale.[2] These limitations have motivated the exploration of alternative semiconductor families, including perovskite-inspired materials (PIMs), which combine favorable optoelectronic properties with improved chemical robustness.[3]

In this talk, I will present recent advances in PIM-based absorbers for indoor photovoltaics, with an emphasis on how materials design translates into device performance under low-light conditions. Focusing on antimony- and bismuth-based systems and vacancy-ordered structures, I will discuss how compositional tuning, A-site alloying, and structural distortions enable control over bandgap, carrier dynamics, and photovoltage.[4-6] These materials platforms inherently offer wide bandgaps and reduced recombination losses, making them particularly suited for the low photon flux and narrow spectral range of indoor illumination.

A key aspect will be the interplay between defect chemistry and device operation. Under indoor conditions, reduced carrier densities amplify the impact of trap-assisted recombination and interfacial losses, shifting the performance bottleneck from current generation to voltage losses. I will highlight how targeted materials optimization, through defect control, band alignment, and interface engineering, can significantly enhance device metrics under realistic operating conditions.[7]

Finally, the discussion will outline how these insights lead to a redefinition of photovoltaic design rules, where wide-bandgap absorbers, high photovoltage, and controlled recombination pathways become central requirements. In this context, perovskite-inspired materials emerge not only as lead-free alternatives, but as a versatile platform for developing efficient and stable indoor photovoltaic devices, enabling the next generation of energy-autonomous, low-power electronics.

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π–d Conjugated Coordination Polymers for Solar and Thermoelectric Energy Harvesting

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Coordination polymers based on dithiolene ligands are emerging as intrinsically conductive materials for energy harvesting, combining π–dconjugation,redox activity and structural tunability without the need for dopants [1,2]. However, their intrinsic insolubility has historically limited processability and device integration [3].Here we report the synthesis and additive-free processing of Ni- and Cu-based coordination polymers, poly[Kx(Ni-ett)] (Niett) and poly[Kx(Cuett)] (Cuett), as thermoelectric and electrocatalytic materials. Stable dispersions were obtained in polar solvents due to electrostatic stabilization of the counterion, enabling homogeneous thin-film deposition at room temperature.Both materials exhibit narrow bandgaps (<1.0 eV), decomposition temperatures above 200°C and electrical conductivities up to 10^0 S cm^{-1} in thin-film configuration. Periodic DFT calculations rationalize the metal-dependent electronic structure and reproduce the opposite Seebeckbe-haviour of the two systems.Planar and flexible p–n thermoelectric modules assembled from Cuett and Niett display Seebeck coefficients (200μVK^{-1})and output power approaching the algebraic sum of the single legs (Figure 1). Beyond thermoelectrics, the synthesized coordination polymers have also been investigated as counter electrodes in dye-sensitized solar cells. Niett thin films exhibit low charge-transfer resistance (8.0Ωcm²), high exchange current density (5.5 mA cm^{-2}), and full devices delivered photoconversion efficiencies above 10%, exceeding the PEDOT control.

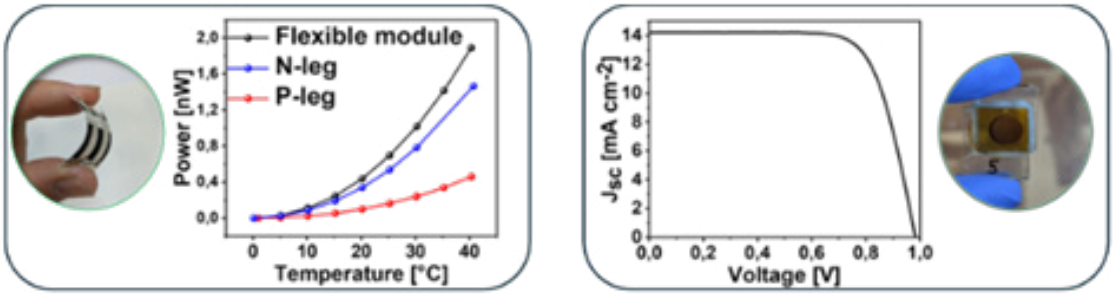

Figure 1: Output power of the flexible thermoelectric module (left) and J–V curve of the Niett-based counter electrode solar cell (right).

This work establishes additive-free dithiolene coordination polymers as intrinsically conductive, multifunctional platforms for thin-film electronic devices, bridging coordination chemistry and conductive materials for sustainable energy harvesting technologies.

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Day-2

NanoSeries2026 Technical Session: NS (C)

Nano–Bioengineering for Medicine: Therapeutics, Diagnostics, and Regeneration

Microelectronics at Mesoscale: Towards Flexible and 3D Biomedical Devices

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Emerging materials and advanced manufacturing strategies are key enablers in the evolution of next-generation microelectronic architectures and sensing devices. In recent years, advanced fabrication techniques have been introduced that support the development of flexible thin-foil systems and self-assembly processes capable of forming complex three-dimensional microstructures. These approaches are based on planar processing of carefully engineered material systems—including organic and inorganic, rigid and soft materials—on conventional wafer substrates. The resulting thin-foil systems are then delaminated in a controlled manner and induced to undergo deterministic shape transformations such as folding, buckling, or rolling. For the first time since the dawn of microelectronics, electronic components can now move beyond traditional two-dimensional fabrication constraints, expanding into the third dimension via scalable, monolithic, wafer-level processes. These ultra-lightweight systems, often in the microgram range and only a few micrometers thick, offer previously unattainable benefits in terms of environmental sustainability and mechanical robustness. When combined with modern electronic fabrication methods, they enable the seamless integration of a wide array of miniature functionalities—including active circuits and specialized sensors such as bio- and magnetic sensors. This development paves the way for a new generation of electronically integrated, miniaturized instruments and sensors, purpose-built for biomedical and environmental applications with high functional density and low ecological footprint.

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From Bioinspired Microrobots to Steerable Catheters: Engineering Local Therapies in Complex Anatomy

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Delivering therapies with high precision within complex anatomical environments remains a significant clinical challenge. This presentation introduces a multi-scale approach to targeted interventions, bridging untethered bioinspired microrobots and tethered steerable endovascular catheters through two shared principles: remote magnetic navigation and localized therapeutic delivery. First, we explore magnetically driven microrobots fabricated via a universal biotemplating approach using the helical cyanobacterium Spirulina platensis. By integrating advanced nanomaterials, these untethered microrobots enable targeted cellular drug delivery (MOFBOTs/COFBOTs), near-infrared photothermal cancer ablation (MoSBOTs), and ultrasound-mediated amyloid dissociation (PiezoBOTs). Second, to translate these principles into complex endovascular procedures, we present a soft-robotic magnetic microfluidic catheter for precision transcatheter embolization. This device enables the in-situ synthesis of a tunable, water-based PEI-PEG hydrogel, eliminating toxic organic solvents. Validated across ex vivo human placenta and in vivo porcine and rat tumor models, the platform demonstrates exceptional guidewire-free magnetic navigability, reliable vessel occlusion, and localized chemoembolization. Together, these technologies showcase the transformative potential of functional nanomaterials and magnetic navigation in next-generation minimally invasive medicine.

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Photo-Active Colloids Confined in Giant Vesicles for Biomimicking and Biomedical Applications

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Introduction: Photo-active colloids have emerged in recent decades with diverse behaviors and responses to light inputs, a non-invasive stimulus used to control motion, organization, and collectivity [1]. Nanomotors have been intensively studied due to their functionality in micrometric environments, steerability, and tunability depending on the material, such as photocatalysts with applications in pollutant remediation, medicine, and biomimicking [2]. Colloidal self-assembly particles exhibit complex behavior including crystallization, phase separation, and hierarchical organization [3]. Confinement integrates colloids into higher hierarchic structures by modifying their behavior within defined geometries [4]. Giant unilamellar vesicles (GUVs) can contain photo-active colloids, providing a cell membrane model for biomedical and cell mimicking applications.

Methodology: Active colloids were synthetized by hydrothermal methods in the case of metal oxides. Ru-based self-assembly colloids were fabricated by crosslinking a polymeric matrix in the presence of a ruthenium source. Encapsulation was achieved through a modified emulsion method reported by Vutukuri et al. [5], allowing sensitizers and fuel to be incorporated within the inner solution.

Results: The behavior of these colloids is strongly altered by the confinement effect. Depending on particle type and encapsulation conditions, different structures are obtained, including aggregates and vesicles with high or low loading, exhibiting functionalities for bio mimicking, synthetic cell research, and cargo release. Self-assembly colloids and photosensitizers were co-encapsulated, resulting in a methodology that combines light-induced cargo releasing with reactive oxygen species (ROS) production for photodynamic therapy.

Conclusion: By combining nanomotor colloids, self-assembly particles, and photosensitizers inside biomimetic compartments, we present a platform for hierarchical materials with tunable structure and light-responsive behavior. Confinement-induced modulation of collective dynamics supports next-generation cell-mimicking and biomedical materials with controlled performance.

Keywords: Active colloids, cell mimicking, photodynamic therapy, confinement, cargo release.

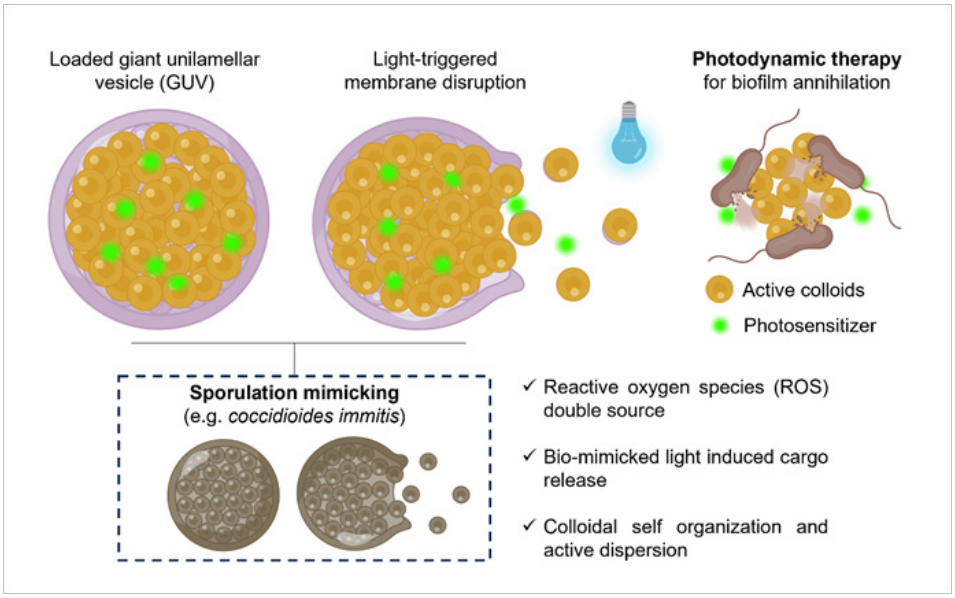

Figure 1. Graphical abstract. Light-induced cargo releasing and ROS generation for photodynamic therapy on bacterial biofilms.

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Chemically Programmable and Dynamic Supramolecular Biomaterials to Instruct Cell Functions

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Nature provides us with a fascinating toolbox of building blocks that inspire the creation of artificial biofunctional systems to recreate living systems. One of the most prominent biological systems that has been gathering immense attention among the biomaterials community is the native extracellular matrix (ECM) – a dynamic supramolecular landscape formed through the highly orchestrated non-covalent self-assembly and reciprocal molecular recognition of mainly proteins and glycosaminoglycans. Despite the progress, the synthetic biomaterial architectures developed to date do not fully emulate the complex biomolecular composition, nanostructural elegance, and dynamic mechanical profileof the native ECM, thus limiting their potential as advanced therapies in regenerative medicine strategies.

In this talk emphasis will be given to the synergistic interplay between naturally sourced macromolecules andsynthetic supramolecular building blocks towards supramolecularly engineering hybrid cell-instructive biomaterials to better emulate the native ECM features.We will discuss bottom-up nano/microtechnologies, including molecular self-assembly, 3D (bio)printing, or layer-by-layer assembly technology to assemble chemically programmable and dynamic biomaterialsfor directing cell functions, while also elucidating cell–material reciprocal interactions. Their potential to act as advanced platforms for the encapsulation and on-demand controlled release of drugs, therapeutics and even cells, and as bioinstructive matrices to guide cell fate in advanced regenerative medicine strategies will also be discussed.

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Hybrid Nanoparticles Enable Targeted Cardiac Regeneration via microRNA Delivery

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The irreversible loss of cardiomyocytes (CMs), together with the formation of dysfunctional fibrotic tissue following myocardial infarction, often progresses to heart failure [1,2]. Recently, microRNAs (miRNAs) have emerged as promising tools for cardiac regeneration. The combination miRcombo (miR-1, -133, -208, -499) can directly reprogram cardiac fibroblasts (CFs) into CMs [1], while miR-199 promotes proliferation of resident CMs [3], thereby improving cardiac function. However, their translation into therapies requires safe and efficient nanocarriers for cell-targeted miRNA delivery. To this end, novel hybrid polymer-lipid nanoparticles (NPs), surface-functionalized with specific ligands, were developed to efficiently deliver miRcombo to CFs or miR-199 to CMs.

NPs were produced via a patented nanoprecipitation method with a lipoplex core capable of encapsulating miRNAs and a polymeric shell to enhance stability [4]. NPs were decorated with an antibody (F-NPs) or a cardiac-specific peptide (C-NPs) for targeting CFs or CMs, respectively. Physicochemical properties, cytocompatibility, uptake, and transfection efficiency were evaluated in adult human cardiac fibroblasts (AHCFs) and H9c2 cells.

NPs showed nanometric size, negative Z-potential, excellent miRNA encapsulation efficiency (99%), good colloidal stability, and controlled miRNA release over 9 days. Both AHCFs and H9c2 transfected with NPs, F-NPs, and C-NPs maintained excellent cell viability, with F-NPs and C-NPs showing enhanced uptake. In AHCFs, miR-1-loaded F-NPs induced significant TWF-1 downregulation after 48 h, while miRcombo-loaded F-NPs increased cardiac troponin T expression at gene and protein levels after 15 days, suggesting successful direct reprogramming of fibroblasts into iCMs. In H9c2 cells, miR-199-loaded C-NPs promoted proliferation within 72 h.

By combining high miRNA loading efficiency of the lipid core with controlled release and stability of the polymeric shell, and cell-specific targeting provided by the surface ligand, F-NPs and C-NPs overcome major limitations of commercial agents. The obtained results highlight their potential for therapeutic application in cardiac regeneration.

Keywords: nanomedicine, microRNA, cell reprogramming, cardiac regeneration

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Nanocarbon Derivatives: From Chemical Functionalization to Bioactive Composite Scaffolds for Tissue Engineering and Regenerative Medicine

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Carbon nanostructures such as carbon nanotubes (CNTs) can be used as fillers in biocompatible matrices to impart enhanced electrical and thermal conductivity as well as mechanical reinforcement. The resulting composites are promising materials for applications including medical devices and implants, tissue engineering, and biosensing.

Surface functionalization of CNTs with suitable organic groups represents an effective strategy to increase the affinity between the nanofiller and the matrix, thereby maximizing the desired effects while minimizing the filler loading and reducing potential cytotoxicity. Moreover, the introduction of charge-bearing functional groups enables the establishment of specific interactions with the matrix.

We synthesized and characterized (by TGA, Raman spectroscopy, XPS, and electron microscopies) a series of CNT derivatives (f-CNTs) soluble either in organic solvents or in water, and used them as fillers in different matrices. The resulting composite materials, obtained as films, electrospun nanofibers [1], and hydrogels, were employed as scaffolds for in vitro biological tests. These studies showed that f-CNTs promote the growth and differentiation of different cell lineages by modulating the mechanical and electrical properties of the substrate.

Specific investigations were performed to determine how CNT fillers modulate the scaffolds' electrical properties - such as electrostatic potential [2], conductivity, and impedance[5,6] - and how these electrical cues directly drive changes in cell behavior. More specifically, 4 probes measurements and microelectrodes were exploited to provide a comprehensive view.

Owing to their improved processability and dispersibility, our derivatives were also employed as fillers for bioinks, maintaining suitable rheological properties while enhancing electrical performance.

Building on the bioinstructive capability observed in vitro, we designed an innovative nanocomposite surgical implant for nerve regeneration based on water-soluble f-CNTs. In vivo tests show promising results in terms of biocompatibility and regenerative effectiveness [3, 4].

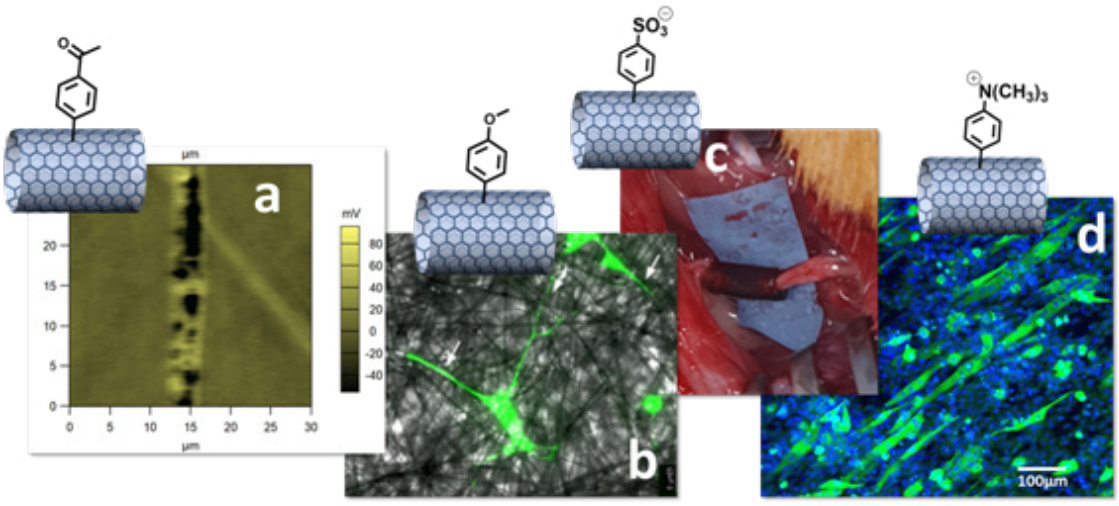

Figure 1: composite scaffolds based on different f-CNT: (a) scanning Kelvin probe microscopy ofelectrospun fibers; (b) SH-SY5Y cells extending neurites along the electrospunfibers; (c) nerve conduits implantation in rat nerve lesion model; (d) myoblasts growing on an alginate-based scaffold.

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Engineering Topographical and Mechanical Cues for Retinal Rod-Like Cell Differentiation for the study of Inherited Retinal Degenerations

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Inherited Retinal Degenerations (IRDs) are a heterogeneous group of rare disorders leading to progressive photoreceptor loss and ultimately to blindness. The high genetic variability underlying IRDs poses major challenges for the development of effective therapies and reliable high-throughput drug screening platforms. Although animal models and retinal organoids represent valuable tools, their cost, variability, and limited scalability hinder large-scale applications. The 661W-A11 rod precursor cell line, despite expressing photoreceptor markers, does not fully recapitulate the mature rod phenotype under standard culture conditions [1]. We aimed to develop an advanced in vitro platform based on micro- and nanopatterned soft biomimetic scaffolds to enhance the differentiation and polarization of rod precursor cells into mature rod-like cells. Using soft-lithography and electrospinning techniques, we fabricated biocompatible substrates with controlled geometry, topography, and mechanical properties that closely mimic the retinal extracellular environment, promoting cell differentiation and the elongation of cellular structures such as axons and dendrites [2, 3]. Cell differentiation has been assessed through morphological and molecular analyses of photoreceptor-specific markers. To functionally validate the maturation process, we have developed nanomodulated electrodes capable of measuring photocurrents generated by differentiated rod-like cells. The proposed platform is expected to provide a rapid, reproducible, and cost-effective system for modeling retinal degeneration and establishing high-throughput screening devices for novel therapeutic compounds targeting IRDs.

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Non-Invasive SERS Biosensor Platforms Utilizing Plasmonic Nanoparticles Anchored ElectrospunFibres for Mass Screening of Cancer Biomarkers

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Early detection of cancer remains a significant challenge in clinical diagnostics, as many cancers are often identified only after advanced stages [1]. In this context, non-invasive diagnostic strategies based on liquid biopsy have attracted considerable attention because they allow simple and painless sample collection while providing valuable biochemical information relevant to disease detection [2]. The present work explores the development of non-invasive Surface-Enhanced Raman Scattering (SERS) biosensor platforms utilizing plasmonic nanoparticles anchored on electrospunfibres for the label-free detection of cancer biomarkers. The main aim is to establish a reproducible and scalable sensing platform capable of supporting early-stage cancer screening using very small volumes of biological samples. In this approach, electrospun carbon nanofibers functionalized with plasmonic nanoparticles are employed as efficient SERS-active substrates for analysing salivary biomarkers. The plasmonic nanostructures generate localized electromagnetic hotspots that significantly enhance Raman signals, allowing the detection of trace-level biomolecular signatures present in saliva. The sensing performance of the substrates has been initially assessed using model analytes to verify signal enhancement and reproducibility, after which the platform has been investigated for its ability to distinguish the salivary molecular profiles of cancer patients from those of healthy individuals. The results demonstrate promising sensitivity and classification capability, highlighting the potential of the proposed platform for non-invasive and point-of-care cancer diagnostics. During the talk, we would like to discuss the design and development of these SERS biosensing platform and key findings from the study will be highlighted. In addition, ongoing research aimed at addressing existing limitations, particularly in terms of sensitivity and analytical reliability, will be discussed, including emerging approaches based on SERS nanotags, which represent an alternative strategy for improving the performance and clinical applicability of SERS-based diagnostic technologies.

Keywords: Surface-Enhanced Raman Scattering; Non-invasive diagnostics; Plasmonic nanoparticles; Electrospun nanofibres; Cancer biomarker screening

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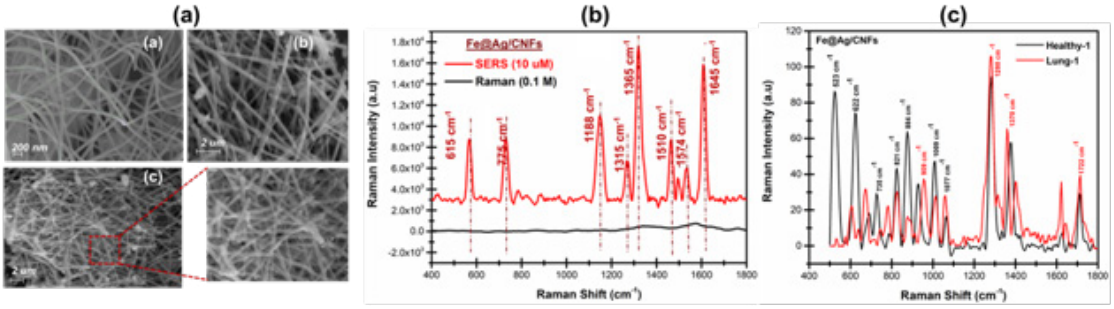

Figure Caption: (a)SEM images of the electrospun fibers (b) evaluation of the SERS performance of the developed sensor using Rhodamine 6G and (c) comparison of the SERS signals of saliva of healthy controls with cancer patients

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Molecularly Imprinted Polymers: Synthetic Antibodies for Medical Diagnostics and Therapy

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Molecularly imprinted polymers (MIPs) [1] are synthetic antibodies that specifically recognize molecular targets. They are cross-linked polymers synthesized in the presence of a molecular template, which induces three-dimensional binding sites in the polymer that are complementary to the template in size, shape and chemical functionality. MIPs against proteins are obtained through a rational approach starting with in silico epitope design. Chemically synthesized peptide epitopes can then be used as templates in a solid-phase protocol for MIP synthesis [2,3]. We demonstrate the potential of MIP nanogels (~50 nm) for medical diagnostics [3], bioimaging [4] and medical therapy [4,5], on the example of cell surface protein targets [4], as well as soluble cytokines and biomarkers [3,5]. We will also demonstrate the study of these synthetic antibody mimics using single-molecule methods.

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Magnetic Nanoparticles for Cryopreservation: Nanowarming and Temperature Monitoring

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The rewarming phase following cryopreservation is a critical process, where the right warming rate is essential to preserve the viability of biological tissues following the procedure.Nanowarming has emerged as an effective strategy to increase the rewarming rate by using magnetic nanoparticles (MNPs) as localized heat sources. However, for this technique to be efficient, we need to be able to control the temperature rise in the entire 3D volume and ensure that the delivered heat dose is not causing damage.Magnetic Resonance Imaging (MRI) offers a non-invasive approach to monitor temperature by leveraging the fact that physical tissue parameters change with temperature. However, within the range from sub-zero to physiological temperatures, MRI signalexhibits a non-monotonous dependence on temperature[1,2,3,4], making it challenging to obtain a reliable calibration.

This work proposes the use of a temperature-sensitive ferromagnetic contrast agent based on gallium-doped iron oxide nanoparticles, coated with APTES and functionalized with indocyanine green (ICG). By changing the gallium doping, it is possible to tune the transition temperature of the particles, enabling control over the temperature range in which the particles exhibit the greatest change in magnetic properties. Imaging was performed using 3D zero echo time sequences, combined with 3D gradient-echo sequences on a low-field MRI system.

The engineered MNPs proved to be successful in reverting thenon-monotonic signal variation from -30ºC to 50ºC, allowing accurate 3D temperature mapping during rewarming. Furthermore, ICG functionalization enabled near-infrared (NIR) laser heating, significantly enhancing rewarming rates. By working as both localized heat sources and temperature sensors, these nanoparticles allow for simultaneous localized temperature increase and 3D temperature monitoring. Such an approach represents a significant advance in cryopreservation technology, offering improved thermal control and potentially enhancing the post-thaw viability of preserved organs and soft biological tissues.

Keywords: MRI Thermometry; Cryopreservation; Magnetic Nanoparticles; Monotonic Signal; Nanowarming

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Beyond Viral Mimicry: Phage-Guided Photoresponsive Nanoparticles for Enhanced Navigation and Targeting in Complex Biological Environments

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Nanomedicine holds significant potential for addressing key technological limitations contributing to treatment-related adverse effects and delayed diagnosis. However, inefficient NP targeting in complex biological environments — where adsorbed biomolecules (i.e. biomolecular corona) mask synthetic functionalities — remains a major challenge. Driven by biomimicry rationale, protein and antibody conjugation strategies have been widely employed to improve target recognition, yet remain hampered by high costs, limited scalability, and poor stability. Viruses, having naturally evolved to navigate complex biological environments with remarkable precision, represent an ideal biomimetic model. While virus-like particles have been explored in this direction, they still rely on synthetic reconstruction of viral functionality. Here, we propose to move beyond synthetic mimicry by directly harnessing M13 bacteriophages as biological vectors to guide the delivery of photo-responsive nanoparticles (PNP). Naturally abundant in human biofluids, phages offer robust stability, low production costs, and straightforward genetic engineering to display multiple tailored targeting peptides or nanobodies. Exploiting the unique filamentous structure of M13, distinct hybrid configurations were obtained by tuning the conjugation strategy — either through self-assembly or covalent binding. A comprehensive characterization platform combining a broad panel of complementary techniques was established to provide key structural and functional insights into these poorly studied hybrid systems. The resulting Phage–PNP platform shows strong translational potential, particularly for theranostic applications, where phage-enabled precise targeting combined with the photoresponsivity of the conjugated NPs could meaningfully advance both therapeutic efficacy and diagnostic outcomes.

Day-2

NanoSeries2026 Technical Session: NS (G)

Nanoscale Engineering for Sustainability

Nanoparticle-Based Aerogels for Photocatalysis and Separation

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Nanoparticle-based aerogels are produced by destabilising colloidal nanoparticle dispersions to form volume-filling gels, followed by supercritical drying [1]. Depending on the nanoparticles used as building blocks, this modular approach allows precise control of the composition, the crystallographic phase, the surface chemistry and, to a certain extent, the microstructure and mechanical strength. In addition to tailoring properties at the nano- and micrometre scale, this method also enables control of macroscopic geometry, which facilitates the production of granular and monolithic materials. Furthermore, the surface of the resulting gel networks can be modified after synthesis using wet impregnation techniques, in which metal salts or coordination complexes are immobilised on the surface via electrostatic adsorption.

Together, these versatile synthesis and post-synthesis methods offer a wide range of parameters for the systematic tailoring of aerogel properties to specific functions in the fields of separation, heterogeneous catalysis and chemical sensing.

This talk provides an overview of our efforts to synthesise metal oxide-based aerogels derived from preformed nanocrystals under various reaction conditions. Particular emphasis is placed on strategies for designing the macroscopic geometry from monolithic forms to millimetre-sized spherical and worm-like granules, with the aim of improving catalytic efficiency in light-driven gas-phase conversions [2]. Furthermore, selected case studies illustrate approaches to modulating surface chemistry to enable efficient CO_2 capture and photothermal CO_2 reduction. The use of chiral or mesoporous nanoparticles as building blocks further expands the functional scope of nanoparticle-based aerogels. Chiral surfaces enable applications in enantioselective separation [3], whilst mesoporous nanoparticles introduce clearly defined pore structures which, following further functionalisation, become of interest as versatile sorption materials.

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Evaluating Nano-Engineered Thermal Energy Converters from a Sustainability Perspective

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Nano-engineered thermal energy converters, such as advanced thermoelectric generators (TEGs), are increasingly explored as promising technologies for waste heat recovery and low-carbon electricity generation. Recent advances in nanomaterials, nanocomposites, and nanoengineering strategies have demonstrated clear improvements in TE materials properties and device-level conversion efficiencies. However, whether these efficiency gains translate into improved sustainability at the system level remains an open question. In particular, the production of TE nanomaterials often involves energy-intensive processes, critical raw materials, and complex manufacturing routes that may offset the environmental benefits achieved during operation.

This contribution discusses the role of life cycle assessment (LCA) as a systematic framework to evaluate the sustainability of nano-engineered thermal energy converters beyond performance metrics alone. LCA enables the quantification of cumulative energy demand, greenhouse gas emissions, and selected non-climate environmental impacts associated with material extraction, synthesis, and device fabrication. Using TE technologies as a representative case, we highlight how synthesis routes, material choices, and energy sources used during manufacturing can strongly influence energy payback times and carbon offset potentials.

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Subnanoscale Engineering of Single-Atom Catalysts for Electrosynthesis of Green Chemicals

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The electrochemical reduction of carbon dioxide (CO2) and nitrogenous small molecules (N_2, NO_x) holds promise for the synthesis of valuable chemicals under ambient conditions. Yet, achieving precise control over the reaction pathway to tune product selectivity remains a significant challenge. Single-atom catalysts (SACs) show potential due to their tunable coordination environments, which may facilitate tuned catalytic activities and selectivities, while also offering insights into structure-activity relationships.

Our work demonstrates that the local atomic coordination environment of bismuth (Bi) in singleatom morphology can be systematically tuned through thermal processing, as evidenced by nearedge and extended X-ray absorption spectroscopy (XANES and EXAFS) in combination with Xray photoelectron spectroscopy (XPS). By correlating these spectroscopic insights with electrochemical measurements, we show that the reaction pathways of CO_2 reduction can be rationally modulated to achieve on-demand selectivity toward either CO or HCOOH[1]. Furthermore, we are investigating electrochemical organonitrogen synthesis in our home-built electrochemical workstation[2]. The primary focus is on identifying the possible key parameters governing urea formation via the coupled reduction of CO_2 and N_2/NO_x. For this purpose, we are using a series of transition-metal-based SACs (Cu, Fe, Ni). While mechanistic investigations are underway, systematic control experiments indicate a correlation between HCOOH formation, the oxophilicity of the reaction sites, and urea production within this group of catalysts. This finding offers valuable insights into the urea generation reaction pathway and highlights opportunities for catalyst optimization.

Overall, this research advances the understanding of structure-activity relationships in SACs, establishes strategies to control CO2 reduction and C–N product distributions, and highlights the potential of engineering atomic coordination environments to modulate reaction pathways for asdesired ‘green’ chemical synthesis.

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Boosting the Quantum Efficiency of Ionic Carbon Nitrides for Solar-Driven Fuel Synthesis

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Solar-driven catalysis offers a sustainable route to produce valuable fuels. Metal poly(heptazine imide) (MPHI), a crystalline ionic carbon nitride, has emerged as an efficient photocatalyst due to its favorable band alignment for H_2O_2 and O_2 evolution. Crucially, enhancing and shifting the light absorption of PHI into the visible region is essential for maximizing solar energy utilization. Here, we summarize recent advances in boosting the quantum efficiency of MPHI. We found that introducing oxamide during KPHI synthesis induces lattice distortion and activates n→π* transitions, extending solar absorption and improving H_2O_2production; the optimized catalyst reached an AQY of 41% at 410 nm. Further gains were achieved by incorporating NH4Cl, which fragments KPHI into distorted nanocrystals, raising the AQY to 49% at 410 nm and 5% at 525 nm—the highest for metal-free H_2O_2 photocatalysts. Additionally, $NaBH_4$ treatment enabled B doping and N defects, yielding an AQY of 4.57% at 420 nm for oxygen evolution. Future efforts will focus on precise electronic-structure engineering to further extend visible-light absorption while maintaining high charge-separation efficiency.

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Synergistic Substitution-Hybridization Strategy to Boost Visible-Light-Driven Photocatalytic Nitrogen Fixation With Pb-Substituted BiOBr-RuO_2 Nanohybrids

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Photocatalytic nitrogen reduction reaction (NRR) has garnered prime attention as an economically feasible option for energy-effective production of ammonia. Herein we report a synergetic substitution-assisted hybridization strategy to develop high-performance visible-light-active photocatalysts toward NRR via a reinforced interfacial electronic coupling. The Pb^{2+} substitution into the Bi^{3+} site of BiOBr lattice improved the visible-light-driven NRR performance via the introduction of anion vacancy, the enhancement of light absorptivity, and the depression of electron-hole recombination. The subsequent hybridization with monolayered RuO_2 nanosheet enabled to further enhance the NRR activity of $Bi_{1-x}Pb_xOBr$ via the improvement of charge transport property, charge separation, and N2 adsorptivity. The strongly coupled $Bi_{1-x}Pb_xOBr$-RuO_2 nanohybrid delivered outstanding NRR photocatalyst performance with NH4+production rate2 times higher than non-substituted BiOBr-RuO_2 hybrid and 4 times higher than non-hybridized Bi0.9Pb0.1OBr. In situ X-ray absorption spectroscopic analysis revealed that the hybridization with conductive RuO_2 nanosheet effectively suppressed the accumulation of photo-excited electron to BiOBr, which subsequently promoted prolonged charge lifetime and activation of adsorbed N_2 molecules.The excellent ammonia production activity of $Bi_{1-x}Pb_xOBr$-RuO_2 could be ascribed to the synergistic effect of Pb-substitution and RuO_2-hybridization. The interfacial interaction between BiOBr and RuO_2 was strengthened by the introduction of oxygen vacancy in BiOBr lattice, which was formed by Pb substitution, further improving the optical, absorption, and charge transport properties of the nanohybrids.

Keywords: Nitrogen reduction reaction, Interfacial interaction, Visible-light photocatalysis, Defect engineering

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Engineering 3D-Printed Nanoporous Carbon Composites with Fly Ash for Sustainable CO_2 Capture

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The escalating impact of CO2 emissions necessitates the development of high-performance, sustainable carbon capture materials. Biochar, derived from the controlled pyrolysis of biowaste, has emerged as a premier candidate due to its highly tunable physicochemical properties [1]. This work details the optimization of chitosan-derived biochar adsorbents through innovative synthesis strategies, focusing on the nanostructural evolution governed by polymerization routes, drying protocols, and pyrolysis conditions [2–4].

We employed a comprehensive suite of advanced characterization tools, including X-ray photoelectron spectroscopy (XPS), solid-state NMR, electron microscopy, and operando TGA-IR, to elucidate the fundamental correlations between synthesis parameters and CO2 adsorption mechanisms. To transition from powder-based adsorbents to scalable, monolithic architectures, these N-doped biochars and activated carbons were integrated into self-standing, 3D-printed geopolymer composites, achieving loadings of up to 50 wt.%.

A central finding of this research is the synergistic role of industrial fly ash as a performance-enhancing additive. Our results demonstrate that fly ash significantly accelerates adsorption kinetics by promoting the formation of interconnected microporous networks and increasing effective surface area. The optimized 3D-printed architectures achieved CO2 adsorption capacities of up to 1.20 mmol g^{-1}, maintaining robust structural integrity and stable performance across multiple regeneration cycles. This study highlights a scalable, circular-economy pathway for carbon capture by merging nanostructured carbons with industrial byproducts through additive manufacturing.

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Advanced Design of Energy-Functional 2D Nanosheets via Interface- and Defect-Engineering

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Highly anisotropic 2D nanosheets of layered inorganic solids (metal oxides, layered double hydroxides, metal chalcogenides, metal carbides, metal nitrides, and carbon nitrides) have evoked great deal of research activity because of their outstanding performances as energy-functional materials. A great diversity in the chemical compositions, crystal structures, and defect structures of inorganic nanosheets provides this class of materials with a wide spectrum of physical properties and functionalities. The inorganic nanosheets can be used as powerful building blocks for exploring high performance hybrid catalysts and electrodes. Since the crystal defect and interfacial interaction have profound influence on the catalyst and electrode functionalities of hybrid materials, the energy-related performances of 2D inorganic nanosheet-based hybrid materials can be greatly enhanced by defect- and interface-engineering. In this talk, several classes of 2D inorganic nanosheets and their nanohybrids applicable for renewable energy technology will be presented together with the discussion about the relationship between chemical bonding nature and catalytic/electrode activity. The crucial role of interface/defect engineering in optimizing the energy performances of 2D nanosheet-based materials will be highlighted.

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Surface Engineering of Nanocatalysts in 3D-Printed Porous Scaffolds for Water Remediation

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The transition from powder-based photocatalysts to structured, porous systems is essential for overcoming the recovery and mass transfer limitations of traditional water treatment processes. This study explores the use of Direct Ink Writing (DIW) to fabricate ceramic-like inorganic polymer (IPs) scaffolds, providing a modular and mechanically robust platform for supported photocatalysis [1]. By leveraging the geometric freedom of additive manufacturing, we designed porous lattice structures optimized for flow-through applications and evaluated three distinct catalyst integration strategies for the degradation of antibiotics (Ciprofloxacin, Sulfamethoxazole) and complex mixtures of emerging pollutants.

Two independent catalyst integration strategies were investigated. In the first study, multi-walled carbon nanotube (MWCNT) functionalization of the scaffold surface was followed by conformal TiO_2 deposition via Atomic Layer Deposition (ALD), yielding a well-controlled photocatalytic interface. In a second, separate study, g-C_3N_4 was deposited onto the printed scaffolds by drop-casting to promote visible-light-driven activity [2].

The results demonstrate the high chemical and mechanical resilience of the inorganic polymer matrix in aqueous environments. While bulk incorporation offers manufacturing simplicity, the surface-localized engineering strategies (ALD and drop-casting) significantly enhanced the accessibility of active sites and light utilization. Notably, all fabricated scaffolds exhibited exceptional stability and consistent reusability across multiple cycles, confirming the potential of 3D-printed inorganic polymers as a scalable technology for modular water treatment applications.

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Atmospheric Water Harvesting: Can Sulfur Be the Solution?

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A lack of access to global clean water is leading to a water crisis. United Nations Sustainable Development Goal 6 states that we must "…achieve universal and equitable access…" to clean drinking water by the year 2030. The atmosphere contains 6x the liquid volume of water as all the freshwater sources on Earth combined. Tapping the natural water reserves of the atmosphere is the next step to provide clean water to all. Atmospheric water harvesting (AWH) materials are hydrophilic structures, capable of adsorbing moisture from the atmosphere for collection and consumption.

Sulfur, extracted from the desulfurisation of crude oil, collects in quantities in excess of 7 tonnes per annum as waste. The chemistry of sulfur can introduce interesting new properties and characteristics to AWH materials. Disulfide cleavage drives reversible structural rearrangement upon water sorption. Base-stimulated sulfur ring-opening converts hydrophobic sulfur to hydrophilic metal polysulfides, used to synthesise AWH polymers and hydrogels. Thiol self-condensation can prepare polymer scaffolds for hydrophilic metal moieties at room temperature in minutes. Here, we blend sulfur - a hydrophobic material - with the field of AWH, to design and enhance materials for the future of water harvesting.We present a catalogue of sulfur-containing polymer and hydrogel materials (Figure 1) with impressive AWH properties. Sulfur chemistry proves capable of introducing new characteristics and properties to materials to address problems such as waste and water management.

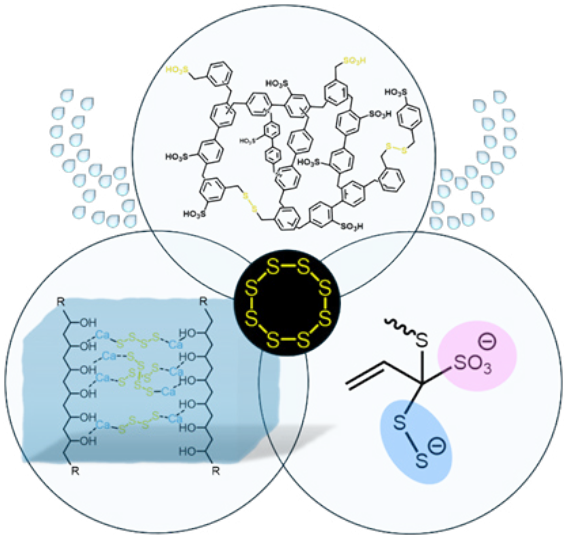

Figure 1. A collection of materials, prepared from elemental sulfur waste or using sulfur chemistry, for AWH.

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Deciphering the Molecular Factors Influencing Water Harvesting From Air in Metal-Organic Frameworks

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Water insecurity will affect an estimated six billion people by 2050 and it is crucial to address the global water shortage crisis by advancing supplemental methods of freshwater generation [1-3]. In this regard, atmospheric water harvesting is a powerful strategy allowing decentralized access to potable water. Metal-organic frameworks (MOFs) are a class of crystalline solids receiving exponentially growing attention as sorbents for water capture from air in both arid and temperate climates, owing to their intrinsic porosity, programmable water binding sites and unrivalled chemical tunability. MOFs may in fact be designed to exhibit high water uptake and long-term water stability, while MOF water harvester prototypes have been proven able to extract ultra-clean water in the desert [3].

While further optimizing the energy efficiency of the water collection process is required for the commercialization of MOF water harvesters, knowledge on how water harvesting performance is affected by the MOF structural and electronic properties, including by the presence of defects, is still lacking. Here, a novel approach based on synchrotron powder X-ray diffraction (PXRD), X-ray Pair Distribution Function (PDF) and X-ray Absorption Spectroscopy (XAS) measurements is presented to investigate the local and global structural modifications in state-of-the-art water harvesting MOFs as a function of water uptake. In particular, the prototypical systems Mg-MOF-74, MIL-100(Fe) and MOF-303 {[Al(OH)(PZDC)], $PZDC^{2-}$=1-H-pyrazole-3,5-dicarboxylate} [1] were investigated by our innovative interdisciplinary approach.

The complementary experimental techniques, supported by in-depth theoretical analyses, shed light on the variation of the local structural properties (coordination geometry, bond distances, nature of ligands) and long-range distribution of the MOF key adsorptive sites as water populates the MOF pores, providing molecular-level insights into the dynamic water adsorption-desorption process.

The obtained understanding of will aid in accelerating the development of MOF water harvesters for clean water generation.

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Day-2

NanoSeries2026 Technical Session: NS (F) & NS (C1)

Next–Generation Light–Matter Interactions at the Nanoscale: Photonics and Optoelectronics

Bionanosensors and Bioelectronics: In Vitro and In Vivo Applications

Theme: Quantum Photonics, Functional Devices & Advanced Bioelectronics

Implanted Spin-Wave Waveguides for Large Magnonic Networks

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The rapid growth of artificial intelligence and data-driven technologies has sparked an immense interest in alternative computing architectures, which go beyond conventional electronics. Spin waves (magnons) have emerged as a promising platform for next-generation physical computing. They offer several key advantages, such as excellent energy efficiency, broad operational frequency bandwidth and nanometer-scale wavelengths, rendering highly integrated devices possible. The material of choice with the lowest known spin-wave damping is the magnetic insulator yttrium iron garnet (YIG). YIG has recently become available as high-quality single-crystal films on the wafer scale.

We demonstrate low-loss spin-wave waveguides in a thin YIG film using a maskless silicon ion implantation technique [1]. By using the focused ion beam, an amorphous cladding of the magnon waveguide is created, where the magnetization is drastically reduced. At the same time, the excellent magnetic properties in the YIG core of the waveguide are preserved. The spin-wave propagation is imaged via optical Faraday rotation microscopy, which enables spatially resolved measurements of spin-wave amplitude and phase throughout the engineered structures. We achieve spin-wave decay lengths exceeding 100 µm even in submicron waveguides, substantially outperforming current state-of-the-art etched devices. Furthermore, the dispersion relations of these waveguides are highly tuneable by adjusting both waveguide width and implantation dose, providing unique flexibility for integrated magnonic circuit design. Using our new technique, we fabricated a large-scale spin-wave network, featuring 198 crossings with 34 input and output ports.

Our etchless, scalable approach paves the way for wafer-scale, low-loss magnonic integrated circuits (MICs), enabling advanced, high-efficiency spin-wave-based computing and signal-processing architectures.

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Perovskite Nanocrystals – Fast Emitters for Optical Wireless Communications?

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A fast PL lifetime, narrow spectral width, and broad colour tuneability render perovskite nanocrystals intriguing candidates for use in optical wireless communications (OWC) – a potential alternative to existing WiFi technology, in which data communication can be integrated with ambient lighting.

In this talk, I will discuss the requirements of novel emitter materials and how to test their merit for application in OWC. My discussion will connect the fields of materials science and photophysics with the application and performance of novel emitters in communication systems.

Based on these considerations, I will highlight the great potential of perovskite nanocrystals for OWC applications and show our recent results towards establishing a multi-channel communication platform based on different perovskite compositions as luminescence converters. In particular, I will discuss how we employed advanced keying schemes and data processing to achieve data transmission rates on the order of Gbit/s.

Design, Fabrication, and Characterization of Graphene-Silicon Nitride Integrated Mode Filters

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We present the design, fabrication, and characterization of broadband graphene-silicon nitride integrated mode filters working in the optical C-band, centered at a wavelength of 1.55 µm. The devices presented here prevent modal crosstalk, thus avoiding signal degradation in multimode communication systems. In particular, the fabricated filters are based on a dual-mode silicon nitride waveguide, partially covered by a centered graphene nanoribbon that induces a stronger absorption for the TE0 mode than for the TE1 mode. The geometry of the design has been optimized to minimize the length and insertion losses of the device. A complete fabrication process, including the transfer and lithography of commercial graphene, has been developed. A novel approach was introduced during the etching step, which entailed the simultaneous curing of the resist to encapsulate the graphene nanoribbons prior to the deposition of the upper cladding. Finally, transmission through an array of fully fabricated filters of varying lengths was characterized with a measurement setup employing optical fiber coupling. The maximum experimentally measured contrast between the TE0 and TE1 modes is 123 dB/cm, achieved at a wavelength of 1569 nm, simultaneously with a minimum loss of −38 dB/cm for the TE1 mode. Overall, we fully demonstrate an integrated mode filter based on commercial graphene that paves the way for the implementation of integrated multimode optical communication systems.

Controlling Carrier-Trap-Assisted Recombination in Organic Emitters

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Persistent luminescence and thermo-/photostimulated luminescence are charge-mediated optical phenomena in which photogenerated charge carriers are stored in trap states and later released through gradual or externally stimulated recombination [1]. These functions have been developed mainly in inorganic materials, where stable trapping centers can be easily formed. In organic materials, however, achieving such behavior has been difficult because photogenerated electrons and holes are generally unstable and tend to recombine rapidly.

Here, we present an organic-semiconductor approach to persistent and stimulated luminescence inspired by the basic operating principles of organic optoelectronic devices. In organic photovoltaics, donor–acceptor interfaces enable photoinduced charge separation, whereas in organic light-emitting diodes radiative charge recombination produces light [2]. Our strategy connects these two processes by introducing a controlled charge-storage step between charge separation and recombination. In contrast to conventional organic semiconductor devices, where trap states are usually minimized because they cause carrier loss, we intentionally use and control trap states as part of the emission mechanism.

By combining charge separation at donor–acceptor interfaces with charge diffusion and controlled trapping, we have realized persistent luminescence as well as thermo- and photostimulated luminescence in organic semiconductors [3-5]. In this talk, I will discuss the main factors that govern charge generation, retention, transport, and recombination, and show how trap control can provide a new way to design long-lived and stimulus-responsive emission in organic materials.

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Correlating Lasing Emission from Halide Perovskite Crystals with Pump-Probe Spectroscopy

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Due to their tunable optical bandgap along with exceptionally high luminescence quantum yields and defect tolerance, halide perovskites are outstanding candidates for lasing applications. Since optical pumping results in a variety of excited states, a clear picture of their decay dynamics is required for improving the lasing performance. Pump-probe spectroscopyis an excellent tool for investigating the carrier and relaxation dynamics in halide perovskites. The decay dynamics of halide perovskites provides insights into the initial makeup of the excited states [1,2].

By combining the emission spectrum with pump-probe spectroscopy from the same region of the sample, we discuss the nature of the excited states responsible for lasing in cesium lead bromide (CsPbBr3) and methylammonium lead bromide (MAPbBr3) crystals. The lasing thresholds for both crystals were found to be around 30 µJ/cm2. Both space-confined melt crystallization, which yields uniform perovskite crystals, and spin-coated films demonstrate lasing. The overall transient absorption (TA) features from CsPbBr3 and MAPbBr3 crystals are similar. Detailed analysis of the TA spectra is presented from a thin MAPbBr3 crystal where a large range of pump fluence was used. We present a deconvolution decay model that is developed for extracting features of the stimulated emission from the ground state bleaching and photoinduced absorption.

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Designing the Complex Conditions for What Has Not Yet Been Invented

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Photonics offers significant advantages over electronics, primarily higher speed, massive bandwidth, and superior energy efficiency by using light (photons) instead of electrons, leading to less heat, lower power consumption, reduced cooling needs and overcoming electronic limitations for AI, data centers, and high-performance computing. Though electronics still lead in miniaturization and cost for many current tasks.

The transfer of photonic technologies to commercial applications is now enabled by pilot manufacturing initiatives. It's a key step toward cost-effective, high-volume deployment of advanced photonic integrated circuits (PICs). The shift also aligns with semiconductor industry standards, enabling better integration (silicon photonics) with existing manufacturing infrastructure.

The design of an photonics research/pilot production facility requires a complex suite of technical, logistical and environmental challenges including precise control of particles, vibrations, electromagnetic interference, airborne chemical contamination, and temperature. The planning, design and realization to meet these extremely stringent conditions leads to ever more complex and costly cleanrooms, both in terms of investment and operations.

Based on several case studies, including the design of an InP 6-inch pilot fabrication line this presentation highlights solutions on how to balance the technical complexity with the financial and sustainability challenges. It will be demonstrated that applying the experiences from lab scale to production is crucial. Moreover, solutions from the semiconductor manufacturing facilities can cater for future flexibility, scalability and future process automation.

Lastly, a perspective will be presented how these experiences can drive us into integrated silicon photonics production facilities.

References

Various NanoScience technology conferences including The Netherlands, Singapore, Italy, Germany and Spain

Chiral and Structured Light as Probe and Control Knob of Light–Matter Interaction in Layered Materials

Jana Kalbacova Vejpravova

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Layered (van der Waals materials) provide an ideal platform to study light–matter interaction in reduced dimensionality, where crystal symmetry, chirality, and magnetic order strongly influence optical excitations. In this contribution, chiral and structured light are employed both as a spectroscopic probe and as a tuning parameter of electronic, optical, and magnetic responses in layered materials. Using polarization- and phase-controlled excitation combined with photoluminescence (PL) and Raman scattering spectroscopy, we investigate symmetry-selective excitations. Measurements performed at low temperatures and under external magnetic fields allow us to resolve angular-momentum transfer processes and field-dependent modifications of excitonic and vibrational modes. The results demonstrate how tailoring the polarization and spatial structure of light enables selective access to electronic degrees of freedom, establishing structured light spectroscopy as a powerful approach for studying and controlling optical phenomena in low-dimensional materials.

Neuromorphic Behavior in Single-Crystal Hybrid Perovskite Devices

Valeria Demontis

University of Cagliari, Italy

After revolutionizing the field of photovoltaics, halide perovskites are now emerging as highly promising platforms for neuromorphic electronics. Their intrinsic mixed ionic-electronic transport, long considered a challenge for device stability, is increasingly recognized as a powerful functional asset for emulating synaptic dynamics. Most studies have focused on thin polycrystalline films, where grain boundaries and defect in the surface and in the bulk dominate charge transport, creating poorly controlled channels for ion migration andobscuring the intrinsic properties of the material.

Here we focus on single-crystal halide perovskites, which retain the outstandingoptoelectronic properties and low-cost, solution-based growth of their polycrystalline counterparts, but are characterize by a long-range spatial order and much lower defect density. Wefabricate two-terminal memristor devices,based on 2D and 3D halideperovskites, and we investigate transport properties and synaptic plasticity effects under electrical and optical stimuli and assess the potential of these devices for neuromorphic computing.

Reconfigurable Field Effect Transistors: A Versatile Technology Platform as CMOS Add-On

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NaMLab gGmbH, Germany

Reconfigurable Field Effect Transistors (RFETs) are emerging devices based on intrinsic semiconducting channels, source and drain Schottky barrier contacts, and multiple independent gates. Researched since more than 20 years, after a first phase of material optimization and device-level exploration, they are nowadays considered as promising candidates for several applications such as hardware security, tunable analog circuits, energy-efficient architectures, and sensor electronics. This presentation covers the whole spectrum of RFET research, ranging from material requirements (such as nanometer sharp Schottky junctions), device-level architectures (channel geometry and number of gates for enhanced performance) up to application scenarios.

Ion-Gated Multifunctional Semiconductor Nanowire Transistors: An Interdisciplinary Journey Through Material Science and Quantum Technology

Francesco Rossella

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Innovative nanowire-based prototypical device architectures with potential applications encompassing quantum technologies (Figure 1) [1], nanoelectronics [2,3,4] and sustainable energy conversion [5,6] have been recently enabled by iontronics [7,8], combining semiconductor nanowires with (poly)electrolytes where ions are free to move upon electrical or thermal biases. These devices are multi-gate nanotransistors which exploit electrolytes as dielectrics to build up electric double layers at the nanowire-electrolyte interface, providing ultra-intense local electric fields that can be tailored to control the transport properties in the nanowire. Implementing this paradigm, ion-gated and ion-sensitive nanowire transistors were proven to enable alternative measures of electrical parameters as well as novel architectures for thermoelectrics, and more recently have been proposed for zero-dimensional density of states engineering in InAs nanowires, namely, for engineering the iontronic nanowire quantum dot.A brief review of nanowire iontronics is discussed and the novel concept of quantum iontronics in nanowire-based devices is reported.

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Day-2

NanoSeries2026 Technical Workshop: NSAW3

Smart Soft–nanomaterials – Development Directions and Challenges

Soot-Derived Carbon Aerogels as Sustainable Porous Platforms for Adsorption Applications

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The upcycling of combustion-derived carbonaceous by-products into functional porous materials represents a promising strategy for the development of sustainable adsorbents. In this contribution, we present the fabrication of lightweight, monolithic aerogels based on soot-derived carbon particles embedded within a biopolymeric matrix. The work emphasizes the aerogel architecture, its hierarchical porosity, and the role of carbon inclusions in tailoring structural and surface-related properties.

The proposed approach exploits soot as a low-cost, nanostructured carbon source, which is homogeneously integrated into a chitosan-based framework to obtain mechanically stable, highly porous aerogels. The resulting materials exhibit interconnected macroporosity combined with carbon-rich walls, a morphology that is particularly attractive for mass transport–driven processes.

Preliminary investigations indicate that the presence of soot significantly enhances the functional performance of the aerogels, highlighting their potential as versatile adsorption platforms, for either air or water remediation.

Soft Sensing Junctions

Poltorak L.*

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During my presentation I will cover several aspects of electrochemistry at intrinsically soft sensing platforms known as electrified liquid–liquid interfaces (eLLI) or interfaces between two immiscible electrolyte solutions (ITIES). The junction formed between an aqueous and an immiscible organic electrolyte solution can be used to study and control interfacial ion-transfer processes with the full range of electroanalytical tools. Because ions differ in their affinity for aqueous versus organic solvents, their transfer is governed by partitioning behavior and can be modulated by the externally applied Galvani potential difference. Take-home message: detection at the ITIES arises from interfacial charge-transfer processes that are not limited to electron transfer but most often involve ion transfer.

With this in mind, during my presentation, I will oscillate around three key aspects: (i) guidelines on how to formulate such soft junctions to be applied for sensing [1]; (ii) how to construct sensing platform (the several supporting materials will be covered) [2-3] and finally (iii) ITIES application for the detection of compounds holing sound societal concern, this is illicit drugs [4-6].

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Engineering MXene-Based Soft Nanocomposites for Biointerfacing, Targeted Therapy, and Stimuli-Responsive Sensing

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Smart soft nanomaterials with integrated functionality are emerging as key platforms for advanced biomedical interfaces, where controlled interactions with biological systems are essential. In this work, we present a comprehensive approach to engineering MXene-based soft nanocomposites by linking synthesis-driven surface chemistry with biological performance and functional responsiveness.

We demonstrate that the biocompatibility and bioactivity of Ti-based MXenes are strongly governed by etching and delamination strategies, which determine surface terminations, defect density, and residual impurities. Optimized synthesis routes reduce fluorine content and oxidative stress, enabling high compatibility with human cells while preserving electrical and optical properties. Furthermore, we critically reassess the intrinsic antibacterial activity of MXenes and show that pristine nanosheets exhibit limited bactericidal effects, whereas externally triggered photothermal therapy (PTT) provides efficient and selective bacterial eradication.

Building on these findings, we develop hybrid MXene-based systems with enhanced functionality. Polydopamine-mediated surface engineering enables stable biofunctionalization with targeting antibodies, leading to selective photothermal ablation of tumor cells under near-infrared irradiation. Additionally, the role of MXene flake size and mobility in biological environments is elucidated, revealing size-dependent interactions with cellular systems and implications for intracellular processes.

These results establish MXenes as a versatile platform for smart soft nanomaterials, where tunable surface chemistry, stimuli-responsive behavior, and biofunctionalization enable applications in targeted therapy, biosensing, and adaptive biointerfaces. The presented strategy bridges materials engineering and biomedical functionality, offering pathways toward next-generation implantable and responsive diagnostic systems.

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Hydro- and Organogels for the Cleaning of Works of Art

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Cultural Heritage represents a socioeconomical driver for resiliency, but its maintenance is a challenge owing to degradation processes enhanced by climate changes and even wrong interventions. In this context, soft matter and colloids science have contributed valuable solutions over the last decades. Hydro- and organogels act as confining matrices for fluids able to detach, swell, solubilize or dewet unwanted layers from the surface of works of art, such as soil and aged coatings/varnishes from canvas paintings. Gels allow the treatment of water- or solvent-sensitive surfaces in a controlled and time-effective way, surpassing conventional polymer thickeners or bulk, non-confined solvents. Their polymer networks can be modified and tuned taking advantage of phase separation processes, functionalization and interaction with solvents, controlling the gels' micro- and nanoscale porosity and tortuosity. This, in turn, reflects in enhanced cleaning properties that grant the preservation of works of art and their transfer to future generations. In addition, gels for Cultural Heritage represent also promising systems for transfer to cosmetics, detergency, pharmaceutics, the food industry, and other technological sectors.

Smart Nanocomposites for Sustainable Sensing in Environmental Monitoring, Robotics, and Wearables

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Electronics are rapidly spreading across society. Yet the material demands of key emerging fields such as environmental monitoring, robotics, and wearables are markedly different. Agricultural and environmental applications require materials that safely biodegrade after use.[1] Robotics demands durability, repairability, and end-of-life recyclability.[2] Wearable physiological monitoring benefits most from reusable, washable, and self-healing devices, cutting reliance on single-use ones.[3] Across these domains, the need to combine reliable sensing with scalable manufacturing is driving the development of smart functional materials with a truly cradle-tograve sustainable life cycle. Conductive polymer composites, built on degradable, recyclable, or healable matrices loaded with carbon nanofillers, provide a common platform for multifunctional sensing devices deployable across diverse fields.

This contribution highlights three complementary directions. First, for agriculture and environmental monitoring, biodegradable composites formulated from biopolymer matrices and carbon fillers enable resistive devices[4], yielding degradable thermistors, thermocouples, and electrodes for ripeness assessment. Second, for robotics, circular-economy coatings bring sensing to high-wear components: self-healing vitrimer nanocomposites enable recyclable strain and motion monitoring[2], while recyclable biocomposite coatings deliver piezoresistive and piezocapacitive pressure and touch sensing in cobot grippers[5]. Third, for wearables, extruded thermoplastics conductive nanocomposites are embedded into cotton fabrics and produce hydrophobic, healable, and washable smart textiles capable of high-fidelity movement and temperature monitoring at practical scale.

Together, these examples show how smart nanocomposites can move toward robust, applicationdriven systems, with degradability, repairability, and recyclability embedded in materials design from the outset.

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Continuous Monitoring in 3D Cell Models with Smart DNA-Hydrogel Sensors

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Organ-on-chip and 3D organoid platforms are reshaping in vitro physiology, but spatiotemporal monitoring of their chemical microenvironment remains a bottleneck. Conventional optical readouts rely on multi-step labelling, sparse nanomaterial probes or spectrally distinct fluorophores, all of which compromise time resolution, biocompatibility or analyte multiplicity.

We describe a class of smart soft nanocomposites that integrate DNA-scaffold sensors with photopolymerizable poly(ethylene glycol) diacrylate (PEGDA) hydrogels into a single, stimuli-responsive platform patterned directly inside Lab-on-Chip devices in one fabrication step. A short oligonucleotide bearing a fluorescent recognition element (6-FAM for pH) is end-modified with an acrydite group and covalently anchored into the PEGDA network during stereolithographic crosslinking driven by visible/UV-light projection. The DNA scaffold provides programmable control over probe density, orientation and aqueous solubility, while the soft, biocompatible matrix is shaped into discrete micropillars whose geometry (circles, triangles, rectangles) encodes the chemical identity of each sensor. A custom shape-recognition machine-learning algorithm segments and classifies the microstructures in time-lapse images, returning ratiometric, spatially resolved concentration maps in real time without spectral multiplexing [1].

We demonstrate the platform through continuous pH monitoring inside microfluidic chambers, resolving the kinetics of urease and acetylcholinesterase reactions and the metabolic acidification of human iPSC-derived embryoid bodies during early differentiation, with high spatial resolution, reversibility and biocompatibility [1]. Because the recognition module is genetically encoded, the same chassis can be reprogrammed to other physiologically relevant analytes simply by swapping the DNA sequence and reporter [2,3], turning a single-step fabrication scheme into a general toolbox for in situ monitoring of physiological and pathological processes. I will close by discussing nano–bio interface design rules and translation routes toward implantable, bioresorbable and closed-loop diagnostic systems.

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Formation of Gold-Modified Titania Nanotubes via Anodization of Ti/Au Sputtered Films for Energy-Related Applications

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Semitransparent titania nanotube (TiO2 NT) materials fabricated by anodizing titanium films deposited on transparent conductive oxide (TCO)-coated glass have recently attracted considerable attention owing to their unique combination of optical transparency, tunable nanostructure, and large specific surface area. These characteristics make them highly promising for photoelectrochemical and optoelectronic applications such as photocatalysis, solar energy conversion, and sensing devices.

In this work, the preparation of semitransparent electrode materials comprising oxide nanotubes formed from alternating layers of pure titanium and titanium-gold films, sputtered with different gold concentrations is reported. The layered structures were subjected to anodization followed by thermal treatment performed either in air (in a tubular furnace) or in a hydrogen atmosphere (using a rapid thermal annealer). Microscopic analyses confirm the formation of well-aligned nanotube arrays incorporating spherical Au nanoparticles of approximately 10 nm in diameter. Raman spectroscopy evidences the presence of the anatase phase, while UV-vis absorption spectra reveal a red shift of the absorption edge beyond 400 nm and a notable reduction in the band gap compared with bare TiO2 NTs.

The air-annealed electrodes exhibit improved oxygen evolution reaction activity, with the sample containing 2.35 at.% Au achieving an anodic current density of 2.7 mA cm-2 at +1 V vs. Ag/AgCl/0.1 M KCl, compared to 0.22 mA cm-2 recorded for unmodified TiO2 NTs. Among the hydrogen-annealed series, the sample with 0.96 at.% Au shows the highest photoresponse, generating photocurrent densities up to approximately 17 times higher under chopped visible light and 27 times higher under chopped UV-vis illumination than the pristine material. The incident photon-to-electron conversion efficiency (IPCE) of this sample reaches about 7.9 % under irradiation at 320 nm and 700 mV, compared to a maximum of 5.9 % for hydrogenated TiO2 illuminated near 300 nm. Despite its reduced UV absorption, this behavior indicates more effective charge separation and transport under UV excitation.

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Stimuli-Responsive and / or Super-Elastomeric Nanocomposite Hydrogels and Xerogels

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Stimuli-responsive elastomeric hydrogels attract wide research interest because of their ability to undergo large and reversible changes in volume, shape, and mechanical properties in response to external triggers such as temperature, pH, light, or electric fields. These features make them highly attractive for applications in soft robotics, sensing and actuating systems, as well as in adaptive devices. However, a fundamental challenge persists: The materials that respond rapidly, typically generate low forces and lack mechanical robustness, whereas mechanically strong systems often exhibit slow stimulus-response due to limited mass transport and structural constraints.

To address this long-standing trade-off, several families of nanostructured hydrogels were synthesized by the authors, followed by the development of their corresponding elastomeric xerogel analogues. The latter are typically not stimulus-responsive, but are of great interest as smart structural materials. The chosen strategies relied on tailoring the internal architecture at the nano- and micro-scale. The design concepts included ultra-fast-responsive cryo-porous networks with pore walls stabilized by nanoparticles.Nano-heterogeneous intercalated polymer structures provided highly improved tensile properties (network regularity), combined with very fast one-way response, even in bulk non-porous specimens.Similarly promising results were obtained with non-porous materials, which displayed reversible micro-phase separation induced by the same stimulus like their volume response.Many of these attractive products were nanocomposites with 1D- and 2D nanofillers. Some of the developed gel and xerogel systems were notable for their simultaneously high stiffness, toughness, and extraordinary extensibility. This contribution demonstrates, how rational nano-architectural design enables the development of mechanically robust yet highly responsive soft materials.

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Advanced GO-Based Coatings for Multifunctional and Durable E-Textiles

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Wearable electronics have recently attracted increasing attention due to the growing demand for health monitoring, human-machine interaction, and smart sensing technologies. In this framework, the development of flexible, energy-efficient, and sustainable materials is of primary importance. Textile-based platforms are particularly appealing, as they enable integration into everyday life. Among emerging solutions, coatings based on graphene derivatives stand out for their scalability, low-cost processing, and multifunctionality. These approaches are aligned with current challenges in smart soft nanomaterials, including durability, comfort, and integration into wearable systems.

Case studies representative of the use of coatings based on graphene derivatives for the development of smart textiles are here reported.

Cotton fabrics were functionalized through a two-step dip-coating application of a reduced graphene oxide conductive layer followed by an ultra-thin polyurethane (PU) coating. This approach enhanced electrical conductivity while preserving the intrinsic flexibility and softness of the cotton fabric. The PU layer also improved durability, enabling stable performance after repeated washing cycles. The coated fabrics exhibited additional functionalities, including localized heat retention and piezoresistive behavior, with measurable and repeatable electrical responses under mechanical deformation [1].

In a different work, a three-dimensional PET fabric was coated with graphene oxide (GO), then thermallyreduced, and subsequently an external PU layer incorporating hexagonal boron nitride was applied. This hybrid system was designed to improve thermal transport properties, showing potential for efficient heat conduction and distribution within complex textile architectures.

Ongoing worksare focused on the development of advanced coatings based on GO and other emerging two-dimensional materials such as borophene, with the aim of further tuning electrical, thermal, and mechanical properties.Overall, these results highlight the potential of coatings based on 2D nanostructured materials for the development of durable, conductive, and multifunctional e-textiles, in line with the evolving landscape of smart soft nanomaterials and their application in next-generation wearable technologies.

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Day-2

NanoSeries2026 Technical Workshop: NSAW4

Probing Surface Chemical Processes on 2D Materials

Characterization Methods for 2D Materials: Raman Scattering and AI Spectroscopy

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Two-dimensional (2D) materials have recently gained prominence in the semiconductor industry, battery, and sensor applications due to their unique physical properties. However, they still face challenges regarding reproducibility. To achieve reproducible material production, highly reliable evaluation methods must be employed. This presentation will discuss the development of methods to analyze structural deformations in 2D materials using non-destructive optical techniques, including Raman scattering, and AI-based analysis methods. It will also share insights and opinions on the ongoing research to establish these methods as international standards through the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC).

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Unveiling the Nature of Defects and Their Consequences on the Mechanical Response of 2D Materials by AFM

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Defects play a crucial role in determining the physical properties of conventional three-dimensional materials; however, in low-dimensional systems their impact is dramatically amplified. The investigation of atomic point defects in two-dimensional (2D) materials therefore represents a fundamental scientific challenge with broad implications across physics, materials science, and nanotechnology.

A comprehensive understanding of these defects, including their morphology, atomic structure, and chemical nature, requires a highly multidisciplinary approach. In this talk, I will present our recent advances achieved using advanced atomic force microscopy (AFM) techniques to identify the structure, spatial location, and chemical nature of atomic point defects in 2D transition metal dichalcogenides (TMDCs).

Furthermore, I will discuss how these defects influence key material properties such as tribological behavior, mechanical reliability, and elastic response, providing new insights into the structure–property relationships governing two-dimensional materials.

Magnetic Phase Transitions in CrSBr: A 2D Magnetic Semiconductor

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CrSBr is rapidly gaining attention as a prominent candidate within the family of van der Waals magnetic semiconductors[1-3]. Below the Néel temperature of 132K, the material is supposed to exhibit prototypical A-type antiferromagnetic order, as predicted by mean-field theory years ago. Recently, however, several groups reported the observation of unusual magnetic signatures indicating a second magnetic phase transition at temperatures around 40 K. In this contribution, we are going to discuss: (1) whether these signatures reflect an intrinsic property of the material or are caused by extrinsic influences; (2) if not the former, whether one can tailor the magnetic properties after growth.

We start with the single crystals grown by the group of Z. Sofer. Surprisingly, by extensive magnetization measurement utilizing SQUID magnetometry, we cannot detect the second, 40K magnetic phase transition [4]. Our magnetometry measurements confirm the theoretically predicted magnetic phase diagram and thus demonstrate that the 40K phase observed by other groups is not an intrinsic element of the magnetic phase diagram of CrSBr. The pure antiferromagneticCrSBr crystals and flakes were then subjected to non-magnetic ion irradiation, which produces structural defects in the crystals in a controllable way. We observe a transition from antiferromagnetic to ferromagnetic behavior in CrSBr [5, 6]. Already at moderate fluences, ion irradiation induces a remanent magnetization with hysteresis adapting to the easy-axis anisotropy of the pristine magnetic order up to a critical temperature of 110 K. Structure analysis of the irradiated crystals in conjunction with density functional theory calculations suggest that the displacement of constituent atoms due to collisions with ions and the formation of interstitials favors ferromagnetic order between the layers. Increasing irradiation fluences gradually lowers the Curie temperature, reflecting the impact of crystalline degradation. This suggests that by finely tuning the irradiation parameters and employing precise lithography techniques, it's possible to selectively modulate induced ferromagnetism in CrSBr in terms of magnetization strength, critical temperature, and spatial distribution.However, in our opinion, the origin and nature ofthe second phase with a transition temperature around 40 K in pristine CrSBr samples by various studies still remains elusive.

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Nanoscale Chemical Characterization of Functionalized Graphene by AFM-Based Nano-Spectroscopy

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Nanoscale analysis of surface functional groups on two-dimensional (2D) materials is essential for understanding and engineering their functional properties, especially in applications that require precise control over surface chemistry. In this context, we have been investigating the use of AFM-based nano-spectroscopy for the characterization of graphitic surfaces at the nanoscale. Our advancement in nanowire-based tip-enhanced Raman scattering (TERS) microscopy has enabled us to analyze the defect density and chirality of graphene nanoribbons at a nanoscale level, revealing the mechanisms behind the unzipping process[1].

More recently, we have utilized AFM-based mid-infrared (AFM-IR) microscopy for the chemical analysis of graphitic surfaces. By integrating chemical force microscopy (CFM) with density functional theory (DFT) calculations, we are able to visualize the nanoscale distribution of various functional groups produced by a liquid-phase photoinduced covalent modification (PICM) method[2]. Furthermore, we are applying 'nanowire technology' in AFM-IR—a nanowire-based AFM-IR—to achieve chemical analysis with the performance that greatly exceeds that of conventional AFM-IR microscopy. Our latest results suggest that the nanowire-based AFM-IR microscopy can achieve spatial resolution below 10 nm with sub-monolayer sensitivity, allowing for the visualization of edge functionality on graphene oxide. My talk will provide a comprehensive introduction to these topics.

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Comprehensive Electrochemical Imaging Analyses of Electrochemical Activities Correlated to Two-Dimensional Materials

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The application of two-dimensional (2D) materials in electrochemical devices has become an important research topic, particularly in the development of energy-related materials. In this study, a variety of 2D materials were employed to systematically investigate how their atomic structures influence electrochemical reactions, including electrocatalytic processes. Using scanning electrochemical cell microscopy (SECCM)[1], it was conducted detailed local analyses of electrochemical activity at the nanoscale.By visualizing and quantitatively evaluating electrochemical reactions at specific atomic configurations, this approach provides deeper insight into the correlation between structure and electrochemicalactivity[2,3]. Such localized assessment enables the rational design of advanced materials that can enhance electrochemical performance[4,5]. These findings contribute to the development of next-generation electrochemical energy devices, such as lithium-ion batteries and electrocatalysts.Furthermore, this research also explores the optimization of functional 2D material systems for practical electrochemical applications[6].

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Substrate-Enhanced Reactivity of Pristine Graphene in Cycloaddition Reactions

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Cycloaddition reactions such as Diels-Alder reactions are among the most powerful transformations in organic chemistry. However, for Diels-Alder reactions, the reaction barrier is too high to be feasible on pristine graphene. Conventional strategies to increase the reactivity of pristine graphene such as oxidation or defect creation often compromise its structural integrity. One strategy to activate pristine graphene without introducing defects is to leverage the supporting substrate by modulating charge density through doping or orbital hybridization and by inducing strain via lattice mismatch or surface curvature. We found that graphene supported on Ni showed enhanced reactivity in Diels–Alder reactions. Density functional theory (DFT) calculations indicate stronger HOMO–LUMO interactions and lower activation barriers for graphene supported on Ni. This Ni-promoted activation of graphene also applies to other cycloaddition reactions such as the (2+1) cycloaddition with perfluorophenyl nitrene. DFT calculations revealed charge transfer from the metal substrate to graphene, leading to stabilization of the singlet nitrene intermediate and increased functionalization. Our recent studies further demonstrate that substrate crystallinity and curvature strongly influence graphene reactivity, as seen in the (2+1) cycloaddition with perfluorophenyl nitrene with graphene grown on Cu(111). In addition, graphene supported on metal substrates behaves as an electron-rich dienophile, favoring inverse-electron-demand Diels– Alder reactions with electron-deficient dienes. For the reaction with tropone, enhanced reactivity was observed for graphene supported on Cu(111). Furthermore, the reaction pathway is catalystspecific, leading to [4+2] and [8+2] cycloaddition products in the $B(C_6F_5)_3$- and BPh_3-catalyzed reactions, respectively.

Galvanic Molecular Intercalation of van der Waals Crystals: A Platform for Hybrid Quantum Materials

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Molecular intercalation provides a promising route to hybridize the electronic properties of van der Waals (vdW) crystals with the chemical functionality of molecular species.[1] Despite this potential, the approach has been relatively underdeveloped, largely because conventional intercalation methods often degrade crystalline quality and are difficult to apply to ultrathin flakes.

Here we introduce a galvanic intercalation strategy that exploits the low reduction potentials of selected metals to drive the insertion of molecular cations under mild conditions. [2] This method enables the incorporation of a broad range of species—including organometallic complexes and chiral molecules—into both bulk crystals and few-layer flakes of vdW materials, producing more than fifty distinct organic–inorganic superlattices.

Using this platform, we directly compare the electronic transport of the vdW superconductors NbSe2 and TaS2 before and after molecular intercalation in the same few-layer devices. [3] In TaS2, the guest species effectively decouple adjacent layers, producing robust monolayer-like Ising superconductivity largely independent of molecular size. In contrast, NbSe2 retains quasithree-dimensional transport, with the 2D character emerging progressively and approaching the monolayer limit only at the largest interlayer separations.

Beyond uniform intercalation, the galvanic approach also enables the fabrication of more complex architectures. We demonstrate vertical intercalation heterostructures in which molecular species are selectively confined to one component of a vdW stack, as well as lateral heterostructures where different molecules occupy neighboring regions of the same flake. Finally, we show that these intercalated materials can be integrated into superconducting devices, [2] illustrating the potential of galvanic intercalation as a versatile platform for engineering hybrid quantum materials and exploring new collective phenomena.

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Harnessing Interfacial Phenomena in Hexagonal Boron Nitride for Hydrogen Generation and Photonic Enhancement

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Hydrogen is an important building block in global strategiestoward a future green energy system. To make this transition possible,intense scientific efforts are needed, also in the field of materials science.Hexagonal boron nitride (hBN) is a very promising candidate for such applications, as it has been demonstrated that micrometer-sized flakes are excellent barriers to molecular hydrogen.

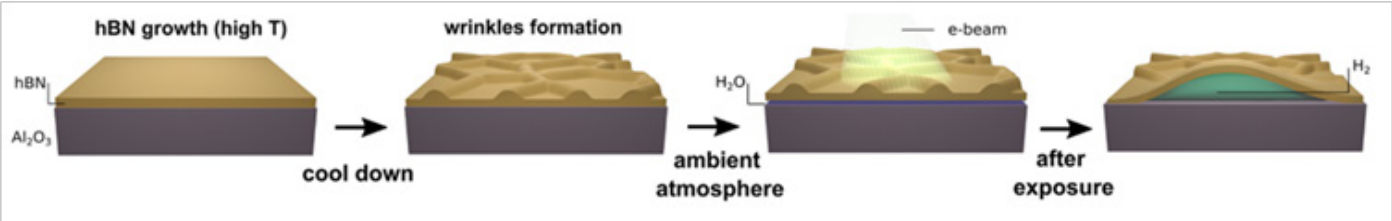

Fig. 1: Schematic illustration of the bubble formation. hBN is grown by MOVPE at temperatures above 1000 °C. After the growth the sample is cooled to room temperature, which leads to the formation of hBN wrinkles. The sample is removed from the reactor and exposed to ambient conditions. Electron beam exposure in an SEM leads to bubble formation [4].

In thiswork, we show that electron-beam-induced splitting of water creates hBNbubbles (see Fig. 1) that effectively store molecular hydrogen for weeks[1]. The hBN layers used in this study were grown epitaxially on two-inch sapphire substrates using metalorganic vapor-phase epitaxy (MOVPE). Raman spectroscopy proves the presence of molecular hydrogen and experiments withheavy water provide evidence that hydrogen generation istriggered by the radiolysis of interfacial water.We further show that the curved shape of the bubbles can be used for photonic enhancement single-photon emitters present in hBN [2], using a lithography-based method that enables the deterministic creation of bubbles at predefined positions.

A different type of interference-related photonic enhancement can be achieved by exploiting another interfacial chemical process. We have demonstrated that graphene on germanium can be directly underetched using light and water in a photocorrosion process [3]. Recently, we extended this approach to hBN, leading to membranes that exhibit polarization-dependent Raman signal enhancement [4].

Our findings demonstrate that interfacial processes involving hBN are highly promising for a wide range of applications, including hydrogen generation and optical signal enhancement.

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Chemical Interface Engineering of Transition Metal Dichalcogenide Devices

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Transition metal dichalcogenides (TMDCs) are a class of two-dimensional (2D) materials that have attracted significant attention for applications in advanced semiconductor and optoelectronic devices. The confined nature of their 2D crystalline lattice is particularly appealing due to the high electron and hole mobilities, which are advantageous for electronic devices, as well as the large exciton binding energy, which is beneficial for luminescent applications. However, practical device applications inevitably require interfaces with other materials; therefore, interface properties are a critical issue in TMDC-based devices. In this talk, I will present recent research focusing on the control of interface properties in TMDCs.

The first topic is the suppression of surface Fermi level pinning (FLP) in WSe2 devices. FLP fixes the energy level at the metal–semiconductor interface in TMDC devices and thus poses a significant challenge for improving metal contacts. To date, inserting a thin interfacial layer between metals and TMDCs has been reported [1], typically using mechanical transfer processes, which require individual sample preparation. In this work, we develop a method to introduce an interfacial layer using a solution-based chemical technique [2]. Specifically, we use poly-L-lysine (PLL) as an insertion layer beneath the metal contacts in WSe_2 devices. This approach suppresses FLP, as confirmed by temperature-dependent transport measurements. I will also introduce our recent work on alternative insertion layers that provide further improvements compared to PLL.

The second topic involves introducing a molecular treated interfacial layer beneath the metal contacts to create trap states that changes electron injection barrier into the channel region. By inserting this layer, we can generate pronounced hysteresis behavior even under drain bias conditions in MoS2 devices. This hysteresis enables applications in reservoir computing, and we have successfully demonstrated electrocardiogram signal monitoring using this approach. Further details will be discussed during the presentation.

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Surface- and Interface-Trap-Driven Neuromorphic Photoresponse in 2D Tin Dichalcogenides

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Two-dimensional tin-based dichalcogenides have attracted considerable interest as promising platforms for integrating conventional nanoelectronics with neuromorphic computing technologies. In this presentation, we provide a comparative investigation of SnS_2, $SnSe_2$, and the ternary SnSSe alloy, highlighting how differences in defect landscapes and interface characteristics give rise to a wide range of functional behaviors.

Tin disulfide (SnS_2), an n-type semiconductor exhibiting high on/off ratios up to 10^8, shows outstanding capabilities in memory operation and high-gain photodetection. Remarkably, its memory window expands with temperature, remaining robust up to 400 K, and it delivers a large synaptic weight modulation ($\Delta W/W \approx 3000$), mainly attributed to interface trap states and oxygen-assisted photogating effects under ambient conditions.

Tin diselenide ($SnSe_2$), also n-type and governed by trap-related phenomena, generally presents higher carrier mobility, exceeding 50 $cm^2/V \bullet s$. Its neuromorphic response is dominated by gate-controlled persistent photocurrent, and in contrast to SnS_2, its mobility follows a bell-shaped dependence on temperature, reaching a maximum around 220 K. $SnSe_2$ successfully replicates synaptic functionalities such as Paired-Pulse Facilitation (PPF), demonstrating high reproducibility enabled by reversible memory modulation.

The ternary SnSSe alloy combines key advantages of both binary compounds. A distinctive feature is the coexistence of positive (PPC) and negative photoconductivity (NPC): the positive component arises from trap-mediated processes similar to those in the binary materials, whereas the broadband NPC (780–1000 nm) originates from a photogating.

Overall, intrinsic and interfacial trap states, often regarded as detrimental, play a central functional role in enabling synaptic plasticity across all three systems. Progressing from binary to ternary compositions offers a pathway to finely tailor device performance, balancing high-sensitivity visible photodetection with broadband, gate-tunable neuromorphic memory.

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Day-2

NanoSeries2026 Technical Workshop: NSAW5

Advanced Materials, Catalysts and Industrial-Scale Electrolysis

Efficiency-Driven AEM Electrolysis: From Single-Cell Insight to Stack-Level Engineering for Green Hydrogen

Sebastiano Bellan

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The large-scale deployment of green hydrogen depends not only on advances in catalysts and membranes, but also on the ability to engineer electrolyser stacks that preserve performance under realistic operating conditions. In this perspective, Antares Electrolysis highlights electrochemical efficiency as a key driver of hydrogen cost competitiveness, while arguing that stack engineering is equally essential for translating laboratory progress into industrial value.

AEM electrolysis is a promising platform due to its potential for low-cost materials, reduced reliance on critical raw materials, and compatibility with scalable manufacturing. However, single-cell studies alone are not sufficient to guide industrial development. Critical phenomena such as fluid distribution, compression uniformity, contact resistance, thermal gradients, sealing, crossover, and performance dispersion emerge or become amplified at stack level and strongly affect efficiency, durability, and manufacturability.

We therefore propose a system-oriented framework in which single-cell testing is used for rapid screening and physical understanding, but stack engineering becomes the decisive step for validation, scale-up, and technology derisking. The main message is that competitive green hydrogen will require not only better materials, but also a deeper understanding of stack-level effects and their integration into electrolyser design from the earliest development stages.

From Discovery to Industry: Scalable PGM-free Electrocatalysts for Green Hydrogen Production

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The development of efficient and scalable catalysts for water electrolysis requires integrated strategies spanning materials discovery, synthesis, and electrode engineering. Here, we present a pathway bridging rapid screening with scalable manufacturing toward near-industrial performance.

A non-conventional approach combining wet chemistry and thermal treatment enabled fast exploration of HER-active compositions, identifying promising PGM-free catalysts with reduced overpotentials. To overcome scalability limitations, the process was also validated using electrodeposition, allowing direct catalyst growth on conductive substrates with improved control over morphology, loading, and interfaces. Optimized cathodes achieved <1.8 V at 1 A•cm^{-2} in PGM-free single-cell operation, and also in short stacks, approaching industrial targets.[1]

Moreover, for industrial scalability, we developed a synthetic route for the production of benchmark NiFe-LDH anodes.[2] Indeed, we introduce a room-temperature, atmospheric-pressure synthesis route for NiFe-LDHs via homogeneous alkalinization. Using chloride nucleophilic attack on an epoxide ring, we obtain low-dimensional, highly defective NiFe-LDHs featuring cation clustering. Spectroscopic analyses (XANES, EXAFS, SAXS) combined with ab initio calculations reveal the pivotal role of Fe clustering in optimizing catalytic performance.[3] This energy-efficient, scalable method offers a cost-effective alternative to noble metal catalysts, advancing the industrial deployment of LDH-based materials in water splitting, energy storage, sensing, and environmental remediation.

In overall, this work shows a unified strategy linking catalyst discovery to scalable PGM-free electrode fabrication.

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ECO-RED: Bridging Research and Industry in CO_2 Electroreduction to CO

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The electrochemical reduction of CO_2 is emerging as a key enabler for decarbonizing hard-to-abate sectors, particularly the steel industry, by enabling on-site production of carbon monoxide as a drop-in substitute for fossil-derived syngas. Within this context, ECO-RED, a startup initiative focused on industrial CO_2 valorization, is developing scalable electrochemical solutions designed for integration into existing steelmaking processes.

This work presents the scale-up of a CO_2-to-CO electrochemical platform from laboratory-scale cells (5 cm^2) to industrially relevant membrane electrode assembly (MEA) configurations exceeding 250 cm^2. Moving beyond proof-of-concept, the objective is to deliver a technology compatible with continuous operation, high throughput, and cost-efficient performance under industrial conditions.

A key differentiator of the ECO-RED approach lies in the development of low-cost, scalable Cu-Sb bimetallic catalysts as an alternative to conventional silver-based systems. Catalyst formulation and loading strategies were engineered to operate at industrially relevant current densities, achieving Faradaic efficiencies above 95% for CO production. High catalyst loadings combined with an anion-exchange binder proved critical to ensuring both selectivity and operational robustness.

In parallel, the electrochemical system was optimized at the reactor level to minimize energy consumption and improve process efficiency. Membrane selection, electrolyte concentration, and counter electrode materials were systematically engineered to reduce overall cell voltage and enable stable performance under continuous operation. This integrated design approach delivers a scalable and cost-efficient solution aligned with industrial requirements.

The technology demonstrates a clear advancement toward TRL 4-5, marking the transition from laboratory validation to pre-industrial development. The next phase targets pilot-scale deployment (TRL 6-7) and long-term operation beyond 500 hours, with a focus on integration into steel production environments. ECO-RED aims to provide a robust, efficient, and economically viable platform to support the decarbonization of the steel sector through circular carbon utilization.

From Nanoparticles to Gigawatt Electrolysis: Scalable Catalyst and Electrode Engineering for Next-Generation Hydrogen Technologies

Farnaz Sotoodeh

C2CAT, The Netherlands

The large-scale deployment of electrolysis technologies requires not only high-performance catalysts, but also scalable and reproducible electrode manufacturing approaches. At C2CAT, we develop advanced nanoparticle catalysts, tailored catalyst inks, and structured electrode coatings for PEM and emerging AEM electrolysis systems.

This presentation will highlight recent progress in catalyst synthesis, particle size and loading control, and the fabrication of highly uniform membrane electrode assemblies (MEAs). Emphasis will be placed on bridging nanomaterials engineering with industrially relevant coating and manufacturing processes to enable efficient, scalable, and cost-effective hydrogen production and electrochemical conversion technologies.

Advanced Materials and Experimental Platform for Hydrogen-Systems

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ENEA contributes to the development of hydrogen technologies through activities focused on the selection and assessment of advanced materials, including nanostructured systems relevant for catalytic processes and industrial-scale electrolysis. The aim is to enable sustainable and scalable solutions that support the transition toward low-impact hydrogen production and use.

These activities include collaboration with industrial partners and national initiatives to strengthen the emerging Italian hydrogen supply chain, also through the development of experimental platforms for the validation of innovative storage and conversion systems. Within this framework, ENEA acts as a bridge between applied research and industrial deployment, contributing to the maturation of materials and processes oriented toward sustainability.

Decarbonized Low-cost Hydrogen via Catalytic Methane Splitting: Advances from Lab to Fab

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After 4.5 billion years of natural evolution and optimization, nature selected water splitting through photosynthesis as the pathway for hydrogen production. However, rather than storing or directly using hydrogen, biological systems evolved to transform it into energy-carrying biomolecules and structural building blocks. In the transition toward a sustainable energy economy, an important challenge remains: how can decarbonized and low-cost hydrogen be produced locally and at scale?

Methanesplitting (MS), also known as methane decomposition, or methane cracking, reaction has emerged as a promising pathwayfor clean hydrogen production [1]:

$$CH4 \square C\ (s) + 2H2, \qquad \Delta H^0 = 75.3\ kJ/mol$$

When using biomethane as a feedstockand green electricity, the resulting hydrogen is considered CO_2 negative. However, the more mature MS technologies are energy-intensive and operationally complex, typically requiring temperaturesin the range of 1200-1300°C. Intermediate temperature catalytic methane splitting (IT-CMS) offers an attractive alternative by lowering the energy barrier while maintaining high methane conversion efficiencies [2]. Simultaneously, the process generatesrenewable highly graphitic carbon nanofilaments with high market value, and CO_2 emission permissions, further improving the economic viability of the technology. To accelerate the industrial deployment of this technology, the spin-off company HyCarb was established in 2024, focusing on the rapid development and commercialization of IT-CMS systems.This presentation will discuss recent advances in catalyst activation, reactor engineering, process upscaling, and pilot-scale implementation, highlighting the key challenges and opportunities toward the commercialization of sustainable hydrogen production via catalytic methane splitting.

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Advancing Scalable CO_2 Electrolysis from Catalyst Design to Industrially Relevant Reactor Architectures

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The transition toward a climate-neutral chemical and energy sector requires technologies that can convert unavoidable CO_2 emissions into valuable fuels and feedstocks using renewable electricity. Electrochemical CO_2 reduction is one of the most promising routes to close the carbon cycle, yet industrial deployment remains limited by electrode instability, mass-transport constraints, carbonate accumulation, and the difficulty of transferring laboratory performance to scalable architectures.

In our group, we are developing a modular, low-temperature CO_2 electrolysis platform for decentralized carbon valorization, targeting CO_2-rich streams from biogas upgrading. The approach integrates CRM-lean Cu-based catalytic layers, scalable electrode fabrication, electrolyte optimization, membrane-electrode engineering, and reactor design. The platform is tunable, directing conversion toward syngas and formate as primary C1 products, and — through tandem CO_2-to-CO and CO/CO_2-to-C2+ pathways — toward ethylene and ethanol.[1-4]

Spray-coated catalytic layers are optimized for uniformity, triple-phase boundary formation, and robustness. Ionomer chemistry and membrane selection are investigated to mitigate flooding, carbonate accumulation, and reactant crossover.

At laboratory scale (active areas of 5, 25, and 120 cm^2), our Cu-based catalytic system has been operated at current densities up to 500 mA cm^{-2}. As regards C1 products, we achieved up to 80% Faradaic efficiency toward syngas and ~20% toward formate, while for C_2^+ products we achieved>20% C-conversion in the tandem system, confirming our ability to operate in industrially relevant regimes while retaining product tunability. These results, at TRL 4, underpin the ongoing scale-up toward a 500 cm^2 device.

COMSOL-based Multiphysics modeling serves as a digital twin to identify kinetic, transport, and pressure-management bottlenecks. Post-operation analyses (SEM, TEM, XRD, ICP) inform degradation mechanisms. Combined with techno-economic assessment,[5]our work aims to establish a robust pathway toward scalable CO_2electrolyzers for the circular carbon economy.

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Posters

Synthesis of Carbon Nanotubes by CVD Using Bio-Derived Shochu as a Carbon Source: Effects of Catalyst Type and Growth Temperature

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Carbon nanotubes (CNTs) have been intensively studied since their discovery due to their exceptional mechanical strength, chemical stability, and unique electrical properties, which are rarely observed in other materials [1]. Owing to these outstanding characteristics, CNTs are expected to play a significant role in a wide range of applications, including semiconductor devices, energy storage systems, composite materials, and sensing technologies. However, despite extensive research efforts, a standardized and fully optimized synthesis method has not yet been established. In particular, the selection of appropriate catalysts and carbon sources remains a critical issue for achieving controlled growth and desirable morphology.

In this study, we investigated the synthesis of CNTs using a chemical vapor deposition (CVD) method in which shochu distilled from sweet potatoes was employed as an unconventional and renewable carbon source. The use of bio-derived alcohol as a precursor offers potential advantages in terms of sustainability, cost-effectiveness, and environmental impact. We systematically examined the influence of catalyst type and growth temperature on the morphology and structural characteristics of the resulting CNTs. Transition metal catalysts with different compositions were prepared, and the growth process was conducted under controlled thermal conditions to evaluate their effects on nanotube formation.

The synthesized samples were analyzed to compare differences in diameter, alignment, density, and overall structural uniformity. The experimental results reveal that both catalyst selection and growth temperature play decisive roles in determining CNT morphology. This study demonstrates the feasibility of employing a bio-based carbon source for CNT synthesis and provides insights into optimizing growth conditions for tailored nanostructure fabrication. The findings contribute to the development of more sustainable and controllable CNT production methods for advanced technological applications.

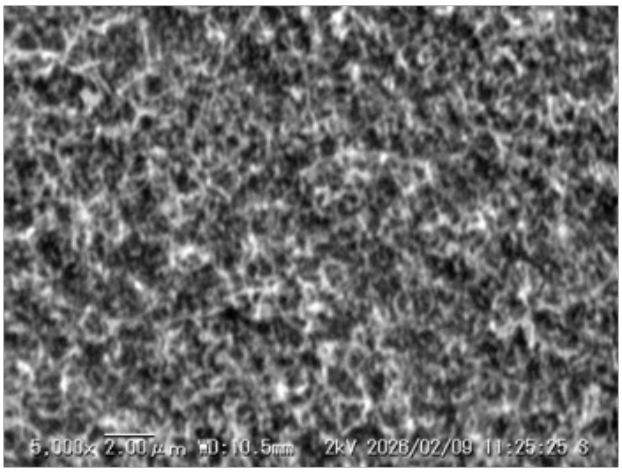

Figure: SEM images of CNTs grown by CVD using bio-derived shochu as a carbon source

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Defect-Topology Control of Anisotropic Lattice Flexibility for High-Performance Fluoride-Ion Electrolytes

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Fluoride-ion conductors show promise for next-generation solid-state ionics,1 but achieving high roomtemperature conductivity and strong thermal stability remains a significant challenge, especially in rareearth fluoride systems,2 where vacancy formation, clustering, and microstructure intricately influence ion transport. Here, we show that mechanochemical synthesis followed by moderate hot pressing within the effective temperature range of 200–300 °C yields a tysonite-type Ca-doped rare-earth fluoride with high room-temperature conductivity. Within the low-temperature processing route, vacancy topology, c-axis lattice expansion, and grain-boundary structure are collectively optimized, resulting in a 5-orderof-magnitude increase in room temperature (RT) fluoride-ion conductivity to approximately 10−4 S cm−1, while also lowering the activation energy to approximately 0.4 eV. Thermogravimetric analysis, combined with time-resolved Electrochemical Impedance Spectroscopy (EIS) data, indicates that fluctuations in conductivity can be attributed to changes in defect chemistry, particularly the formation of vacancies at the fluorine site. Hot pressing at 400 °C results in vacancy clustering, c-axis collapse, the formation of intergranular glassy phases, and a sharp decrease in conductivity to approximately 10−9 S cm−1, highlighting a trade-off among processing, structure, and ion transport. Notably, pellets pressed at 300 °C show slow conductivity relaxation over approximately 30 days under ambient conditions, indicating metastable defect dynamics and long-term stabilization. We demonstrate that near singlecrystal ion conductivity in polycrystalline tysonite fluorides can be attained not via densification or equilibrium defect optimization, but by kinetically stabilizing an anisotropic defect network through low-temperature thermomechanical processing.

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Deciphering Amino-Functionalization of Graphene Oxide through Correlated NMR, XPS, and DFT

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Over the past two decades, the discovery of graphene has stimulated extensive research on two-dimensional carbon materials. However, the limited processability and low chemical reactivity of pristine graphene hinder its direct exploitation [1]. Conversely, graphene oxide (GO) is a non-stoichiometric carbon-based nanomaterial consisting of a graphitic sheet decorated with a plethora of oxygen-based functional groups (OFGs). Due to its intrinsic chemical complexity, the execution of selective and controllable functionalization strategies remains challenging, as its high reactivity often leads to competing side reactions, partial deoxygenation, and non-covalent interactions [2]. Consequently, reliably distinguishing between covalent grafting, non-covalent interactions, and concurrent structural rearrangements remains an open challenge in GO chemistry.

Epoxide groups, among the most abundant OFGs located on the basal plane, represent attractive reactive sites for nucleophilic ring-opening reactions [3]. In this work, three structurally distinct amines, N-Boc-ethylenediamine, γ-aminobutyric acid, and L-lysine, were employed under mild aqueous conditions to produce amino-functionalized graphene oxide.Beyond demonstrating functionalization, our goal was to elucidate the selectivity and structural evolution of the substrate through a comprehensive multi-technique approach.

A combination of advanced solid-state 13C NMR pulse sequences (MultiCP and UDEFT) and 1H NMR studies, high-resolution X-ray photoelectron spectroscopy, and density functional theory calculations was implemented. This correlative strategy enables a critical reassessment of nucleophilic substitution on graphene oxide, allowing us to keep track of covalent and non-covalent functionalization and concomitant deoxygenation. Comparative quantitative correlations between spectroscopic features provide a robust transferable framework for assessing functionalization efficiency and structural variations.

Our results reveal that nucleophilic attack on epoxides leads to covalentfunctionalization, electrostatic interactions, and a concurrent redistribution of oxygen functionalities through partial deoxygenation of GO. As a prospective application, the amino-functionalized GO will be incorporated into chitosan-based nanocomposites for proton exchange membranes, providing a pathway to correlate functionalization with electrochemical performance [4].

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Colloidal Noble Metal Nanoparticles as Tunable Nanoelectrodes

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We demonstrate that colloidal noble metal nanoparticles behave as tunable nanoelectrodes whose surface potential can be controlled through synthesis parameters and solution chemistry, providing a mechanistic framework for optimizing SERS-active substrates

Metal nanoparticles were synthesized via citrate reduction using the Turkevich and Lee-Meisel protocols for gold and silver, respectively. By systematically lowering the citrate concentration for AuNPs and the synthesis temperature for AgNPs, incomplete reduction was promoted, leading to the persistence of surface-associated Au^{+} and Ag^{+} species. X-ray photoelectron spectroscopy (XPS) provided direct evidence for partially oxidized silver atoms at the nanoparticle surface. Consistently, SERS detection of citrate and chloride in both colloidal solutions indicated adsorption of these anionic species, driven by the positive electrochemical surface potential of the as-prepared nanoparticles

We further show that even fully reduced nanoparticles (synthesized with excess reducing agent according to the original protocols) can undergo a positive shift in surface potential upon addition of Ca^{2+}. We propose a model in which oxidative processes arise from proton (H^{+}) accumulation at the nanoparticle interface combined with electron depletion mediated by dissolved oxygen. The addition of Ca^{2+} increases ionic strength, shortens the Debye length, and accelerates the decay of the electric field within the double layer. Consequently, ion transport becomes diffusion-dominated rather than migration-controlled. Because H^{+} diffuses more rapidly than OH^{-}, protons preferentially accumulate at the nanoparticle interface, generating localized surface acidification.

In the presence of dissolved O_2, this acidified nanoenvironment promotes the formation of surface M^{+} sites through electron depletion, inducing a Fermi level downshift and a positive shift of the surface electrochemical potential. This enhances adsorption of anionic species and facilitates their SERS activation. Argon purging experiments confirmed the critical role of oxygen, as removal of dissolved O_2 significantly attenuated the citrate SERS signal.

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First-Principles Study of Dopant Interactions With I3 Basal Stacking Faults in Hex-Si

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Group IV semiconductors in their hexagonal phase have attracted significant attention due to their distinctive electronic and optical properties, which differ significantly from their cubic counterparts.1 Notably, in 2020 light emission from hexagonal-diamond SiGe alloys has been clearly demonstrated.1 This has driven advancements in growth techniques that enable fabrication of large, stable hexagonal samples. These materials are characterized by a prominent structural feature known as I3-basal stacking faults (BSFs),2 which influence carrier dynamics and defect interactions. The effects of point defects on the electronic properties of these materials has been studied extensively,3–5 however, the interactions between these defects and extended structures such as BSFs remain largely unexplored. This work focuses on the behavior of acceptor and donor dopants in hexagonal silicon with BSFs by employing first-principles calculations based on density functional theory (DFT), using the SIESTA code.6 From the results obtained, acceptor dopants tend to migrate away from the stacking fault, as their interaction with the planar defect reduces their stability,6 while donor dopants reflect minimal migration tendency, indicating less sensitivity to local strain and wave function distortions. In both cases, dopant displacement depends on how well the impurity fits within the lattice and the nature of the electronic states involved.6

These findings bring forth fundamental insights into the factors governing dopant distribution near extended defects, thus, offering valuable implications for the design and optimization of electronic devices.

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Porous Sol–Gel TiO_2 Films Doped with Noble Metal Nanoparticles: Tailored Properties for High-Performance Sensing

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Titanium dioxide (TiO_2) has attracted significant attention and has emerged as one of the most widely used materials in photocatalytic applications. In addition, TiO_2 exhibits a high refractive index, which can be tailored through compositional modification and the formation of nanocomposites—features that are particularly attractive for optical coating applications. Doping TiO_2 with noble metal nanoparticles represents an effective strategy for tuning its functional properties and adapting it for a variety of applications.

In this study, TiO_2 thin films were prepared by spin coating using a titanium sol derived from titanium(IV) isopropoxide as a precursor, ethanol as a solvent, and nitric acid as a catalyst. Commercially available Au and Ag nanoparticles with diameters ranging from 5 to 20 nm were employed as dopants. To introduce porosity and promote uniform nanoparticle distribution within the oxide matrix, a commercially available triblock copolymer, Pluronic (PE9400), was added to the nanoparticle colloidal solutions at a concentration of 15 wt%. After deposition, the films were annealed using two different protocols: (i) a gradual temperature increase from 20 to 320°C followed by a 30 min hold at 320°C, and (ii) a stepwise temperature increase with intermediate holds at 120, 220, and final hold at 320°C.

The morphology and structure of the films were investigated by transmission electron microscopy (TEM) and selected area electron diffraction (SAED). Optical parameters and film thicknesses were determined by nonlinear curve fitting of the reflectance spectra. The sensing performance of the films was evaluated using quartz crystal microbalance (QCM) measurements and optical reflectance spectroscopy, performed before and during exposure to acetone vapor.The results demonstrate that the films are amorphous and that nanoparticle doping does not significantly affect film porosity or refractive index. Nevertheless, the incorporation of noble metal nanoparticles leads to a notable enhancement of the sensing performance.

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Effect of Grafting Density and Side-Chain Length on the Hydration Properties of Polymer Brush Films

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Humidity monitoring plays an essential role in diverse fields like agriculture,meteorology, food industry, pharmaceutical industry. It is a novel strategy that has gained significant attention in the human respiratory monitoring. Nowadays, a great demand has been paid to exploiting the developmentof high-performance, low-costand easy-to-use humidity monitoringequipment.

Thin films of poly(vinyl alcohol) derivatives comprising grafted poly(N,N-dimethylacrylamide) chains of varied length and graft density were deposited by spin-coating onto quartz resonators. A combined gravimetric and optical approach was applied to investigate the impact of themacromolecular architecture on the humidity sensing performance.Hydration levels under high humidity conditions were studied using a quartz crystal microbalance method. The films were continuously exposed to relative humidity (RH) values in the range [5% - 95%] at constant temperature t = 20°C. The films demonstrated a behavior suggesting slightly viscoelastic properties. To evaluatethe adsorbed water mass, the model for a single viscoelastic film in air was applied. The water content at RH = 95%, accumulated in the copolymer with the more closely grafted and shorter brushes was estimated as 23.9%, while the more loosely grafted but longer PDMA brushes for the other sample led to a higher water content of 30.9% stored into the polymer matrix.The higher absorption capacity was attributed to the greater density due to higher number of polymer chains per unit volume. The same high density restricted the film's ability to swell significantly, resulting in smaller changes in thickness compared to the other copolymer,as has been optically demonstrated.

The obtained results proved the crucial role of the macromolecular brush designon the sensing characteristics of polymer brush films. Tailoring graft density and side-chain length provides an effective strategy for engineering smart materials with tunable characteristics highlighting a potential for use in simple and high-performance humidity sensors.

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Structure–Property Relationships in Architecturally Engineered PVA-g-PDMA Thin Films for Optical Humidity Sensing

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The development of highly sensitive, miniaturized, and optically readable humidity sensors remains a key challenge in advanced environmental monitoring technologies. Polymer-based thin films are particularly attractive due to their tunable macromolecular design, enabling precise control over swelling and optical response. In this work, we investigate how the architecture of double hydrophilic copolymers - poly(vinyl alcohol) (PVA) backbones grafted with poly(N,N-dimethylacrylamide) (PDMA) side chains with different grafting density and length -affects the optical and humidity sensing performance of nanosized thin films.

Thin films were deposited by spin-coating onto silicon substrates and thermally stabilized. Optical constants (refractive index n, extinction coefficient k) and thickness were calculated from reflectance spectra using nonlinear curve fitting. Sensitivity and accuracy/resolution were determined.

Systematic optical measurements in the 5–95% relative humidity (RH) range revealed pronounced architecture-dependent behavior. The copolymer with higher grafting density and shorter PDMA side chains exhibited swelling exceeding 100%, a broad dynamic sensing range (5–95% RH), lower hysteresis (13%), and distinct colorimetric response. In contrast, the copolymer with longer, more loosely grafted chains showed reduced thickness variation (~49%) and a narrower effective sensing range. Humidity-induced changes in refractive index and thickness were fully reversible for both systems.

The results demonstrate that macromolecular brush architecture critically governs optical modulation, swelling amplitude, and sensing characteristics of polymer thin films. Tailoring graft density and side-chain length provides an effective strategy for engineering high-performance optical humidity sensors with tunable dynamic range and sensitivity, highlighting the potential of architecturally controlled copolymers for advanced responsive coating technologies.

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Creating Chirality in Twisted and Screw-Dislocated MX2 Transition Metal Dichalcogenides Through Screw Dislocation by Chemical Vapor Transport

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Unprecedented attention in research towards two-dimensional (2D) materials has been gradually garnered since 2004. To achieve screwed structures, the dislocation-driven growth needs defects that provide self-perpetuating growth steps and, then allow anisotropic growth. Controlling the crystal growth of twisted and screwed nanostructures is central for exploiting their structure-related properties. However, bottom-up syntheses of 2D transition metal dichalcogenides usually contain 'trial and error' approaches [1-6].

Here, we propose the rational synthesis planning and realizing for twisted $MoSe_2$ and screw dislocated chiral WSe_2 by short-time chemical vapor transport. For that purpose, key parameters were modelled based on thermodynamic datasets. Crystal growth by in-situ CVT under addition of $MoCl_5$ succeeds for nano-$MoSe_2$from 710 °C → 685 °C with a dwell time of 30 min on SiO_2@Al_1O_3(0001) substrates. A twist angle of 20° with respect to the [010] zone axis was observed. Screw dislocated triangular 3R-$MoSe_2$ with individual step heightsbetween 0.9 nm and 2.9 nm on SiO_2@Si(100) was confirmed by electron backscatter diffraction and atomic force microscopy. Chiral WSe_2 was grown under addition of $SeCl_4$ for right-handed spirals from 850 °C → 800 °C with a dwell time of 60 min, while left-handed spirals are obtainedfrom 915 °C → 860 °C. Chirality of screwed WSe_2 was unprecedentedly investigated by circular-polarized Raman Spectroscopy and showed an intensity increase of the E12gmode of 29 % and 15 % for right and left-handed spirals, respectively. Pyramid-like WSe_2 exhibits step heights of 10 nm. Electron backscatter diffraction patterns reveal a convex curvature with the curvature radii determined as R_x = (270 ± 32) µm and R_y = (141 ± 9) µm, respectively.

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Computational Design of Phthalocyanine-Based 2D Metal-Organic Frameworks for Selective Electrochemical CO_2 Reduction to C_2 Products

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CO_2 reduction towards the formation of solar fuels is an important due to its ability to turn a greenhouse gas into useful chemicals. At the same time, it is still difficult to develop catalysts that are active, selective, and stable. In my PhD research, I work on 2D metal-organic frameworks (MOFs) consisting of a phthalocyanine core and metal linker for CO_2 reduction towards the formation of C2 products. My main focus is on the linkers' effect on the selectivity and kinetic of the reaction. I am especially interested in how these structural factors change the electronic properties of the material, the binding of reaction intermediates, and as a result, the activity and selectivity of the catalyst.

In my work, I use materials design, computational electrocatalysis, and atomistic modeling to better understand the relation between structure and catalytic behavior in 2D systems. By retrieving to the recently developed Grand Canonical Potential Kinetic (GCP-K) method, my aim is to find design rules for more efficient and stable catalysts for electrochemical CO_2 conversion. I would like to attend the Summer School on Single-Atom Catalysis because its topics are closely related to my research. In particular, it will help me better understand the role of well-defined active sites and coordination environments in catalytic performance. It would also help me see my work on 2D MOF-based materials from a broader perspective in the field of single-site and single-atom catalysis.

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Elucidating the Role of Surfactant Structural Parameters in Au Nanoparticle Morphology

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The use of cationic quaternary ammonium halide as a surfactant is popular in aqueous seed-mediated growth methods of noble metal nanoparticles (NPs). Despite the effective shape control of NPs that can be achieved by modifying the surfactant chemistry, these structural parameters have been insufficiently probed. The number of cationic quaternary ammonium halide surfactants explored for the synthesis of Au NPs have been limited primarily to cetyltrimethylammonium bromide (CTAB) and cetyltrimethylammonium chloride (CTAC). In this study, we investigate the effect of structural parameters, including the headgroup, chain length, and counter-anion of the quaternary ammonium halides, on the resultant Au NPs formed using seed-mediated synthesis. By employing pentatwinned Au NPs as the starting seeds, we observe that (i) increasing the bulkiness of the surfactant headgroup results in the formation of Au NPs with fewer stellations and more shape polydispersity, (ii) surfactant chain length affects the dimension of Au NPs, and (iii) the counter-anion associated with the surfactant affects the Au NPs' final morphology. These structural parameters provide a practical handle to tune the shape, size, and polydispersity of the final Au NPs.

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Controlled Vertical Alignment of Functionalized CNT Networks in CNT/ SU8 Composite Films via Atmospheric Pressure Plasma

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Carbon nanotube(CNT)-based thin-film composites constitute an emerging class of materials with considerable potential for advanced technological applications[1]. Within this framework, CNT-based thin films comprising vertically aligned nanotubes exhibit superior structural, electrical, and mechanical properties compared with films containing randomly oriented CNTs[2]. Nevertheless, the reliable fabrication of vertically aligned CNT (VACNT) films remains a critical challenge for the development of high-performance device technologies.

In this work, we present atmospheric pressure plasma (APP) as a novel, in-situ method for fabricatingVACNT/ SU8 composites. The use of APP for CNT alignment not only enables controlled orientation of CNTs within the polymer matrix, but also promotes crosslinking throughout the matrix.

Because in-situ nanostructure alignment requires the deposited materials to retain sufficient mobility for translation and rotation, and pristine CNTs are known to exhibit poor dispersibility in most solvents[3], we employed recently developed p-methoxyphenyl-functionalized multi-walled CNT (MWCNT-PhOMe) as nanofillers [4].

MWCNT-PhOMe at different loadings were dispersed in SU8 photoresist by ultrasonic agitation and subsequently deposited onto substrates via drop casting to form thin-film composites. APP in a corona discharge configuration was then applied to induce vertical alignment of the MWCNT-PhOMe within the uncured composite film. Concurrently, polymerization of the SU8 matrix was achieved by thermal curing of the substrate.

Scanning electron microscopy(SEM) revealed the vertical alignment of the MWCNT-PhOMe within the SU8 matrix after plasma treatment. Nanoindentation measurements revealed an increase in the elastic modulus with plasma exposure, consistent with enhanced nanostructure alignment and matrix crosslinking. Impedance spectroscopy showed an increase in the resistive and capacitive impedance by several orders of magnitude, corroborating the preferential orientation of the nanotubes.

Overall, these findings demonstrate APP as an effective new strategy for the in-situ orientation of carbon-based nanostructures in liquid polymer matrices, thereby providing a promising technique for achieving controlled alignment in nanocomposite films.

Keywords: CNT, atmospheric pressure plasma, vertical alignment, SU-8

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Shaping Light, Trapping Pollutants: Hybrid Monolithic Photocatalysts

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Persistent emerging pollutants, including herbicides, antibiotics, and perfluorinated compounds, are increasingly detected at trace levels inenvironments. Their exceptional chemical stability renders many of these contaminants resistant to conventional water treatments, posing significant risks to human health and ecosystems. Photocatalysis has emerged as a promising strategy for their remediation; however, its practical implementation is limited by the use of powdered semiconductors, which require post-treatment recovery, risk particulate release, and suffer from light scattering that complicates process control.Thin-film photocatalysts offer a potential solution by eliminating the need for catalyst recovery, minimizing environmental dispersion, and suppressing light scattering. Nevertheless, their reduced surface area relative to powders limits pollutant–catalyst interactions and constrains overall photocatalytic performance.

To address these limitations, we developed hybrid polymer–inorganic monolithic films engineered to simultaneously concentrate photons and pollutants within the catalytic layer. Multiple complementary strategies were applied: in addition to conventional approaches, such as energy band-gap tuning and the use of plasmonic absorbers, we demonstrate that nanostructuring the catalyst into dielectric lattices increases the local density of photonic states and reduces photon group velocity in selected spectral regions, thereby enhancing light absorption and accelerating reaction kinetics compared with unstructured films. Furthermore, highly adsorbing polymer networks and porous inorganic matrices were incorporated with both inorganic and organic photocatalysts to facilitate selective pollutant uptake and degradation.

Overall, these hybrid monolithic films provide an effective and scalable platform for enhancing photocatalytic performance, advancing the development of practical and efficient photocatalytic water treatment technologies.

Keywords:Photocatalysis, plasmonic, adsorbers, light management, pollution.

High-Density Nanophotonic Platform for Spectrometer-Free Mid-Infrared Biomolecular Detection

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Non-invasive detection of biomolecular signatures is essential for early health monitoring and rapid diagnostics. However, many conventional sensing approaches rely on bulky spectroscopic instruments or invasive sampling procedures, which limit their applicability in continuous and wearable sensing platforms. Developing compact spectrometer-free sensing architectures capable of extracting rich spectral information therefore remains an important challenge [1,2].

Here, we present a spectrometer-free mid-infrared (MIR) sensing platform based on bound states in the continuum (BIC) supporting high-Q resonances using asymmetric elliptical meta-atoms [3]. The structure was designed and experimentally realized using a gradient-scale fabrication approach that enables a high density of resonant modes within a compact footprint. The fabricated device exhibits 400 resonant peaks within the 6–8 µm spectral range, with a maximum Q-factor of 67.4 at 6.3 µm, confirming the stable formation of high-Q BIC modes and the capability to generate dense spectral fingerprints within a limited wavelength range.Accurate molecular identification in the MIR requires a high density of resonant modes within a limited spectral window. In conventional passive BIC systems, however, increasing the number of resonant modes typically necessitates enlarging the spatial footprint of the device. To overcome this limitation, we further investigate an active BIC architecture incorporating the electrically tunable conducting polymer PEDOT:PSS. Electromagnetic simulations indicate that modulation of the optical constants of PEDOT:PSS enables dynamic tuning of the resonance wavelength within a single BIC structure, allowing multiple spectral responses to be accessed without increasing the device size. This strategy provides a pathway toward compact spectrometer-free MIR sensing platforms for non-invasive biomolecular detection.

Keywords: Myocardial infarctions, Non-invasive, Nano-photonic filters, Active biosensor

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Dual-Band Electrochromic Display on a Flexible Active-Matrix Backplane for Artificial Systems

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Rapid advances in artificial intelligence (AI) are expanding environments in which humans and robots interact, such as autonomous driving, collaborative robotics, and smart factories. In these systems, there is increasing demand for platforms that can simultaneously transmit information to different receivers through visible and near-infrared (NIR) channels using a single device [1-2]. Electrochromic reflective displays are promising candidates for next-generation wearable and human–robot interface technologies because of their ultralow power consumption and compatibility with flexible fabrication processes. Although pixelation is essential for practical deployment of electrochromic displays, most studies have adopted passive-matrix (PM) architectures for fabrication simplicity. Realizing graphic displays necessitates an active-matrix (AM) architecture, enabling independent pixel addressing and eliminates crosstalk.

In this work, we propose a Gires–Tournois (GT) resonator-based electrochromic monopixel array operating across dual visible and NIR bands, using PEDOT:PSS as the active material. PEDOT:PSS exhibits reversible changes in its complex refractive index (n, k) depending on the redox state. In the oxidized state (1 V), NIR absorption is dominated by the Drude free-carrier response, whereas in the reduced state (-2 V), visible absorption arises mainly from the π–π* transition [3]. The GT resonator structure employs an Au pad as a back reflector, effectively converting these refractive-index modulations into reflection contrast. The device achieves a reflectance modulation in the visible region (ΔR = 55% at 570 nm) and the NIR region (ΔR = 38% at 1270 nm) with response time of 88 ms. Notably, opposite modulation behaviors in the visible and NIR bands are simultaneously realized under a single applied voltage. We demonstrate that a 4×4 AM pixel array on a flexible transistor backplane enables visible and NIR recognition under bright conditions and NIR pattern recognition under dark conditions, highlighting its potential for applications such as active security tags and human–robot vision systems.

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Correlative Metrology for Studying the Physicochemical Properties of Graphene Oxide During Its Reduction

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For years now, the most studied 2D material has been graphene, a material that has attracted a significant interest from researchers due to its exceptional properties. Graphene is obtained through various processes, but the least costly and time-consuming method is the reduction of graphene oxide (GO). However, when produced in this way, the reduced graphene oxide (rGO) differs from perfect graphene and a degradation of the physicochemical properties is observed. One way to quantify the evolution of physicochemical properties would be to observe the same object throughout the process.

However, there is no single technique that can provide a complete characterization of graphene. Each technique has its advantages and limitations and provides only quantitative information on a single physicochemical property. A way to obtain the most comprehensive characterization is to combine different techniques.

In this study [1], we propose an in-depth characterization of rGO at different stages of the reduction process. A method for correlating different microscopy techniques on individual particles is developed. This method consists of analyzing exactly the same particle using different techniques to understand the link between the physicochemical properties and to be able to control them for specific applications. The techniques used here are Atomic Force Microscopy, Scanning Thermal Microscopy, Scanning Microwave Microscopy, Scanning Electron Microscopy, and Raman spectroscopy.

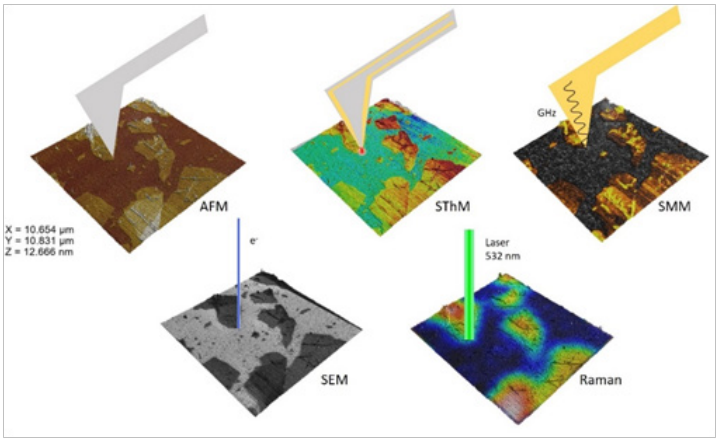

Figure 1: Principles of correlativemicroscopyusingvarious instruments (AFM, SThM, SMM, SEM, Raman) on reducedgraphene oxide particles.

This approach means that the limitations of each technique must be taken into account. Particularly when choosing the substrate, which must be suitable for all the methods used. A strategy must be put in place to ensure that the objects are easy to locate and that the least invasive techniques are used before the most invasive ones, in order to minimize material degradation.

The objective of this communication is to show the strategies used to obtain the physicochemical properties of a single GO/rGO particle using the correlative microscopy approach.

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Reducing Open-Circuit Voltage Loss by Photon Emission Inhibition via Nanopatterned Layers in Thin-Film Solar Cells

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Several years ago it was proposed that a forbidden photonic band overlapping the electronic band edge in semiconductor-based devices could lead to a rigorous inhibition of the spontaneous emission providing a path to overcome the limiting performance for semiconductor devices, among them, solar cells [1]. In solar cells such photon emission restriction can lead to a full reduction of the open circuit voltage (Voc) Boltzmann losses [2]. When photon emission and the sunlight absorption cone are matched Boltzmann losses vanish setting a power conversion efficiency limit for single junction solar cells well above the limit established by the detailed balance. We report first a PM6:Y6 organic blend inverted solar cell configuration, where the use of a front ultra-thin Ag electrode displayed inhibition of the photon emission, leading to a higher power conversion efficiency for solar cells based on this particular configuration compared to standard ITO inverted solar cells. A fully optical control exerted on radiative recombination was also demonstrated to provide Voc variations as high as 26.7 mV. However, due to reduction in transmission of light in the device for increasing silver thickness, the maximum open circuit voltage enhancement obtained without power conversion efficiency loss was 4 mV, well below the complete Boltzmann loss suppression limit. To maintain large-angle reflection properties of thicker Ag and improving at the same time normal incidence transmission, we included Ag metasurfaces, optimized by inverse design for final configurations exhibiting a broadband high transparency to the normal incident sunlight simultaneous to a high reflectivity off-normal at the narrow band of the device emitted light. The proposed design approach is also explored in terms of applicability to perovskite solar cells.

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Metal Oxides Nanoparticles for Integrated Solar Energy Conversion and Photo-Assisted Charge Storage

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The growing demand for compact and sustainable energy technologies has stimulated increasing interest in integrated devices capable of simultaneously harvesting and storing solar energy.[1]Photocapacitors, which couple photoelectrochemical conversion with electrochemical storage within a single architecture, represent a promising alternative to conventional systems based on externally connected solar cells and supercapacitors. [2,3] In this framework, we investigate a two-electrode photocapacitor configuration in which one electrode is photoactive and based on hexagonal WO_3 (h-WO_3) nanoparticles, while the counter electrode operates as a capacitive storage element, thanks to the interaction with our dual function material.

We report the characterization of the h-WO_3 photoelectrode. This metal oxide, characterized by an indirect bandgap of ~2.6 eV, exhibits visible-light photoactivity combined with intrinsic ion intercalation capability. In our work, proton (H^+) intercalation was explored using 0.5 M H_2SO_4 as electrolyte, enabling photo-assisted pseudocapacitive behaviour. The nanostructured morphology promotes efficient light absorption and short carrier diffusion pathways, which are critical for minimizing recombination losses.

Electrochemical and photoelectrochemical measurements reveal an enhancement of specific capacitance and charge storage efficiency under 1 sun illumination (AM 1.5G, 100 mW cm^{-2}) compared to dark conditions, demonstrating a synergistic coupling between photogenerated charge carriers and proton intercalation processes.

This study highlights the potential of nanoscale-engineered WO_3 as a multifunctional semiconductor platform for integrated solar energy conversion and storage, contributing to the development of compact, self-powered, and sustainable energy devices.

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Towards Plasmonic Imaging and SECM Investigation of Photosupercapacitive ITO NCs/MoS_2 Heterojunctions

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Hybrid 0D/2D heterojunctions based on the coupling between degenerately doped conductive indium tin oxide (ITO) nanocrystals (NCs) and mechanically exfoliated MoS_2 flakes constitute a promising platform for investigating photoinduced charge separation and storage processes in ultrathin multilayered architectures. In such systems, optical excitation leads to a redistribution of charge carriers between ITO NCs and MoS_2, resulting in a behavior that can be described as photosupercapacitive, manifested through quasi-permanent changes in the optical properties of the twodimensional material [1,2].

While optical spectroscopic techniques provide valuable insight into photodoping and carrier dynamics, electrochemical approaches can access to quantities such as local electrochemical activity, surface charge density, and the spatial distribution of the electrostatic potential at the interface, as well as their evolution under illumination [3– 5]. In this context, the use of large-area mechanically exfoliated MoS_2 flakes for the fabrication of ITO NCs/ MoS_2 heterojunction represents a particularly suitable geometry for the application of spatially resolved techniques, enabling the investigation of heterogeneity at the single-flake level.

While conventional electrochemical methods such as cyclic voltammetry and electrochemical impedance spectroscopy probe interfacial processes at the macroscopic scale, their ensemble-averaged nature limits spatial resolution. To overcome this limitation, plasmonic imaging can be employed as a non-invasive technique to visualize local variations in surface charge and electrochemical activity in real time [3,4]. In parallel, Scanning Electrochemical Microscopy (SECM) operated in constant-distance mode allows high-resolution mapping of local electrochemical responses while decoupling topographical and functional contributions [5].

The integration of plasmonic imaging and SECM with optical characterization would enable direct correlation between photoinduced charge accumulation, electrochemical response, and spatial heterogeneity in the ITO NCs/MoS_2 system, providing deeper insight into the mechanisms governing its photosupercapacitivebehavior. #NanoSeries2026, June 15-17, 2026, Polytechnic University of Turin, Italy

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Flavin-Assisted Plasmonic Nanozymes for Enantioselective Photocatalysis in Flow

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Plasmonic nanozymes offer a promising bridge between heterogeneous photocatalysis and biocatalysis[1-3], as they offer higher catalytic efficiency than other inorganic particles and increased robustness compared to natural enzymes. Flavin-dependent enzymes enable highly selective redox chemistry under mild and sustainable conditions; however, their practical deployment is often limited by cofactor cost, stability, and integration into scalable continuous processes. Conversely, inorganic nanozymes provide robust catalytic platforms but typically suffer from limited selectivity and control over activity[3,4]. Hybrid systems that integrate biomimetic cofactors, such as flavin derivatives, with plasmonic nanomaterials therefore present an attractive strategy to combine the advantages of both approaches. Coupling flavin photochemistry with plasmonic excitation may enable light-driven redox transformations while improving selectivity through additional modification of the nanozyme surface with chiral peptides.

We present the development of flavin-assisted chiral plasmonic nanozymes based on gold nanoparticles (AuNPs) for enantioselective redox catalysis in continuous flow, using molecular oxygen and visible light as sustainable reagents. AuNPs exhibiting intrinsic oxidoreductaselike activity are engineered as scaffolds onto which two different species are immobilised: (i) a chiral peptide ligand environment for enantioselection, and (ii) flavin cofactors as redox-active photosensitisers[2,4,5].Current work focuses on establishing and benchmarking the catalytic platform by functionalising AuNPs with chiral peptide ligands and flavin derivatives. The resulting nanozymes are characterised using oxidase- and peroxidase-like assays to quantify activity and plasmonic enhancement[1,6]. To increase the translational potential of the system, the most active nanozymes are being immobilised on sepharose beads and integrated into a packed-bed flow reactor.This work seeks to establish a framework for plasmon-driven asymmetric catalysis and may open avenues for sustainable photo-biomimetic transformations.#NanoSeries2026, June 15-17, 2026, Polytechnic University of Turin, Italy

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Performance Improvement of Near-Infrared Organic Photodetectors by Applying $MoSe_2$ Nanosheets to the PBDB-T:Y6 Active Layers

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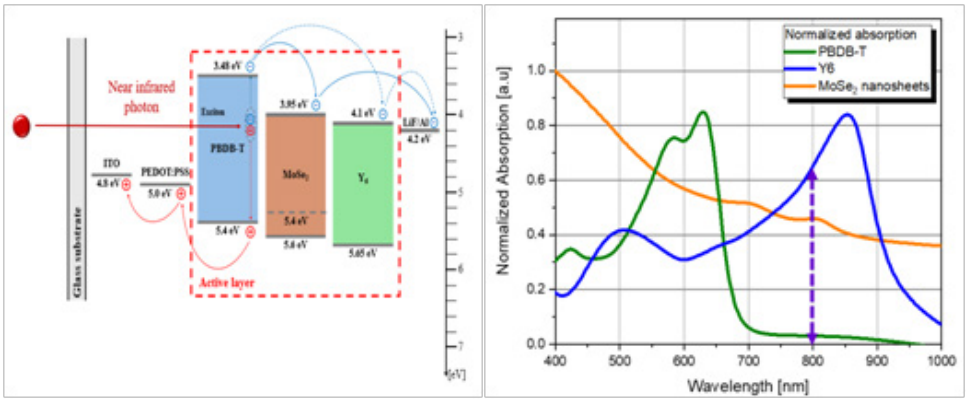
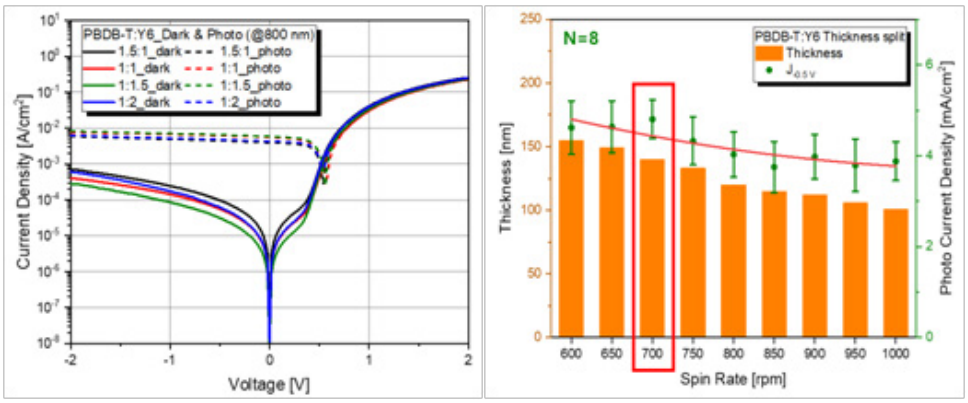
Near-infrared (NIR) organic photodetectors have been studied in the fields of photonics and optoelectronics due to their mechanical flexibility, low-cost solution processing, and spectral tunability. To improve the performance of NIR photodetectors, efforts are required to increase the photo-conversion current density and lower the dark current density. As shown in Fig. 1,$MoSe_2$ nanosheets were introduced into a PBDB-T:Y6 bulk-heterojunction active layer.$MoSe_2$ was selected as an additive material because it absorbs near-infrared light at 810 nm (Fig. 1b) and is expected to increase photocurrent by providing an additional charge transfer pathway.Experiments were conducted with the donor-acceptor mixing ratio, active layer thickness, and MoSe2 nanosheet size as variables.In Fig. 2, the active layer of the photodetector exhibited excellent characteristics when the PBDB-T:Y6 ratio was 1:1.5 and the thickness was approximately 140 nm. Fig 3 shows the results of forming 2H-phase $MoSe_2$ nanosheets by liquid exfoliation and HR-TEM image of 51 nm nanosheets (at 8000 rpm) dispersed within PBDB-T:Y6 active layer.Fig. 4 shows the results of changes in external quantum efficiency (EQE), responsivity (R), and detectivity (D*) when different-sized MoSe2 nanosheets (1 wt%) are added.Compared to the pristine state (composed only PBDB-T:Y6) NIR photodetector, the detectivity (D*) increased by approximately 67% when 51 nm MoSe2 was added.According to the space charge-limiting current (SCLC) analysis in Fig. 5, the addition of nanosheets increased charge mobility by 47% and decreased trap density by 18%, indicating that charge recombination decreased and charge extraction increasedwithin the active layer.



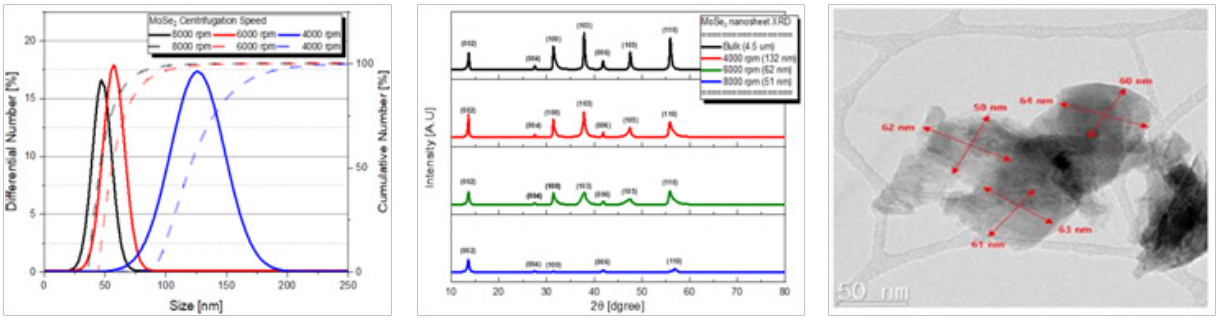
(a) **(b)**

Figure 1: (a) The energy band diagram of device, (b)UV-Vis-NIR absorption of materials



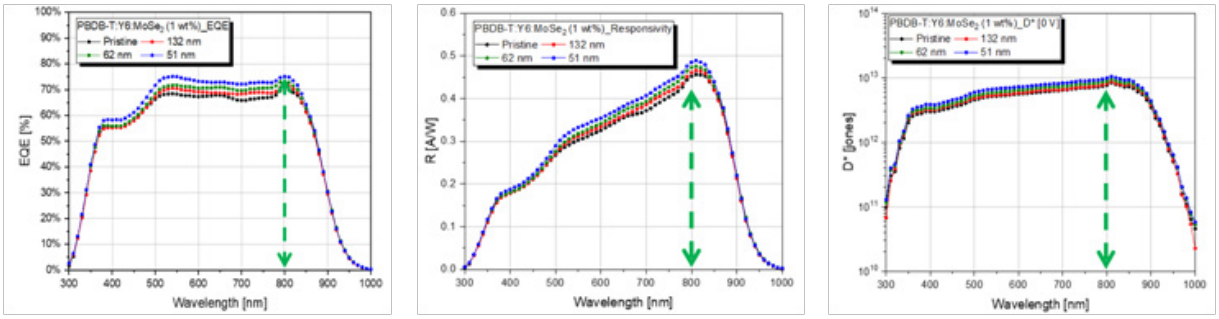
(a) **(b)**

Figure 2: (a) Dark & Photo current density by polymer ratio variation, (b) Thickness and photocurrent density for each spin rate



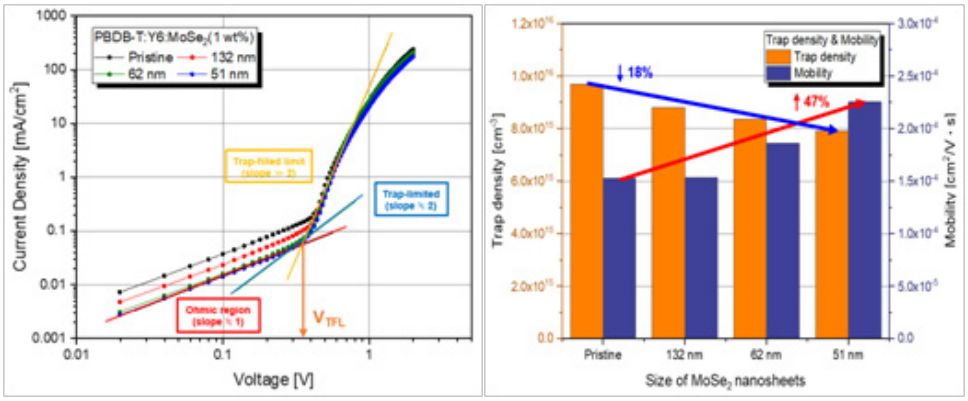
(a) (b) (c)

Figure 3: (a) Size distribution of $MoSe_2$ at centrifugation speeds, (b) XRD pattterns of $MoSe_2$ with different siszes, (c) HR-TEM image of lattice structure of 8000rpm $MoSe_2$ nanosheets



(a) (b) (c)

Figure 4: (a) External Quantum Efficiency(EQE) by MoSe2additive, (b) XRD pattterns of MoSe2 with different siszes, (c) HR-TEM image of lattice structure of MoSe2 nanosheets



(a) (b)

Figure 5: (a) SCLC model of device, (b) Trap density and mobility of device

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Keywords - NIR Organic Photodetector(NIR-OPDs),TMDs, MoSe2, 2D materials

Data-Driven Optimization of Organic Photovoltaics Using Design of Experiments and Active Learning

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This workaddresses the experimentalcomplexity of optimizingorganicphotovoltaic (OPV) devicesthrough a sequentialapproachcombining Design of Experiments (DoE), machine learning (ML), and active learning (AL). A fractionalfactorialDoEwas first implemented to reduce a large processingspaceinto 20 representative OPV devices, generating an initial experimentaldataset [1]. Machine learningregressionmodels, including support vectorregression (SVR), decisiontreeregression (DTR), randomforestregression (RFR), gradient boostingregression (GBR), and k-nearestneighbors (k-NN), werethentrained to predict power conversion efficiency (PCE) fromprocessingparameters, with SVR achieving the best predictive performance (RMSE = 1.10%, MAE = 1.00%, R^2 = 0.88). To evaluate data-efficient optimizationstrategies, an active learningframeworkwasimplementedusing the pre-existingexperimentaldatasetwithin a virtual active learning setup, where the AL loopisemulatedusingpre-acquired data and unlabeledsamples are iterativelyselectedbased on uncertainty and query-by-committeestrategies [2,3]. The results show progressive improvement in model performance as new samples are incorporated, withdifferentquerystrategiesdemonstrating distinct behaviorsacrossiterations. Thesefindings highlight the potential of a sequentialDoE–ML–AL approach to reduceexperimental effort whilemaintaining effective exploration of high-dimensional OPV processingspaces, providing a practical route for integrating data-drivenmethodsinto OPV optimizationunderlimited data conditions.

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The Electronic Structure of 1D Pd@Ni Nanospikes and Their Electrochemical Activity in Ethanol Oxidation

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The world's sustained high demand for electricity requires the development of ever more efficient, cost-conscious catalysts for its production. Among the many catalysts based on Pd, combination of PdNi electrocatalyst has gained the great attention. Due to the nano-structural architecture plays a crucial role in the catalytic activity, we synthesized novel Pd@Ni unsupported with carbon black catalyst in form of one-dimensional nickel nanospikes (Ni NSs) decorated by palladium nanoparticles.In this work, the impact of the changing in electronic structure of Pd@Ni catalysts on their catalytic properties was studied (XANES, EXAFS, XPS, TEM).For small Pd crystals surrounded by a large dispersion of Ni substrate atoms, can refer to an increased metal-substrate interaction, which is associated with an increase in d-state vacancies in the Pd@Ni catalyst [1]. This may imply a greater susceptibility to chemisorption of unsaturated hydrocarbons (acetylene, ethylene), which may be electron donors. The higher number of d-state vacancies in material may indicate greater susceptibility to chemisorption of ethanol molecules, which further improves its catalytic activity.By using two different concentrations of Pd catalyst (0.5 mM and 0.75 mM), an attempt was made to determine the optimal electronic structure for the Pd@Ni system. By using synchrotron X-ray absorption spectroscopy, it was possible to determine the differences in the density of unoccupied Pd d-state in the produced materials, as well as changes in the local structure of the used support - 1D Ni nanospikes (NWs). Analysis of valence spectra from X-ray photoelectron spectroscopy (XPS), in turn, confirmed differences in density of states at the Fermi level between the samples and determined d-band center and its width (d width) for each. The conclusions obtained on the correlation between structure and activity can be used in the design of working metal-to-metal supported catalysts used in catalytic oxidation and reduction reactions.

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Carbon Nanostructures in Membrane Engineering: Polarity-Driven CQD Localization and US-SWCNT-Mediated Protein Transport

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Carbon quantum dots (CQDs) are promising for bioimaging and theranostics, yet single-precursor polarity control remains limited. In this poster, we will present a curcumin-derived platform enabling hydrophobic (Hb-CQD) and hydrophilic (Hp-CQD) dots via solvothermal synthesis with or without 3-aminopropyl-trimethoxysilane. Surface polarity governed spatial localization in liposomes: Hb-CQDs embedded in lipid bilayers, while Hp-CQDs resided in aqueous cores, including liposome-in-liposome architectures. Spectroscopy, TEM, and confocal microscopy confirmed positioning and stability. Flow cytometry revealed polarity-driven redistribution of CQDs in the vesicles upon mixing. In MDA-MB-231 cells, liposomal Hp-CQDs showed enhanced uptake and viability versus free dots, demonstrating membrane-directed modulation for multifunctional theranostic nanoplatform design. Further, we will present our work on designing artificial nanopores for protein translocation. Understanding controlled protein transport across biological membranes is crucial for biomimetic channel design and targeted delivery systems. In this study, ultra-short single-walled carbon nanotubes (US-SWCNTs) were embedded within synthetic lipid bilayers to function as artificial transmembrane nanochannels. Successful incorporation was confirmed through single-channel recording experiments. We will present the results on the ionic current signature of protein transport through SWCNT. We will also present our work on the high resolution characterization of the pores in lipid bilayer membrane.

Structure–Property–Performance Relationships in Low Band-Gap $AgBiS_2$ Photoanodes

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AgBiS2 is a narrow-band-gap, water-stable semiconductor with strong visiblelight absorption, making it a promising absorber material in devices for solardrivenphotoelectrocatalysis (PEC)[1,2]. Although its photovoltaic properties have been widely studied, the influence of cation disorder on PEC performance remains largely unexplored[3,4]. Solvothermally synthesized AgBiS2 nanoparticles were processed in photoanode thin films via ultrasonic spray coating. A combination of X-ray diffraction and spectroscopic analyses reveal how thermal annealing partially homogenizes the cation distribution, showing lattice contraction and subtle band-structure tuning toward a slightly n-type behavior. The annealed electrodes exhibit higher photocurrents for water oxidation and increased donor density. The improved performance was also #NanoSeries2026, June 15-17, 2026, Polytechnic University of Turin, Italy

observed in a hole scavenger solution, which was employed to thoroughly characterize the behavior of the photoanodes: impedance spectroscopy suggests enhanced hole flux to the semiconductor/electrolyte interface, while transient absorption spectroscopy identifies sub-bandgap trap-mediated recombination as the primary limitation of the photoanode's performance. These results support the implementation of AgBiS2 as low band gap absorber in electrode architectures and suggest its use with fast redox mediators for selective photooxidation for sustainable solar energy conversion as a promising application.

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Structure and Magnetodielectric Properties of Ferrite-Based Nanoparticles for SMC Applications

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Soft Magnetic Composites (SMCs) are advanced materials composed of electrically insulated ferromagnetic particles bonded with a dielectric binder, which effectively suppresses eddy current losses. Due to their isotropic magnetic behaviour and the ability to be formed into complex geometries, SMCs are widely used in modern electrical machines and power electronic devices operating at elevated frequencies. The present work focuses on ferrites as ferromagnetic particles for SMC applications. Ferrites are ceramic materials with unique properties, including ferromagnetism, high saturation magnetisation (up to 91 emu/g), high electrical resistance, low electrical losses, and excellent chemical stability. These properties depend on the synthesis conditions, for example, the type of solvent and reaction temperature, which affect the shape and size of the particles.

This study investigates the influence of synthesis conditions and chemical composition on the structure, morphology, as well as the magnetic and dielectric properties of ferrite nanoparticles. To investigate the impact of these variations, we conducted a series of studies. X-ray diffraction analysis confirmed the formation of a single-phase spinel structure with no impurities. Morphology was observed using scanning transmission electron microscopy (STEM). Magnetic properties were evaluated using vibrating sample magnetometry (VSM). Measurements of hysteresis loops provide key parameters such as saturation magnetisation and coercivity, which are essential for assessing magnetic performance. Magnetic characterisation is essential for assessing the suitability of materials for SMC applications. Finally, the magnetodielectric properties were investigated using broadband dielectric spectroscopy (BDS) over a wide range of frequencies and temperatures. This approach enabled the determination of complex permittivity and permeability, which are crucial for evaluating magnetic and electrical losses, energy storage capability, and other key parameters defining the potential application of the developed materials.

Keywords: ferrites, SMC, ferromagnetism, nanocomposites

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Comparative Study of Hematite Deposition Methods for Fe_2O_3/SnO_2 Nanocone Photoanodes

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Hematite-based heterostructures remain attractive photoanode materials for photoelectrochemical (PEC) water splitting due to their favorable band gap and visible-light absorption [1]. In this work, Fe_2O_3/SnO_2 photoanodes were developed, using tin(IV) oxide nanocones as the electron-collecting underlayer and hematite as the visible-light-absorbing top layer. The favorable band alignment at the Fe_2O_3/SnO_2 interface promotes charge separation and suppresses interfacial recombination. Several hematite deposition strategies, including chemical bath deposition [2], electrodeposition [3], and spin coating [4], were investigated to identify a synthesis route that yields uniform, well-adhered hematite coatings on SnO_2 and achieves the best PEC performance.

The obtained Fe_2O_3/SnO_2 electrodeswere compared in terms of their structural, optical and photoelectrochemical properties. Particular attention was paid to the uniformity and continuity of the hematite overlayer, as homogenous coverage is important not only for efficient PEC operation, but also for protecting the underlying SnO_2 from degradation in highly alkaline electrolyte.

Additionally, samples obtained usingvarying number of spin-coating cycles were compared and analyzed. Structural and morphological characterization confirmed the formation of Fe_2O_3/SnO_2 heterojunctions, while PEC measurements showcased a strong relation between the photoresponse and the hematite layer thickness. An optimal overlayer thickness was identified based on these parameters, maintaining a balance between improved light harvesting and efficient charge separation and transport across the heterostructure interface. In contrast, excessively thick hematite layers likely promoted charge recombination. These results demonstrate that precise control of the hematite layer synthesis is crucial for optimizing the performance of Fe_2O_3/SnO_2heterostructured photoanodes.

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Anodizing Aluminum in Etidronic Acid Electrolytes: A Simple Route to Surfaces with Distinct Optical Properties

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Anodization is a simple and cost-effective method for producing nanostructured metal oxides, such as anodic aluminum oxide (AAO) with hexagonal ordering. This process can also be used as a simple method for nanostructuring metal surfaces, in addition to commonly used methods such as lithography or applying specially designed molds[1]. As the oxide forms on the metal surface, characteristic nanoconcaves are created, which remain after the oxide layer is removed. If the AAO cell diameters are in the range 500–800 nm, the metal surfaces after oxide removal exhibit rainbow-like structural coloration with distinct optical properties[2]. Although malic and citric acids are commonly used to achieve such dimensions, they require high voltages during anodization, yield poorly ordered structures, and may cause “burning phenomenon”.Etidronic acid-based electrolytes (with the addition of other acids) have emerged as a promising alternative. Such mixed electrolytes can be used effectively to avoid problems associated with poor ordering of structure[3].

This study explores the influence of etidronic acid-based electrolyte composition on the morphology and optical properties of AAO layers, as well as the underlying aluminum surface after oxide removal. AAO films were fabricated via one- or two-step anodization of aluminum foil at 100–200 V and room temperature. The chemical oxide removal was carried out in a mixture of 6 wt.% phosphoric acid and 1.8 wt.% chromic acid at 60 oC. Surface morphology and topography were examined using scanning electron microscopy (SEM) and atomic force microscopy (AFM), respectively, while UV-Vis spectroscopy was used to evaluate optical properties.

The results indicate that both anodization voltage and electrolyte composition significantly influence metal surface structure and coloration. The addition of phosphoric acid enhances optical performance by improving the ordering of the alumina layers and, consequently, the hexagonal ordering on the aluminum surface.

Keywords: Anodic alumina, anodization, optic properties, topography, nanoporous layers

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The SEM imaging was performed in the Laboratory of Field Emission Scanning Electron Microscopy and Microanalysis at the Institute of Geological Sciences, Jagiellonian University, Poland.

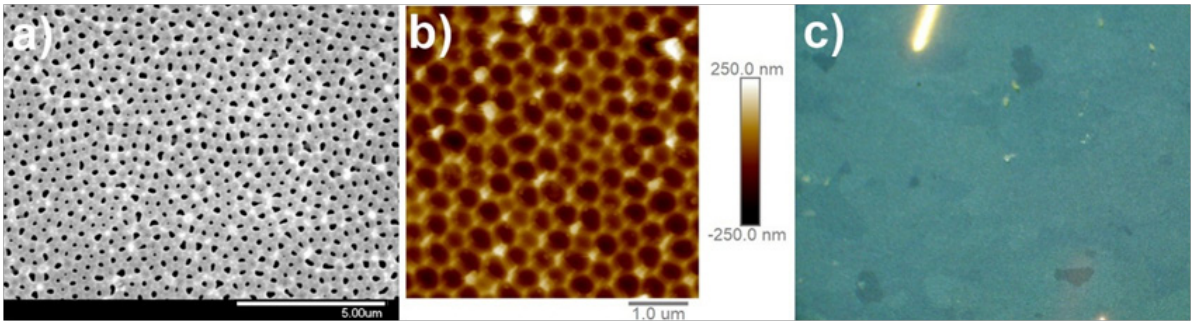

Figure.1: a) SEM image of the AAO surface obtained during anodization in 0.3 M etidronic acidat 160V, 20 oC,b) AFM image, andc) optical microscope imageof the metallic surface after the oxide removal

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Enhanced Thermal Transport at the Graphene Oxide–Water Interface by Uniform Electric Field

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Efficient heat dissipation across the graphene oxide (GO)–water interface is crucial for the thermal reliability of graphene- and GO-based nanoelectronic devices [1, 2].Previous studyhave shown that the oxidation degree of graphene can regulate interfacial heat transfer, and a linear correlation between oxidation degree and interfacial thermal resistance has been identified at low-to-moderate oxidation levels [3]. However, the effects of electric field on the interfacial thermal resistance at the GO–water interface remains unclear. In this study, non-equilibrium molecular dynamics (NEMD) simulations were performed inLAMMPSto investigate electric-fieldcontrolled interfacial thermal transport at the GO–water interface.

The simulation system consists of multilayer GO with a water film sandwiched in the middle (see Fig. 1(a)). The hydroxy (–OH) groups are randomly distributed on the GO surface and equally placed on both sides of graphene, corresponding to an oxidation degree of 40%.The dimensions of simulation systemareLx = 4.0 nm, Ly = 4.0 nm, and Lz= 5.1 nm, and the water film thicknessDis 2.8 nm.The all-atom optimized potential (OPLS-AA) isutilized to describe the interatomic interactions for multilayer GO [4, 5], andthe SPC/E model is used for water. The interactions between GO and water are modeled using theLennard-Jones potential and long-range electrostatics treated byPPPM method with accuracy of 0.0001 [6]. The heating and cooling thermostats are maintained at the constant temperature of 350 K and 250 K, respectively. An external electric fieldis applied to the simulation system with the strengths ofE = 0.5, 1.0, 1.5, and 2.0 V/Å.Periodic boundary conditions are utilized along the x- and y-directions and the fixed boundary condition is applied along z-direction.

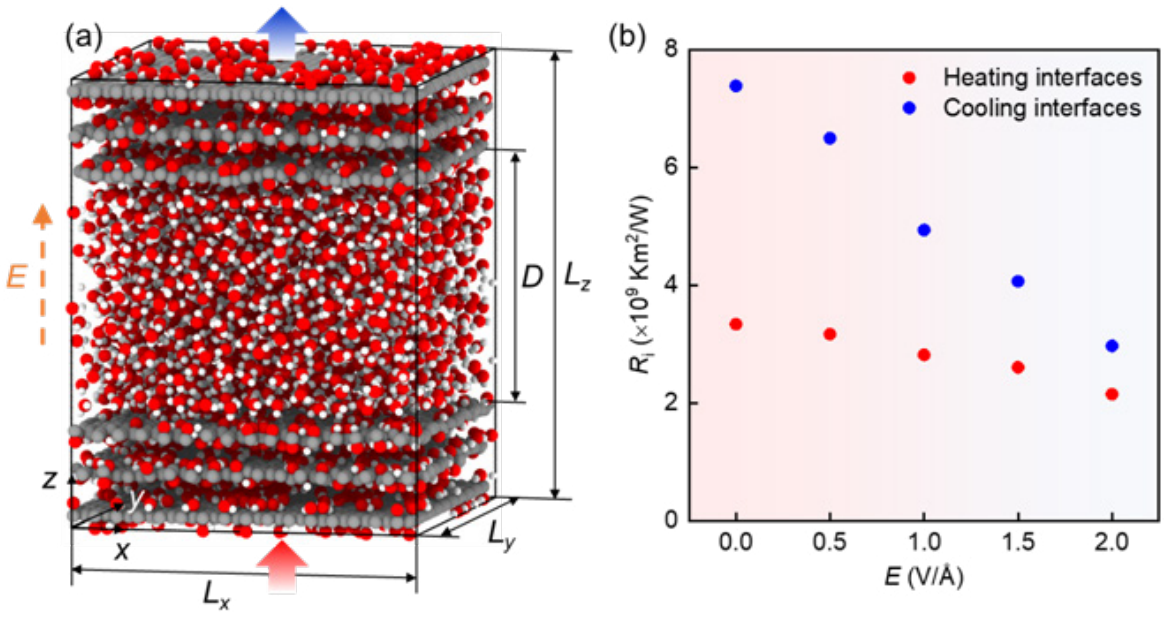

Fig. 1 (a) Schematic of thermal transport at GO–water interface under uniform electric field; (b) Effects of electric field strength E on thermal resistance Ri at heating and cooling interfaces.

The results show that the interfacial thermal resistanceRi decreases monotonically with increasing electric field strength, indicating that the applied electric field enhances interfacial heat transfer (see Fig. 1(b)).Moreover, both the interfacial temperature drop and thermal resistance at the heating side are smaller than those at the cooling side, owing to enhanced mobility of water molecules and vibrational coupling at the heating interface. To reveal the underlying mechanism, the formation of interfacial hydrogen bonds and the water orientation angles are further analyzed, which helps explain the variation of interfacial thermal resistance with electric field strength. These findings provide theoretical insight and practical guidance for thermal management in graphene- and graphene oxide-based electronic devices.

Keywords: GO–water interface; interfacial thermal resistance; electric field; hydrogen bonding; molecular dynamics simulation

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Ocean-Sourced Polysaccharides for Sustainable Bioelectronic Materials

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The transition to sustainable nano-enabled technologies requires materials and manufacturing routes that minimize reliance on fossil-derived polymers, enable scalable fabrication, and support circular material pathways.

Here, we present a sustainability-driven framework for bioelectronics that combines renewable, marine-derived polysaccharides with digital nanomanufacturing approaches, targeting electrically functional materials with improved environmental compatibility.

First, we engineer conductive hydrogel bioinks by functionalizing GelMA-derived formulations with MXene[1] and carbon nanotube (CNT) nanomaterials to increase electrical conductivity and mechanical resilience. Rheology, conductivity, and printability assessments confirm suitability for extrusion-based 3D bioprinting and the fabrication of complex architectures, while electrical stimulation assays indicate robust signal propagation and structural stability, supporting sustainable routes to flexible bioelectronic circuits and wearable sensing concepts.

Second, we demonstrate laser-induced graphene (LIG) formation on agarose-lignin membranes[2] using a dual-laser strategy combining CO2 and UV lasers. Crucially, agarose is a seaweed-derived polysaccharide, establishing a direct link to ocean-sourced renewable feedstocks aligned with the blue bioeconomy. CO2 laser processing supports scalable graphitization, and UV laser patterning provides high-resolution control. Structural and chemical analyses confirm conductive graphene formation with tunable electrical properties and morphology, positioning these substrates as candidates for sustainable printed bioelectronics. Also, other biopolymers are being tested in order to improve biomembranes' performance (e.g., antimicrobial behavior based on chitosan blends).

By integrating conductive bioinks with precision-patterned LIG interfaces on partially ocean-derived membranes, this work outlines a versatile pathway toward nanoengineered bioelectronics compatible with blue biorefinery value chains and low-impact, biodegradable material design.

Keywords: Sustainable Bioelectronics; Ocean-sourced Polysaccharides; Conductive bioinks; MXenes; Laser-induced Graphene (LIG).

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Double- and Multi-Metal Cyanides: Tools to Minimize Environmental Impacts

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The Prussian blue family is representative oldest known complexes. The combination of metals in the cyano bridge enables a wide range of applications. Their structures depend on the synthesis procedure, yet they are underrepresented in fundamental research.

The objective, which focuses on incorporating transition metals, is to elucidate the relationships between the structures of zinc ferri- and ferrocyanide and the synthesis conditions from a colloidal chemistry perspective. This includes analysis using dynamic light scattering (DLS) and laser Doppler electrophoresis (LDE).

Unlike water-insoluble crystalline zinc hexacyanoferrates, a structure with a low degree of crystallinity and an amorphous component has been formed, constituting the structural unit of the colloidal solution – a negatively charged micelle. Such a particle has a size of 40 and 60 nm according to XRD data and 200 and 280 nm according to DLS. They have the potential to serve as Lewis bases and quantum dots.

Their interaction with transition-metal cations leads to the formation of positive multimetallic particles according to LDE. The strong influence of coordinated cations on the charge distribution in the cyanide bridge is reflected in the color of the compounds, which is potentially useful for the identification of heavy metal salts in wastewater. In addition, these compounds have Lewis acid sites and are potential adsorbents for anthropogenic excess CO2.

The captured CO2 is utilized for the production of polymers, and the resulting nanostructures serve as highly effective catalysts for this process.

Thus, the creation of proposed structures requires transition metals, which can be sourced through recycling. Reducing the carbon footprint is achieved through the use of CO2 captured by multimetallic particles for the production of a polymer. The potential for using CO2 for polymer production is estimated at 10–50 million tons per year.

Keywords: zinc hexacyanoferrate, negatively charged micelle, positive multimetallic particle, dynamic light scattering, laser Doppler electrophoresis.

A Biomaterial-Based 3D Neuroblastoma Platform for Evaluating RGD-Functionalized Etoposide-Loaded Solid Lipid Nanoparticles

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Neuroblastoma (NB)is one of the most aggressive pediatric malignanciesand remains associated with poor prognosisin high-risk patients. Despite intensive chemotherapy, survival remains limited and is frequently accompanied by severetoxicity.The effectiveness of preclinical drug screening, and consequently the clinical translation of novel anticancer therapies, is hindered by the heavy relianceon conventionaltwo-dimensional (2D) monolayer cultures, which fail to recapitulate key features of tumors, including architecture, drug penetration barriers, and intercellular interactions observed in vivo[1]. While three-dimensional (3D) models offer improved physiological relevance, they often lack reproducibility and precise structural control.

Here, we report a biomaterial-based 3D platform that enables controlledNB spheroid formation and provides a robust system to evaluate integrin-targeted lipid nanocarriers for enhanced etoposide (ETP) delivery. RGD-functionalized solid lipid nanoparticles (SLNs) were designedto selectively deliver ETP to αvβ3 integrin-expressing NB cells.Two cell lines with differential αvβ3 expression levels were used: SH-SY5Y (~80%) and SK-N-BE(2) (~10%)[2]. To achieve precise control over spheroid size and spatial organization, we employed a patterned polysaccharide-based hydrogel featuringuniform microwell arrays [3]. This platform was thoroughly characterized in terms of structure and morphology, and demonstrated consistent and reproducible spheroid formation.

Comparative evaluation of free ETP, untargeted SLNs, and RGD-functionalized SLNs in both high-confluence 2D cultures and 3D spheroids revealed that RGD-functionalized SLNs significantly enhance cytotoxic efficacy, underscoring the advantage of active targeting. Quantitative analysis of fluorescent nanoparticle uptake by flow cytometry showed that ligand-mediated targeting improves early cellular internalization, with effects dependent on receptor expression levels.

Overall, this study presentsa robust and reproducible 3D NB modelthat more accurately predictsthe therapeutic performance of anticancer therapies.By integrating biomaterial engineering with targeted nanodelivery, this platform provides a powerful preclinical tool to accelerate the development, optimization, and clinical translation of precision nanomedicine strategies for neuroblastoma.

Keywords: neuroblastoma, 3D spheroid model, solid lipid nanoparticles, RGD targeting, etoposide

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Mesoporous Silica Spheres for Enhanced Hemostatic Performance:Influence of Synthesis Parameters on Structural and Surface Properties

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Hemorrhage control requires materials with precisely tuned physicochemical properties to promote rapid clot formation while maintaining safety.Mesoporous silica (MS) isa promising hemostatic agent due to its high surface area, tunable porosity, and surface hydroxyl groups, which accelerate clot formation by adsorbing water and concentrating clotting factors and platelets [1].The present study aimed to develop mesoporous silica spheres (MSS) with enhanced hemostatic properties and to investigate the influence of key synthesis parameters on physicochemical characteristics and clotting performance. To this purpose,hydrothermal treatment temperature (100°C or 130°C) and calcination temperature (350°C or 500°C) were variedwithin the protocol previously used for MSS preparation [2]. Samples were denoted as MSS-x-y, where x indicates the hydrothermal temperature and y the calcination temperature. Materials were characterized by FESEM, nitrogen physisorption, FT-IR spectroscopy, TGA, zeta potential analysis, and water adsorption measurements. Hemostatic activity was evaluated through plasma clotting assays. All samples exhibited particles with spherical morphology. Calcination at 500°C reduced specific surface area, pore volume, and pore diameter compared to that carried out at 350°C. Samples calcined at 350°C showed higher silanol density and greater water adsorption capacity. Hydrothermal treatment at 130°C improved structural order and increased pore size. All MSS significantly reduced bovine plasma clotting time (85–93% vs. control). Among them, MSS-100-350 exhibited the fastest clotting, attributed to its optimal combination of high surface area, elevated silanol density, negative surface charge, and strong water adsorption capacity,as shown in Table 1. These results highlight the controlof structural and surface properties by tuning the synthesis parameters, providing insights for optimizing mesoporous silica as an effective hemostatic material.

Sample	SSABET (m^2/g)	Dp (nm)	ζ Potential (mV)	Silanol density (OH/nm^2)	Adsorbed H_2O (%)	Clotting time reduction (%)
MSS-100-500	591	25	-15.8 ± 1.1	4	19	89.4
MSS-100-350	745	27	-23.4 ± 0.4	12	36	92.7
MSS-130-500	594	27	-19.0 ± 0.3	7	27	85.2
MSS-130-350	689	29	-19.3 ± 1.6	8	28	89.4

Table 1: Properties and clotting performance of MSS samples.

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Engineering Multifunctional β-Cyclodextrin Nanocarrier for miRNA Transport Across the Blood–Brain Barrier

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The treatment of glioblastoma multiforme remains one of the most challenging issues in oncology due to the highly aggressive nature of the tumor and the presence of the blood-brain barrier (BBB), which severely limits the ability of many therapeutic agents to reach the target site. Among emerging therapeutic strategies, RNA-based drugs have attracted increasing interest for their potential to modulate oncogenic pathways. However, their clinical application is hindered by poor stability, large molecular size, and intrinsic polyanionic character. In this work, we report the design and characterization of an innovative delivery system based on a multifunctionalized β-cyclodextrin, developed as a versatile platform for miRNA-146a delivery. The core of the vector consists of a polymer of β-cyclodextrin functionalized with amino groupsexploited for the covalent conjugation of three different bioactive peptides.All peptides were synthesized via solid-phase peptide synthesis (SPPS). Specifically, the nanosystem was decorated with the cell-penetrating peptide gH625 to promote BBB translocation and enhance cellular internalization [1], and with a nine-arginine sequence (R9) to enable efficient miRNA-146a complexation through electrostatic interactions. Moreover, tumor selectivity toward glioblastoma cells was further enhanced by the incorporation of the targeting peptide falGea[2]. Analytical and spectroscopic characterization confirmed successful functionalization and high purity of the resulting conjugates. The complex miRNA-cyclodextrin was characterized in terms of cytotoxicity and cellular internalization. This strategy integrates protection of the RNA cargo, efficient cellular penetration, and tissue specificity within a single nanocarrier, offering a promising approach to overcome the biological and kinetic barriers associated with RNA-based therapies for brain diseases.

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Microscopic Characterization of Magnetosomes in Four Strains of Magnetotactic Bacteria Under Different Seasonal Conditions

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Magnetotactic bacteria are natural microorganisms that biomineralize intracellular magnetic nanoparticles. The latter, called magnetosomes, allow bacteria to orient themselve along the lines of the Earth's magnetic field and they are a fascinating example of controlled biological organization at the nanoscale. Due to their unique structural properties, these bacteria have attracted considerable interest as model systems for studying biomineralization and as a source of biogenic magnetic nanoparticles [1-3]. In this context, the present study aims at the microscopic characterization of four strains of magnetotactic bacteria: Paramagnetospirillum magnetotacticum, Magnetospirillum gryphiswaldense, as well as two less studied strains, Desulfamplus magnetovallimortis and Magnetospirillum aberrantis. The analysis focuses on investigating the cellular morphology and the organization of magnetosomes at intracellular level, with the aim of expanding the existing data for established strains and providing relevant structural information for species that have not been sufficiently characterized to date.

The results obtained provide a solid basis for assessing the feasibility of using magnetotactic bacteria and biogenic magnetosomes in the development of blood cell biosensors and is a part of BIOMAGIC financed projet by the Exploratory Projects EUt+ 2026 established by the Directorate of EUt+ and the Research Directorate of the University of Technology of Troyes.

Keywords: Paramagnetospirillum magnetotacticum, Magnetospirillum gryphiswaldens, Desulfamplus magnetovallimortis, Magnetospirillum aberrantis, magnetosomes, microscopic characterization

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Quantifying Functional Targeting Sites to Optimize Targetable Nanomedicines for PDAC Treatment

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Antibody-mediated targeting is one of the most widely used strategies to increase the selectivity of nanomedicines, yet targeting performance often remains difficult to predict and reproduce across studies. A major reason is that the "design variables" that are routinely reported (e.g., nominal antibody loading or bulk-average conjugation yields) do not necessarily reflect the functional parameters that drive multivalent binding at the nano-bio interface: the fraction of antibodies that remain accessible and active, their nanoscale organisation on the particle, and the resulting avidity effects when interacting with receptors at the cell surface. This limitation becomes especially relevant in aggressive cancers where the therapeutic window is narrow and where delivery efficiency is strongly constrained by biological barriers. In pancreatic ductal adenocarcinoma (PDAC), late diagnosis and limited efficacy/toxicity of systemic treatment options remain major challenges. ZIP4 is an attractive oncotarget in this context. It is overexpressed in aggressive PDAC and has been proposed as a route for selective recognition of ZIP4-positive tumours. Our team has already contributed to the validation of ZIP4 targeting in vivo, providing a strong and realistic biological mechanism.1In parallel, the host environment has demonstrated expertise in quantitative bio-analytical strategies to understand metastasis-relevant processes, including recent findings showing that labile zinc can act as a biphasic mediator of metastasis.2Together, these studies highlight a key need in translational nanomedicine: converting complex biological phenomena into quantitative, testable descriptors that can guide nanoparticle design.A subset of mechanistically informative formulations (top performers, low performers, and key controls) is analysed using DNA-PAINT/qPAINTto quantify functional antibodies at single-particle resolution and capture heterogeneity that is not detectable by bulk measurements.3

Keywords: Drug delivery nanosystems, Molecular targeting, Pancreatic ductual adenocarcinoma (PDAC), ZIP4.

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Photothermal Immunotherapy Using Gold Nanocapsules: Optimizing the Thermal Window for Immunogenic Cell Death

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The immunosuppressive tumor microenvironment (TME) remains a critical barrier to effective cancer therapy. Strategies that remodel the TME to enhance anti-tumor effector functions are increasingly linked to improved clinical outcomes. A promising approach involves the induction of Immunogenic Cell Death (ICD), which triggers the release of Damage-Associated Molecular Patterns (DAMPs), subsequently promoting antigen presentation and systemic anti-tumor immunity.While Photothermal Therapy (PTT) is a potent local ablative strategy, its efficacy against metastatic disease is traditionally hindered by the spatial limitations of laser irradiation. To address this, we investigate the potential of gold nanoparticle-assisted PTT (nPTT) to induce ICD to serve as an in-situ vaccine. We synthesized and optimized plasmonic gold nanocapsules (AuNCs)to serve as precise photothermal conversionagent.Our study evaluates the correlation between specific thermal doses and the spatiotemporal release of ICD markers, including Calreticulin (CRT), ATP, and HMGB1. For further understand the mechanism behind ICD, we also investigate if there is a optimal condition to trigger pyroptosis, a programmed cell death pathway capable of potent immune activation.This research identifies an optimized thermal window that maximizes the systemic immune potential of nPTT, offering a strategic framework for treating metastatic melanoma through photothermal immunotherapy.

Breaking Chemoresistance in Breast Cancer: A Dual Action TLR2-Targeted Nanotheranostic Approach

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Introduction and Objective of the Research: Breast cancer remains the leading cause of cancer-related death among women. Chemoresistance in aggressive breast cancer arises from the interplay between tumor-intrinsic signaling pathways and tumor microenvironment (TME)-mediated immune suppression. Addressing this complexity requires multifunctional nanomaterials capable of coordinated therapeutic and diagnostic action. Here, we engineered a dual-targeted hybrid nanotheranostic platform integrating polymeric and lipid nanoarchitectures for simultaneous inhibition of Toll-like receptor 2 (TLR2) signaling (using CU-CPT drug) and cytotoxic drug (doxorubicin) delivery. The objective was to establish a modular nanoplatform in which surface chemistry, cargo combination, and imaging capability synergistically enhance therapeutic efficacy while enabling non-invasive monitoring. [1].

Methodology or Approach: Hybrid poly(lactic-co-glycolic acid) PLGA–lipid nanoparticles were designed to combine structural stability with controlled drug release. PLGA nanoparticles encapsulating the TLR2 inhibitor CU-CPT22 were synthesized via nanoprecipitation, while doxorubicin-loaded liposomes were prepared by thin-film hydration. Both nanosystems were surface-functionalized with cyclic RGD peptides to promote αvβ3 integrin-mediated targeting. Physicochemical characterization included dynamic light scattering (size distribution, polydispersity), ζ-potential analysis, drug loading efficiency, and colloidal stability in biological media.*In vitro* studies on triple-negative and HER2-positive breast cancer cell lines evaluated uptake efficiency, apoptosis induction, NF-κB pathway modulation, cytokine secretion, and cancer stem cell frequency. *In vivo* biodistribution, immune modulation, angiogenesis, and metabolic changes were assessed in orthotopic 4T1 tumor-bearing mice using optical imaging, ICP-MS quantification, MRI/CEST-MRI, flow cytometry, and HIC.

Results: Surface engineering significantly enhanced tumor accumulation and cellular internalization. PLGA-CU effectively suppressed TLR2-mediated NF-κB activation and reduced pro-tumoral cytokines (IL-6, TGF-β), while LIPO-DOXO induced robust apoptosis. The combination therapy demonstrated synergistic tumor growth inhibition compared to single treatments. Imaging analyses confirmed enhanced tumor localization and metabolic modulation, including normalization of tumor pH and reduced creatine-associated CEST-MRI signals. Importantly, immune profiling revealed increased $CD8^+$ T-cell infiltration and reduced immunosuppressive myeloid populations, highlighting microenvironment reprogramming.

Conclusion or Significance of the Work: This study demonstrates how rational nanoengineering, through hybrid polymer–lipid design, surface functionalization, and dual cargo integration, can overcome chemoresistance by simultaneously targeting cancer cells and the TME. The proposed modular nanotheranostic strategy provides a transferable materials framework for precision oncology and multifunctional nanomedicine design.

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Engineering Biomimetic Lipid Nanosystems for NMR-Based Characterization of Membrane Water Exchange

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Introduction and Objective: Understanding water transport across nanoengineered membranes is critical for the rational design of drug delivery systems and biomimetic materials. Analogously, the study of water exchange across biological membranes membranesprovides insights into cellular homeostasis, especially useful in studying cancer cells where changes in membrane transporters, channel proteins, and lipid composition occurs. [1]

We engineered lipid nanosystems with tunable curvature and composition (permeability, surface charge, etc…) to establish quantitative nuclear magnetic resonance (NMR)-based platform correlating membrane nanoarchitecture with transmembrane water permeability. The approach was translated to biological systems including red blood cells and prostate, pancreatic, and breast cancer cells[2].

Methodology: Liposomes (100–200 nm) with controlled lipid composition (DPPC vs POPC; charged vs neutral) were fabricated via thin-film hydration and extrusion..[3] Vesicles were loaded with Gd-HPDO3A or Yb-HPDO3A to modulate relaxometric response. Longitudinal relaxivity (r_1p) at 0.5 T and CEST-based quenching were used to extract permeability coefficients under controlled osmotic and pH conditions. The framework was translated to RBCs and eight cancer cell lines to validate scalability toward complex systems.Endogenous CEST@2ppm signals were correlated with water exchange properties, and aquaporin expression was evaluated by FACS and Western blot.

Results: Smaller liposomes exhibited significantly higher r_1p values, particularly in less permeable saturated membranes (DPPC-based), underscoring the critical role of the *surface-to-volume* ratio in governing water exchange. In contrast, unsaturated membranes (POPC-based) displayed intrinsically higher permeability, resulting in faster water exchange but reduced sensitivity to vesicle size differences due to the already rapid exchange regime.Osmotic stress markedly influenced membrane behavior. Hypertonic conditions enhanced water exchange, leading to increased relaxivity, whereas hypotonic conditions induced membrane destabilization and, in some cases, vesicle rupture. These findings demonstrate the strong dependence of water dynamics on both membrane composition and environmental conditions.In Yb-loaded liposomes, CEST signal *quenching* showed a clear correlation with membrane permeability. When translated to biological systems, distinct differences in membrane water exchange rates were observed across the analyzed cancer cell lines. Notably, in both breast and prostate cancer models, increased malignancy correlated with enhanced transmembrane water exchange, suggesting a link between membrane permeability and aggressive tumor phenotype. In contrast, pancreatic cancer cell lines exhibited restricted water mobility, consistent with their characteristically dense microenvironment and potentially reduced metabolic dynamics.

Conclusions: We establish a transferable NMR nanoengineering platform linking lipid composition, curvature, and water transport. These findings define design rules for next-generation nanocarriers and responsive membrane systemsasn provide information on cancer metabolism.

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Safety Evaluation of Quatsomes Following Repeated Subcutaneous Administration in Wistar Rats

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Introduction and objective: Quatsomes (QS) are highly stable nanostructured vesicles formed by self- assembly of quaternary ammonium surfactants and sterols, with promising applications in drug delivery and wound healing. This study aimed to evaluate the systemic toxicity profile of QS following repeated subcutaneous administration at low and high dose levels, independently of matrix-based formulations.

Methodology: QS were obtained by DELOS technology. A 28-day *in vivo* study was conducted on Wistar HsdBrl-Han rats of both sexes. Animals were divided into three groups: control (vehicle), low-dose QS (2 mg/kg), and high-dose QS (7 mg/kg). QS were administered subcutaneously every three days (total of 10 administrations). Clinical observations, body weight monitoring, hematological and biochemical analyses, cytokine profiling (ELISA), and histopathological examination of major organs (liver, kidney, stomach, heart, and lymph nodes) were performed 72 hours after the final dose .

Results: Repeated administration of QS demonstrated dose-dependent biological responses, with observable differences between low and high dose groups. Clinical observations and body weight trends indicated overall tolerability, while hematological and biochemical parameters suggested mild systemic effects at higher exposure levels. Cytokine analysis revealed modulation of inflammatory markers, and histopathological findings supported the presence of subtle organ-specific responses without severe pathological alterations.

Conclusion: The findings indicate that QSexhibit an acceptable safety profile under the tested conditions, with dose-related effects that remain within tolerable limits. These results support the continued development of QS-based nanomaterials for biomedical applications, particularly in wound healing strategies.

Keywords: quatsomes, nanomaterials, systemic toxicity, in vivo study, dose-response

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Quatsomes: Vesicles Formed by Self-Assembly of Sterols and Quaternary Ammonium Surfactants

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Cordoba A et al Patent Application EP24382895 (2024)

Predictive Assessment of Lignin-Cobalt-Cyanine Nanoparticles via Galleria mellonella: from Photodynamic Therapy to Antibacterial Efficacy

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Introduction and Aim: This study aims to evaluate the use of *Galleria mellonellalarvae* as a predictive *in vivo* model for assessing the efficacy and safety oflignin-based nanoparticles functionalized with a cobalt-phtalocyanine complex (CoPcLig NPs), designed to exert a dual action: i.photosensitizing agent in photodynamic therapy [1]; ii.antibacterial agent. *G. mellonella*, increasingly recognized for mimicking burn wound infections[2,3], was employed to investigate both the toxicity profile and the therapeutic efficacy of the developed nanomaterials.

Methodology: TheCoPcLig NPs antimicrobial activity was evaluated by determining the Minimum Inhibitory Concentration (MIC) and the Minimum Bactericidal Concentration (MBC) against *Pseudomonas aeruginosa* PAO1 [4] and *Staphylococcus* aureus SA01. G. mellonella was employed as an *in vivo* skin lesion model to assess the efficacy of the nanoparticles. After the realization of the lesion, larvae were treated with CoPcLig NPs and exposed to irradiation at 660 nm for 2 min. To evaluate the *in vivo* antibacterial activity of the nanoparticles, *G. mellonella* was used as a burn wound infection model. After lesion, larvae were infected with *P. aeruginosa* or *S. aureus* and treated with CoPcLig NPs.

Results: *In vitro* microbiological assays showed MIC values of ~2 mg/ml for *P. aeruginosa* and ~2.5 mg/ml for *S. aureus*. *In vivo*, the administration of the CoPcLig NPs followed by 660 nm irradiation was well tolerated in larvae with intact skin. In larvae with cutaneous lesions, irradiation significantly increased survival. Regarding infected wounds, NPs treatment increased survival by 40% in larvae infected with *P. aeruginosa*. Treatment of *S. aureus*-infected larvae did not improve survival, due to differences in infection kinetics, allowing the pathogen to persist in the hemolymph and evade the larval immune response[5].

Conclusions: This study successfully demonstrated the safety and efficacy of CoPcLig NPs, supporting the use of *G. mellonella* as a reliable non-traditional burn wound infection model.

Keywords: *Galleria mellonella*; Cobalt Nanoparticles; *Pseudomonas aeruginosa*; *Staphylococcus aureus*; Photodynamic Therapy.

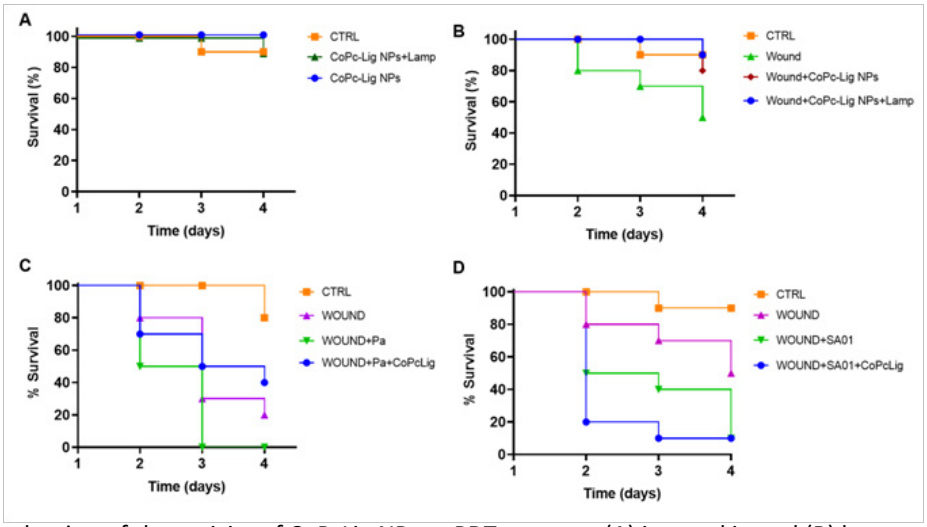

Figure 1: Evaluation of the toxicity of CoPcLig NPs as PDT agent on (A) intact skin and (B) burn wound inG. mellonella. Evaluation of the antibacterial properties of CoPcLig NPs in G. mellonella burn wound infection model against (C) P. aeruginosa and (D) S. aureus.

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Targeted Ge11-Conjugated Liposomes for Combined BNCT and MRI Visualization in Non-Small Cell Lung Cancer

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Lung cancer is one of the most prevalent malignancies, with approximately 80% of cases classified as non-small cell lung cancer (NSCLC). Boron neutron capture therapy (BNCT) has emerged as a promising therapeutic strategy by inducing localized cytotoxic effects in tumor cells which have internalized boroncompounds, through neutron-induced reactions [1]However, its clinical efficacy is limited by the relatively low selectivity of clinically available agents such as sodium mercaptoundecahydro-closo dodecaborate (BSH).

In this work, we used nanoparticle-based systems, particularly liposomes as an approach to enhance tumor targeting and intracellular uptake. We developed epidermal growth factor receptor (EGFR)-targeted liposomes functionalized with the Ge11 peptide to selectively bind NSCLC cells. The liposomes co-encapsulated BSH as a boron source for BNCT and a gadolinium-based contrast agent (Prohance®) for biodistribution tracking by MRI.

Liposomes were prepared using thin film hydrationmethod [2]with a POPC/Cholesterol/DSPE-PEG2000 formulation, incorporating DSPE-PEG2000-maleimide for peptide conjugation. Lipid films were hydrated with Prohance® and BSH solutions. Functionalization was carried out by incubating maleimide-containing liposomes with Ge11 peptide at 25 °C for 15 h. Characterization included size and polydispersity index (PDI) by dynamic light scattering, and stability studies, which wereperformed at pH 7,4 and 37 °C for 48 h. Cellular uptake was evaluated in A549 NSCLC cell line.

All formulations showed mean diameters between 100-120 nm with PDI values below 0,20. Optimal synthesis conditions were obtained using 100mM of Gd for hydration, with peptide conjugation efficiency maximized at pH 5,8 and a 2:1 molar ratio of DSPE-PEG2000-maleimide to Ge11. Liposomes remained stable with <16% release over 48 h. Functionalized liposomes showed higher cellular uptake compared to non targeted systems after 24 h incubation in A549 cells.

These results demonstrate the successful development of stable, EGFR-targeted liposomes with improved cellular internalization, demonstrating their potential for BNCT applications in NSCLC.

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Ionic Liquid-Assisted Lithiation of $FePO_4$ Particles Induces Surface Reconstruction of LFP Cathodes for Enhanced Electrochemical Performance

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The increasing demand for efficient and reliable energy storage technologies has driven rapid progress in advanced systems, particularly for lithium-ion batteries (LIBs) [1,2]. Among various energy storage solutions, LIBs stilldominate the market, due to their high energy density, long service life, and well-established manufacturing infrastructure [3]. Their overall performance is largely governed by the electrode materials, especially the cathode. In this context, $LiFePO_4$ (LFP) has emerged as a highly attractive material, offering excellent thermal stability, inherent safety, cost efficiency, and a theoretical capacity of 170 mAh g^{-1} [4]. Nevertheless, its practical implementation is hindered by inherently low electronic conductivity and moderate lithium-ion diffusion kinetics, resulting in reduced rate capability and lower energy density related to commercial counterparts [5]. Here, a scalable and effective approach is introduced to improve the electrochemical performance of LFP-particles-throughout the preparation process by ionic liquid-assisted lithiation of co-precipitated iron phosphate ($FePO_4$) conducted in the presence of 1-butyl-3-methylimidazolium hexafluorophosphate [BMIM(PF_6)]. The resulting composite shows enhanced electronic conductivity and lithium-ion transportation, attributed to lattice modification and the formation of a homogeneous carbon surface layer accompanied by fluorine-containing surface species. The structural characterization confirmed the formation of phase-pure LFP with a uniform particle morphology. Complementary studies revealed that the added BMIM(PF_6) contents enhance the physicochemical and electrochemical properties of the material. The identified modifications result in enhanced electrochemicalperformance, providing a viable strategy to address the intrinsic energy limitations of conventional LFP. This study underscores the potential of integrating ionic liquids into the lithiation process to enhance the performance of widely used battery materials, providing a practical route toward high-performance, industrially applicable cathode materials.

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Hybrid Nanomaterials for Optimized Cofactor-Mediated Bioelectrocatalysis

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The development of sustainable bio-electrochemical systems for CO_2 valorization[1] and high-precision diagnostic sensing[2] is currently limited by the fragile nature of enzyme-electrode interfaces. While dehydrogenases offer exceptional selectivity, their direct immobilization on conductive supports often leads to rapid denaturation and inefficient cofactor regeneration. This study addresses these challenges through a spatial decoupling strategy, utilizing metal or metal-oxide nanoparticles (NPs) deposited on the electrode surface, while the enzymes are sequestered within an external mesoporous silica support[3,4].

A comparative analysis was performed using Copper (Cu), Tin Oxide (SnO_2), Titanium (Ti), and Silver (Ag) NPs. The results demonstrate that the use of separated systems significantly enhances enzyme stability compared to architectures where enzymes are immobilized directly onto electrode surfaces. Optimization of the applied potential showed that -0.8 V vs. Ag/AgCl provided the most favorable conditions for CO_2 conversion using CuNPs. In the FDH-based system, the higher stability effect afforded by the silica matrix was prioritized over the peak rate of CO_2 production to ensure long-term operational viability.

Conversely, for the LDH-based sensing platform, a potential of 0.66 V vs. Ag/AgCl using Ti-modified electrodes yielded the highest performance. In this context, utilizing the modular approach with stabilized enzymes demonstrated superior reproducibility and sensitivity compared to standard configurations, providing a robust platform for inhibitor screening. This work highlights the advantages of modular bio-interfacial design, offering a versatile and resilient framework for high-performance industrial bio-electrocatalysis and diagnostic sensing.

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A Microfluidic Surface-Enhanced Raman Spectroscopy Platform With Gold Nanoparticles for Real-Time Monitoring of Biofilm Dynamics

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Komagataeibacterxylinusis widely recognized as a model organism for bacterial cellulose (BC) production and has attracted significant interest in biomaterials, plant-associated biofilms, and cell–cell signaling. Monitoring biochemical changes during biofilm formation in a rapid and non-destructive manner is essential for improving BC production processes.

In this study, a proof-of-concept platform is presented for time-dependent monitoring of chemicals released during *K. xylinus* biofilm formation using surface-enhanced Raman spectroscopy (SERS). This technique is highly sensitive to very low concentrations and enables real-time molecular-level analysis while requiring only minimal sample volumes.

Both chemically and biologically synthesized plasmonic enhancers were incorporated into the platform for comparison. Gold nanoparticles (AuNPs) were prepared using the Turkevich citrate reduction method, chosen for its reproducibility and compared with an in situ biologically mediated synthesis approach. A polydimethylsiloxane (PDMS) microfluidic bioreactor channel was fabricated by laser etching at 405 nm and integrated with SERS-active AuNP components, enabling continuous monitoring with spatial resolution and a low sample volume of 5 µL.

The resulting SERS data were analyzed using multivariate methods, with principal component analysis (PCA) applied to track subtle biochemical variations over time. PCA reduced the dimensionality of the dataset and highlighted temporal changes associated with the evolving composition of the biofilm.

Overall, this work establishes the feasibility of integrating AuNPs, a microfluidic device, SERS, and PCA into a single platform for real-time monitoring of BC production and biofilm dynamics. The approach may be extended to broader applications, including the study of metabolite exchange and the optimization of industrial bioprocesses involving bacterial cellulose.

Keywords: Surface enhanced Raman spectroscopy; Gold nanoparticles; Microfluidic bioreactor; Principal component analysis; Biofilm monitoring.

Engineering Fast Domain Switching for Spintronic Technologies

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Domain manipulation underpins emerging spintronic technologies, such as high-speed racetrack devices and THz logic, and quickly moving the domains is a key challenge on the path to faster and sustainable devices. Domain growth speed in ferrimagnets is limited by the spin-wave velocity - setting the ultimate speed limit for magnetic devices. While this relativistic regime has been achieved in crystalline ferrimagnets, they cannot be routinely integrated in devices. To enable technological utilization, we demonstrate relativistic domain wall motion in easy-to-integrate amorphous ferrimagnetic GdFeCo alloys [1]. The current-induced domain wall velocity saturates within 10% of the spin-wave speed of 2 km/s. These results are corroborated with analytical modeling. Our observation of relativistic dynamics in technologically relevant amorphous ferrimagnets opens the way for magnetic devices operating at the ultimate speed limit.

On the theory side, we explored the acceleration mechanisms of magnetic domain switching. Recent experimental advances introduced magnetic materials with non-uniform composition, allowing angular momentum compensation points and fast domain wall motion. We show that spatial non-uniformity [2] enables two new acceleration mechanisms: one analogous to the acceleration of a rocket due to mass loss, and another originating from the spin-wave velocity gradient [3]. Our results identify domains in non-uniform magnets as a new platform for fast and sustainable spintronic devices.

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Polarization Vortices in a Ferromagnetic Metalvia Twistronics

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Recent advances in moiré engineeringhave revealed new pathways formanipulating lattice distortions andelectronic properties in low-dimensionalmaterials. The development of methods forgrowing epitaxial films of complex oxidesand separating them from the substrate viadissolution of a sacrificial layer allowsthese materials to partake in the twistronicgame [1]. Here, we demonstrate thattwisted-stacking can induce polarizationvortices in freestanding metallic SrRuO3membranes, as shown in Fig. 1, despite thepresence of free charge screening [2]. Thesepolarization vortices are correlated withmoiré-periodic flexoelectricity induced byshear strain gradients, and exhibit apronounced dependence on the twist angle.In addition, multiferroic behavior emergesbelow the ferromagnetic Curie temperatureof the films, whereby polarization andferromagnetism coexist and appear tocompete, showing opposite twist-angledependencies of their respectivemagnitudes. Density functional theorycalculations provide insights into themicroscopic origin of these observations.Our findings extend the scope oftopological polarization design beyonddielectric materials and into metals.

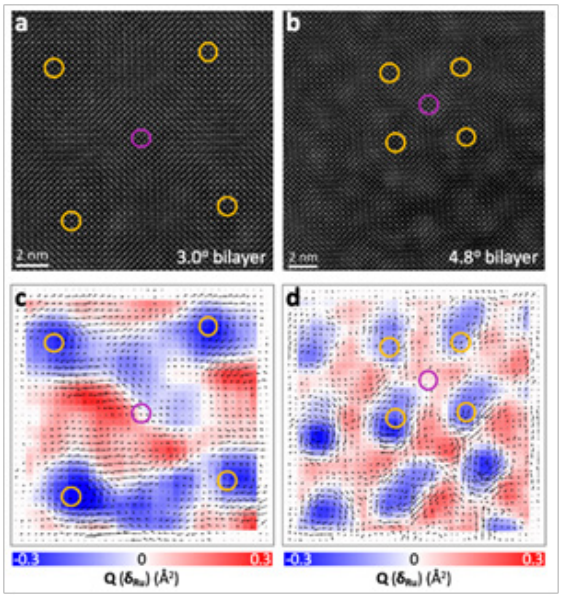

Fig. 1: Atomic-scale imaging of polar vortices in twisted-bilayer SRO membranes. a-b, Planar-view STEM-HAADF images focusing on the interface in the 3.0oand 4.8otwisted bilayers, showing Moiré patterns. c-d, Ru off-center displacement vector maps extracted from the STEM images focusing on the top layer, superimposed with their toroidal momentQ(δRu).

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Shape-Reconfigurable Bistable Nano-Metastructures Enabled by Modified Hybrid Position Feedback Control

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A bistable nanostructure possesses two stable configurations and one unstable equilibrium, which can be exploited to achieve functional metastructures at micro- and nano-scales. The nanostructure concept is based on bistable elements and associated controllers that are unstable-then-stable position feedback controllers. An arbitrary number of bistable segments, or so-called “metastructure elements,” are attached to each other in a serial or parallel manner to generate a “distributed” multi-stable nano structure. This new metastructure concept inherits the multiple bistable positions that its building blocks have; hence, the structure becomes multi-stable. It can hold these positions without consuming power and has the capability of achieving many shapes.

This work introduces a multi-degree-of-freedom nano-metastructure concept governed by a modified Hybrid Position Feedback (mHPF) controller. The proposed controller addresses challenges associated with undesirable cross-well oscillations in bistable systems by combining Negative Position Feedback (NPF) and Positive Position Feedback (PPF). The PPF component is modified through feedback linearization and disturbance rejection terms to ensure stability across multiple interacting elements. Through this approach, the chaotic nature of Duffing-type oscillations is not suppressed but leveraged to facilitate controlled transitions between stable states.

Implementation of complex control architectures at nano-scales is inherently constrained by limitations in sensing, actuation, computation, and energy availability. While mHPF provides improved regulation and stability compared to standard Hybrid Position Feedback (HPF), its structural complexity may limit direct nano-scale realization. In this context, mHPF can be interpreted as defining the achievable control envelope, whereas reduced HPF architectures offer a scalable pathway toward the practical implementation of shape-reconfigurable bistable nano-metastructures with minimal energy requirements.

Shell Effects in Electromigrated Pd Nano-Contacts

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Bulk Pd is a strong paramagnet because its d orbitals contribute significantly at the Fermi level, which brings Pd close to the Stoner criterion for ferromagnetism. Pd also plays an important role as it providesohmic contacts to low dimensional quantum materials. However, because of its limited stability with respect to oxidation, the fabrication of ultimately miniaturized structures at room temperature remains challenging. Furthermore, the multibandelectronic properties require a complex analysis compared to conventionally used noble metals. We carried out electromigration on electron beam fabricated Pd nanoconstrictions at room temperature in both N2 atmosphere and vacuum and compared the results of unipolar andbipolar electromigration. In both environments stable atomic contacts with well-defined preferred conductance values could be achieved.By systematic analysis of a large number of data sets in the conductance range up to 10 G0 (with theconductance quantum G0 = 2e^2/h), we identify preferential conductance valuescorrespondingtoshell-closureeffects[1]in the nanoconstriction despite its multiband character.

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Fabrication of Filter-Based SERS Substrates for the Gas-Phase Detection of Chemical Warfare Agent Simulants

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Chemical warfare agents (CWAs) and toxic industrial chemicals represent a threat in both civilian and military contexts, necessitating rapid, sensitive, and field-deployable detection methods. Conventional laboratory-base-danalytical methodsprovide high sensitivity but are limited by their reliance on bulky instrumentation, sample preparation, and lack of real-time capability, restricting their use in mobile or remote sensing platforms such as unmanned aerial vehicles [1].Surface-enhanced Raman spectroscopy (SERS) offers an appealing alternative by combining molecular fingerprint specificity with high sensitivity enabled by plasmonic nanostructures. While SERS has demonstrated success in detecting CWA simulants in both liquid and gas phases, most studies rely on rigid substrates and controlled flow geometries that do not reflect realistic airborne sampling conditions. In contrast, filter-based SERS substrates present an attractive platform due to their low cost, flexibility, and ability to integrate analyte collection and signal enhancement.Although, challenges remain in achieving reproducible hotspot formation and efficient gas-phase analyte sampling.

In this work, weaim to demonstrate the gas-phase detectability of various CWA simulants. We present theoptimization ofourfilter paper-based SERS platform fabricated via an aerosol method, called spark ablation [2]. Gold nanoparticleswere deposited onto cellulose filter paper, followed by either pre- or post-functionalization strategies using the material called APTES. Enhancement performance and signal reproducibility was evaluated by using Rhodamine 6G as a model probe. The optimized substrates were subsequently used for the gas-phase detection of aerosolized CWA simulants, including methyl salicylate, methyl phosphonic acid, and 2-chloroethyl ethyl sulfide. Our results reveal that analyte-dependent interactions with APTES-functionalized surfacesstrongly influence detectability, indicating that a single surface chemistry is insufficient for broad-spectrum sensing. These findings indicate the need for multiplexed paper-based SERS substrates with spatially tailored surface functionalities and demonstrate the potential of low-cost, flexible platforms as integrated sampling-detection systems for field-deployable, multi-analyte chemical threat monitoring.

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Dye-Free Chromophoric Microgel-Integrated Paper Platform for Multiplex Nucleic Acid Detection of Pathogenic Bacteria

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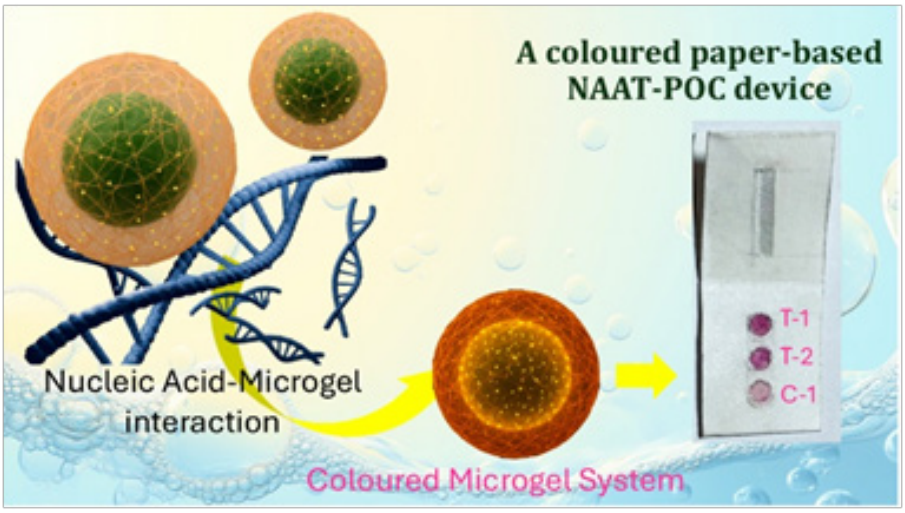
Rapid and accessible detection of pathogenic bacteria requires platforms that combine sensitivity, scalability, and minimal instrumentation.1,2Herein, we report a chromophoric microgel-integrated paper-based diagnostic platform for multiplex detection of both Gram-positive (*Staphylococcus epidermidis*) and Gram-negative (*Escherichia coli*) bacteria through nucleic acid amplification testing (NAAT).

In this approach, engineered chromophoric microgels were synthesised and used to functionalize a cellulosic substrate, which was further integrated into a paper-based device architecture. The platform was coupled with a loop-mediated isothermal amplification (LAMP) strategy to enable sensitive nucleic acid detection in a simplified format.3 The microgel-functionalized regions serve as a visual signal transduction interface, enabling direct readout without external labelling systems.

Upon amplification, the system exhibited a distinct colourimetric transition from pink to deep magenta/dark pink, whereas in non-amplified or control conditions, the signal attenuated, showing light pink colouration. The observed response is attributed to interaction-driven changes in the chromophoric microgel environment under reaction conditions, enabling differentiation between amplified and non-amplified samples. The platform further demonstrated the capability to simultaneously detect multiple bacterial targets, highlighting its multiplexing potential.

Overall, this work presents a microgel-enabled, amplification-integrated paper diagnostic system that combines nanoscale material design with molecular detection strategies. The proposed approach offers a scalable, dye-minimised, and field-deployable solution for rapid pathogen detection and holds promise for next-generation point-of-care diagnostics.



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Arrays of Piezoelectric Nanomaterials for Energy Harvesting and Implants

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Piezoelectricity relies on the capability of non-centrosymmetric crystalline materials to generate electrical charges on their surface in response to an applied stress, and vice versa. It is hence possible to generate electric power from a number of sources, such as the movement of objects and bodies, fluid impact and flow. Such power can be used to support consumable electronics and components in a wide range of applications from energy harvesting to biomedical engineering, environmental/healthcare monitoring, and soft robotics [1]. Although the piezoelectric effect was first discovered and exploited in inorganic materials, it has also been found in a range of other material classes, including biocompatible polymers such as poly(vinylidene fluoride), natural polymers such as cellulose and biomolecules. Among advantages in the use of such materials for building piezolectric devices there are: the mechanical flexibility, the lower cost associated to production and processing conditions as well as the possibility to target large-scale applications. Despite exhibiting a generally lower piezoelectric performance, this last group of materials offers excellent biocompatibility and biosafety and most of them are biodegradable therefore being an optimal choice to interface electromechanically with biological fluids and soft systems for sensing, stimulation, and energy harvesting.

To improve their piezoelectric performance and enable the integration into electronic systems, different approaches can be exploited such as micro- and nano-structuring, the fabrication of composites with the inclusion of organic/inorganic nanofillers and cooperative networks of nanofibers [2]. Here, diverse exploitable strategies to obtain outstanding piezoelectric performances in polymer nanofibers and arrays of nanocellulose are reported. Significant results include the realization of piezoelectric sensors and energy harvesting devices based on biocompatible materials and *in vitro* and *in vivo* experiments [3].

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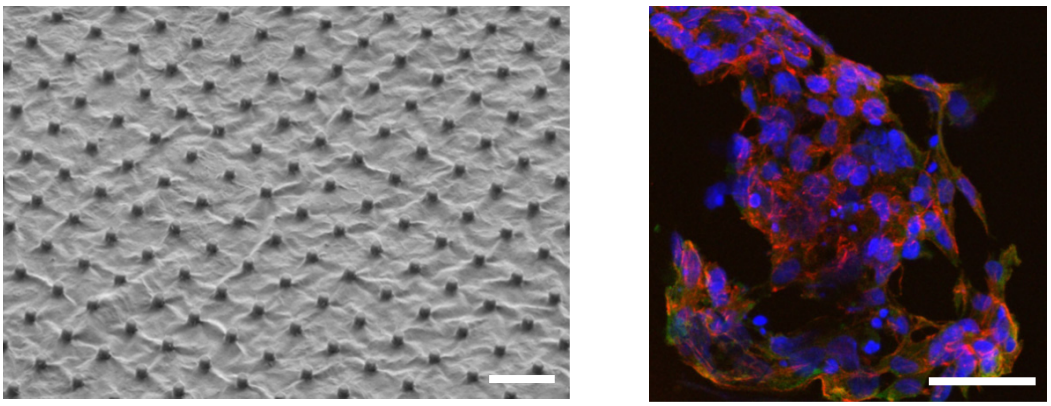

Figure 1. Left panel: scanning electron microscopy micrograph of an array of pillars realized onto biocompatible and biodegradable piezoelectric material based on nanocellulse (scale bar 2 μm). Right panel: representative confocal micrograph of HL-1 cells cultured a piezoelectric device and immunostained for nuclei (blue) and actin fibers (red). Scale bar: 25 μm.

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Mimicking Exosome Targeting Ability Through Engineered Artificial Nanocarriers

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Targeting represents one of the most desirable achievements in modern medicine, as the targeted delivery of therapeutics can enhance drug efficacy even at low doses while reducing off-target effects. The delivery of therapeutics and imaging agents to the desired site is therefore essential for the development of theranostic systems. Targeted approaches improve treatment safety, limit damage to healthy tissues, and enable patient-specific customization, contributing to the development of a personalized medicine [1]. Accordingly, drugs and nanomaterials have been functionalized with different moieties, to promote their accumulation in tumors or specific organs.

Among nanomaterials, porous silica nanoparticles (NPs) represent efficient drug delivery platforms thanks to their advantageous properties, such as biocompatibility, stability, tunable degradability, high drug loading capacity and straightforward surface functionalization. Our group has developed nanocarriers consisting of hollow silica NPs with a hydrophilic cavity and disulfide bonds embedded within the silica framework. In reducing environments, these disulfide bonds are converted to thiols, triggering the degradation of the nanocapsules (ssNCs) and the release of the loaded therapeutics [2].

In this contribution, we investigate how ssNCs can be combined with targeting strategies of natural and synthetic origin. Extracellular vesicles (EVs) play a key role in intercellular communication and retain the homing tropism of their parental cells, facilitating accumulation in specific tissues [3,4]. While natural EVs membranes allow the targeting of a specific organ [5], the low yield obtained from the purification procedure motivated the development of artificial lipidic formulations that mimic the targeting and internalization abilities of EVs[6]. Different artificial lipidic formulations were developed to mimic the bone-targeting ability of prostate cancer EVs and were designed to coat the silica nanocapsules, forming hybrid nanocarriers. Full-length proteins and protein fragments were incorporated into the lipidic coating of the bestperforming formulations, which were then evaluated *in vitro* and *in vivo*.

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3D Reconstruction of AFM Tips: An Open-Source Python Module Using Ray-Traced Particle Generation of Known Tip Characterizers

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Atomic Force Microscope (AFM) is a widely used technique to reconstruct 3D surfaces at the nanoscale. The resulting topographies are the result of the tip-sample convolution, allowing for sub-nanometer resolution in vertical measurements. However, lateral measurements are primarly affected by the shape of the AFM tip.

Understanding the shape and size of AFM tip is crucial in several fields, including biological applications, where it supports traceable nanomechanical measurements of biological and soft materials, and semiconductor industries, which face growing challenges in measuring increasingly smaller nanostructures.

Several methods for AFM tip reconstruction are presented in literature, and we focused on in situ characterisation using known tip characteriser for 3D reconstruction of the tips. We developed algorithms to generate height maps by utilizing multiple tip characterizers.

Our open-source Python module creates an idealized topography based on the tip characterizer, subsequently reconstructing the tip shape by eroding actual measurements, such as AFM images of spherical nanoparticles, against the idealized geometry. Since the fast and reliable generation of this ideal sample is not trivial, by adopting a ray-traced approach, we can produce numerous models of varying sizes and orientations. These can then be analyzed with an image recognition algorithm to match the ideal structures to the measured data.

To validate our module, we compared our results with existing AFM tip reconstruction methods presented in the literature.

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Development and Evaluation of Nanomaterials Synthesized from Agro-waste for Enhancement of CO_2 -reservoir Fluids Interactions: Implications for Carbon Geostorage and EOR Processes

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CO_2-EOR alternatives for carbon capture, utilization, and storage (CCUS) are considered key processes for achieving net-zero emissions by 2050 with the aim of limiting global warming. Currently, significant efforts are being made to develop safe alternatives for carbon capture and storage coupled with traditional enhanced oil recovery processes in the Oil and Gas industry. Thus, under these scenarios, there is an imminent opportunity to improve CCS/CCUS processes, where nanotechnology as an emerging technology can provide particular conditions that allow optimization of process performance. Nanotechnology developments in recent decades have shown exceptional advantages in the Oil&Gas industry. In particular, carbon quantum dots have recently gained great importance owing to their functionality as interwell tracers; however, the carbonaceous composition of CQDs could also allow certain interactions with molecules such as CO_2, which have not been thoroughly studied. Therefore, this study aims to develop and evaluate carbon quantum dots for interaction with CO_2 and reservoir fluids to reduce the interfacial tension (IFT) and increase CO_2 solubility in reservoir fluids. This study included nanomaterials synthesized from agro-waste sources such as coffee mucilage to promote the technical-economic feasibility framed in a circular economy to reduce costs and maximize the use of available resources. The objective of this study was to evaluate the effect of the addition of CQDs to brine and CO_2 streams assessed by fluid-fluid interactions measured by interfacial tension (IFT), adsorption, and solubility tests to determine the contribution and phenomenology involved in the interaction of CQDs with reservoir fluids. The synthesized CQDs were characterized by hydrodynamic size, Fourier transform infrared spectroscopy (FTIR), thermogravimetric analysis (TGA), and absorbance tests. A high-pressure device manufactured by Biolin Scientific was used to measure the IFT using the pendant-drop method. IFT measurements were performed from 1 to 12 Mpa at 25 and 40°C. The effect of the presence of CQDs on– CO_2-Brine solubility and the dosages was evaluated in a batch setup at pressures between 1 and 6 MPa. The results showed that carbonaceous nanomaterials increased CO_2 solubility owing to the presence of nitrogen groups, which promoted acid-base interactions between CQDs and CO_2 molecules, contributing to a higher retention of CO_2 trapped in the aqueous phase. Thus, CO_2 solubility increased to 28% at dosages of 0.01wt%. In addition, an IFT reduction of approximately 25% between the CO_2 streams and aqueous phase was obtained, which could lead to higher oil recovery and carbon geostorage. The major contribution of this study is the development of "Taylor-made" nanomaterials to enhance the interaction conditions between CO_2 and reservoir fluids to promote both higher recovery of oil and underground carbon storage.

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From the Laboratory to the Field: Design, Implementation, and Monitoring of Nanotreatments for Sand Control Based on Statistical Mixture Design

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Sand production in hydrocarbon wells is a persistent challenge in the oil and gas industry, leading to operational losses and increased costs owing to the need for constant interventions, premature equipment wear, and, in severe cases, wellbore undermining and permanent abandonment. In this context, this study proposes a nanotreatment train for sand control in Colombian oil wells that had been shut down owing to high solids production. The proposed nanotreatment comprises a commercial carrier fluid and silica nanoparticles synthesized from rice husk, which were assessed under static conditions considering fluid–rock interactions. The experimental program included zeta potential measurements, sand consolidation tests, and fines migration tests, with variations in concentration, soaking time, and temperature. Furthermore, statistical tools and a mixture design approach were used to identify an optimal nanotreatment formulation, achieving improvements of up to 3400% in consolidation performance, which increased to 23,500% with the incorporation of the nanoparticles. Zeta potential measurements indicated a transition toward more stable colloidal conditions, whereas dynamic tests showed reductions of up to 80% in fines production. Based on the laboratory results, a field pilot was implemented in two intervened wells by batch injection, including a nanotreatment dosage of 8600 ppm. After treatment application, the water cut returned to values comparable to those prior to shutdown, while the BSW decreased by up to 50%, suggesting a significant reduction in solids production. Additionally, an FTIR-based monitoring methodology was developed to quantify the return of the treatment in produced water. Overall, the laboratory and field results demonstrate the strong potential of the proposed nanotreatment as an effective and scalable solution for sand production control in hydrocarbon-producing wells.

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A Flexible and High-Sensitivity PVDF–TrFE/$BaTiO_3$ Piezoelectric Sensor for Physiological Monitoring

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Flexible and wearable sensing systems require materials capable of detecting low-intensity mechanical stimuli with high sensitivity and stability. In this work, a piezoelectric sensor based on electrospun PVDF–TrFE/$BaTiO_3$ nanofibres is developed for wearable physiological monitoring. The aim is to enhance piezoelectric performance through material design while maintaining flexibility and conformability for on-body applications.

The sensor is fabricated by electrospinning PVDF–TrFE with varying $BaTiO_3$ nanoparticle concentrations, followed by integration between metallic electrodes to form a flexible sensing layer. Structural characterisation shows increased β-phase content and improved crystallinity with the incorporation of $BaTiO_3$, which directly contributes to enhanced electromechanical response.

The optimised PVDF–TrFE (3 wt% $BaTiO_3$) sensor demonstrates a pressure sensitivity of 0.37 V/kPa with a stable and linear response under low-frequency loading. The device is capable of detecting subtle biomechanical signals, including arterial pulse and body motion. In addition, spatially resolved pressure sensing is demonstrated using a 3×3 sensor array, enabling localisation of applied forces.

Keywords: Piezoelectric sensor, PVDF–TrFE/$BaTiO_3$, Electrospinning, Wearables; Physiological monitoring

Day - 3

NanoSeries2026 Technical Session: NS (A)

Synthesis and Advanced Characterization of Nanomaterials & Nanostructures

Designing Nanothermometers Based on Rare-Earth Nanoparticles

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Rare-earth doped nanoparticles (RENPs) have gained significant attention in materials science owing to their unique optical, magnetic, and chemical characteristics. These nanomaterials are capable of both emitting and absorbing radiation within the second biological window (NIR-II, 1000–1400 nm), which makes them highly suitable as optical probes for in vivo photoluminescence (PL) imaging. Their spectrally narrow emission lines and long photoluminescence lifetimes further allow for multiplexed imaging without autofluorescence interference. In addition, the pronounced temperature dependence of the PL properties exhibited by certain RENPs enables their use in remote thermometric imaging. In particular, neodymium- and ytterbium-co-doped nanoparticles have been employed as thermal probes for in vivo diagnosis of processes such as inflammation.

Nevertheless, a limited understanding of how the chemical composition and structural design of these nanoparticles affect their thermal response has hindered further optimization. To address this issue, we have conducted a systematic investigation of their emission intensity, photoluminescence decay dynamics, absolute quantum yield, and thermal sensitivity as a function of core composition and size, as well as active-shell and outer inert-shell thicknesses.

Our results highlight the key role of each of these parameters in enhancing thermal sensitivity. We find that an optimal active-shell thickness of approximately 2 nm, combined with an outer inert shell of 3.5 nm, leads to maximized PL lifetime and thermal response. This behavior arises from the interplay between temperature-dependent back energy transfer, surface quenching effects, and the spatial confinement of active ions within a thin layer.

These findings provide a framework for the rational design of RENPs with improved thermal sensing performance.

Peptide-Based Nanofibers on a Mission: A Smarter Way to Treat Glioblastoma

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Combination therapy has emerged as a promising strategy for the treatment of aggressive cancers, including glioblastoma (GBM), by simultaneously targeting multiple biological pathways while potentially reducing systemic toxicity.[1] The current standard of care for GBM consists of surgical resection followed by radiotherapy and concomitant and/or adjuvant temozolomide (TMZ). Although TMZ is a widely used DNA-alkylating agent, its clinical efficacy is limited by poor aqueous solubility, short plasma half-life, low tumor accumulation, limited selectivity, and off-target toxicity.[2]

Recent advances in nanomedicine have focused on multifunctional platforms capable of responding to physiological and biochemical stimuli to improve drug delivery. Here, we developed biodegradable peptide-based nanofibers for the targeted and controlled co-delivery of TMZ and 1,3-bromopyruvate (BrP), a glycolysis inhibitor that disrupts mitochondrial function and cellular metabolism.[3,4] The nanofibers are composed of self-assembling peptides characterized by high biocompatibility, biodegradability, and tunable physicochemical properties. Specifically, the nanofiber structureconsists of two structural peptides P1 and P2, containing a hexa-alanine sequence and a lipidic tail forming the hydrophobic domain, along with hydrophilic amino acids. To enhance functionality, the nanofiber surface was engineered with multiple components (Figure 1): i)the cell-penetrating peptide gH625, enabling blood-brain barrier (BBB) crossing;[5]ii) the targeting peptide falGEA, recognizing both wild-type EGFR and the EGFRvIII mutant;[6]iii) TMZ or BrP conjugated via an MMP-9-sensitive linker for tumor-specific enzymatic release; iv) triphenylphosphonium (TPP^+) for mitochondrial targeting of BrP.[7]

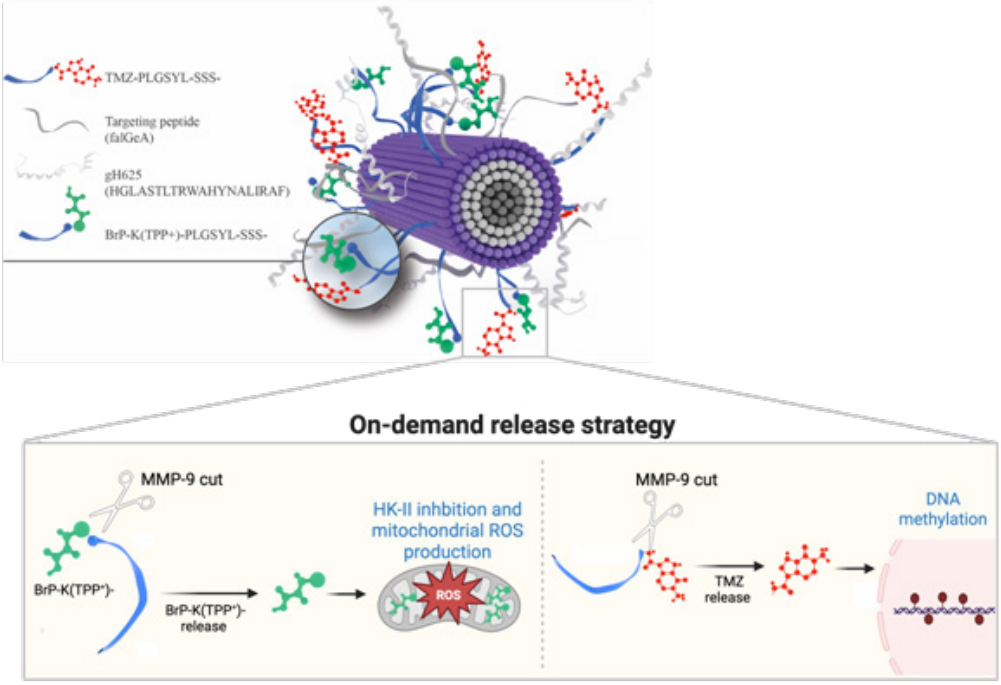

Figure 1. Representation of the nanofiber and and the hypothetical mechanism of the release of BrP and TMZ by the MMP-9 proteolytic cut.

Nanofibers were characterized in terms of aggregation behavior, structural stability, and morphology. Therapeutic efficacy was evaluated in U-87 MG glioblastoma cells cultured in 2D and 3D models. Mitochondrial targeting was assessed using isolated rat brain mitochondria, while BBB permeability was examined in a dynamic 3D in vitro BBB model, confirming the transport-enhancing role of gH625. Overall, these results highlight the potential of multifunctionalnanofibers as advanced platform for precision GBM therapy.

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On-Surface Encapsulation of Azafullerene Radicals Studied by STM

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Qubits based on the electronic spin of molecular radicals offer several advantages. It is possible to synthesize large amounts of exactly the same molecules and on-surface self-assembly makes it possible to obtain large, ordered lattices with tunable properties. One of the main challenges is preserving the radical state, due to their high reactivity.

I will present the example of azafulerene radicals C59N• deposited on Au(111). We used NEXAS and STM to demonstrate radicals are deposited on the surface and identified their spectroscopic fingerprint combining NEXAS and XPS measurements with DFT calculations [1]. We demonstrated that on-surface encapsulation of C59N• in [10]cycloparaphenylenenanohoops protects the radical state of encapsulated fullerenes against dimerization and inhibits coupling to the Au substrate [2]. In this talk I will show how we can combine STM and DFT calculations to understand the encapsulation process and the electronic structure of encapsulated azafullerenes.

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Peptide-Based Nanofibers to Enhance Food Protection

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The antimicrobial peptide (AMP) WMR-4, a myxinidin-derived sequence stabilized by Aib and D-amino acid substitutions, exhibits potent *in vitro* antifungal activity against *Fusarium oxysporum*. [1] Biophysical analyses indicate a lytic mechanism characterized by deep membrane insertion and subsequent leakage. Despite this efficacy, free WMR-4 fails to prevent fungal penetration through physical cellulose barriers, highlighting the limitations of peptide-only treatments in complex environments.

To address these challenges, we developed supramolecular nanofibers functionalized with both WMR-4 and the cell-penetrating peptide gH625 [2]. These nanostructures inhibited germ tube formation and significantly improved protection against membrane penetration compared to the free peptide. In biological models, the nanofibers effectively limited opportunistic saprophytic colonization in compromised apple tissues and preserved the integrity of intact tomato models, demonstrating specialized, barrier-specific therapeutic protection.

Characterization via Scanning Electron Microscopy (SEM) and Atomic Force Microscopy (AFM) confirmed the formation of stable nanoscale coatings that integrate into plant epidermal layers. These findings position WMR-4 as a formidable antifungal candidate and underscore the utility of AMP-functionalized supramolecular nanostructures as a robust platform for advanced agricultural applications [3].

Keywords drug delivery;nanofibers; *Fusarium oxysporum*; tomato fruits

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Polymer Functionalized or Polymer-Based Smart Nanoporous Membranes with Multi-functional Nanopore Activities

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Bioinspired, stimuli-responsive, polymer-functionalized porous membranes are promising platforms for precisely regulating nanopore transport toward applications in water management, iontronics, catalysis, sensing, drug delivery, and energy conversion.[1] While pore functionalization has enabled responsiveness to stimuli such as pH, pressure, or osmotic gradients,[1,2] key challenges remain: (i) achieving graded (beyond on/off) control of both anion and cation transport across pore sizes from a few nanometers to hundreds of nanometers, (ii) adding multifunctionality beyond permselectivity, and (iii) clarifying how analyte–nanopore interactions govern concentration-driven (ΔC) transport.

In this contribution, I will first show how Ca^{2+} (as a ligand) binds to phosphate-bearing, metal-ion-responsive polymer brushes in silica mesopores to gradually regulate both anion and cation transport, enabling selective metal-binding/sensing at sub-µM concentrations with memory.[3] Second, I will present new physical and chemical strategies for homogeneous chitosan deposition inside ion-track-etched polymer nanochannels, leveraging chitosan's biocompatible and versatile polyelectrolyte character, and demonstrate how chitosan can strongly modulate cation transport even in large-diameter nanochannels operating near the bulk conductance regime.[4] Finally, using photophysical readouts, I will elucidate the fundamental role of transient analyte–nanochannel interactions on ΔC-driven transport of the cationic luminescent probe $Ru(bpy)_3^{2+}$ through polycarbonate nanochannels across pH. I will summarize our published results at single-digit micromolar concentrations, where transient interactions between the analyte and charged nanochannel surface groups dominate transport,5 and present new, unpublished findings showing that increasing the analyte concentration into tens-to-hundreds of micromolar regimes can markedly reshape (and potentially invert) pH- and electrostatically driven transport trends. Overall, these results provide a mechanistic framework for interpreting concentration- and pH-dependent transport in polymer nanochannels and inform transport-based sensing and selective nanochannel labeling strategies.

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Advanced Quantitative Characterization of Fluorescent Nanomaterials Inside Living Cells.

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Advances in biophysics, soft matter, and medicine, as well as our understanding of cellular biochemistry, depend on progress in nanotechnology. One of the key factors in this field is the development of functional materials suitable for use in living cells, such as fluorescent nanomaterials. However, the transition from synthetic design to cellular application requires precise analysis of how these materials behave within the complex, crowded intracellular environment. Despite the availability of many modern techniques, the characterization of such materials in and with living cells often remains qualitative.

We will present case studies and a workflow for quantitative characterization based on fluorescence techniques—both single-molecule fluorescence correlation spectroscopy in single cells and population-level analyses—to determine interactions, or the lack thereof, of fluorescent molecules inside living cancer cells. In addition, we will present how to measure nanomolar concentrations inside living cells and discuss the associated challenges and pitfalls.[1] We will also demonstrate how diffusivity (mobility) inside cells can vary depending on molecular properties (e.g., functional groups, and hydrophobic/hydrophilic character).[2]

Finally, we will present exemplary characterization results concerning the cellular use of fully biosourced soluble diketopyrrolopyrrole derivatives. By correlating molecular structure with intracellular mobility (diffusivity) and concentration, this work establishes an approach for assessing nanomaterial–cell interactions. The results highlight the potential of biosourced fluorescent monomers as high-performance, sustainable alternatives to petroleum-based fluorophores [3] for advanced bioimaging.

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Sensing of Human Stress Biomarkers Using BODIPY-Functionalized Carbon Nanoparticles

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Stressisamajorfactorinfluencinghumanhealthandcognitiveperformance.Reliabledetection of stress-related biomarkers such as dopamine (DA), noradrenaline (NAdr), and cortisol is crucial for understanding physiological responses under pressure and for developing rapid diagnostic tools [1]. However, due to their structural diversity, current laboratory analyses are complex and time-consuming, and no single selective method exists for their simultaneous detection.

In this work, carbon nanoparticles (CNPs) functionalized with a BODIPY-based fluorophore (CNPs-Ar-BDPy) were developed for the optical discrimination of DA, NAdr, and cortisol in aqueous solution [2,3]. The design combines the surface functionality of CNPs with the recognition ability of the BDPy unit, enabling specific hydrogen-bond interactions with catecholamine groups and the C=O moiety of cortisol. The nano-sensor performance was investigated through UV–Vis and fluorescence spectroscopy, revealing distinct optical responses for each analyte. A preliminary study on the sensing mechanism highlights the role of the rigid aryl–BDPy spacer in enhancing recognition efficiency in water. Our nanosensor showsexcellentbindingconstantaffinitiestowardsthebiomarkerstested,withhighselectivity, as PLS-DA demonstrated. The importance of the nanoparticle core, as well as the covalent aromatic link with the bodipy fluorophore has been provided by control experiments by using single bodipy and other nanoparticles, non-functionalized and alkyl decorated.

This nanostructured platform represents a promising step toward rapid, one-pot detection of multiple stress biomarkers for future point-of-care applications.

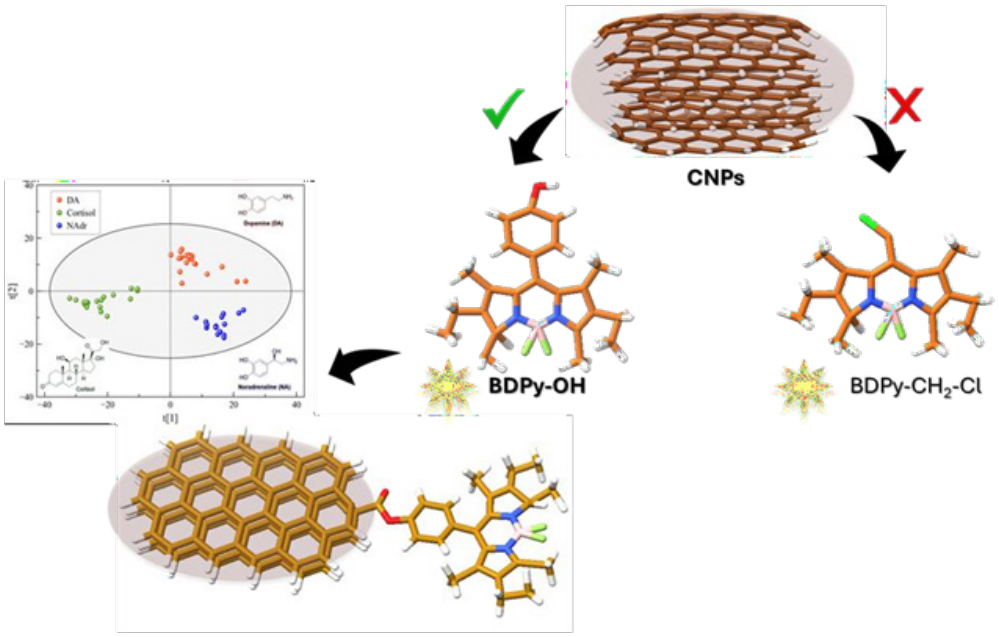

Figure1: Graphical Abstract

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Efficient Measurement of Particle Dispersion Length Distribution, and the Importance of Carbon Nanotube Length in Industrial Applications

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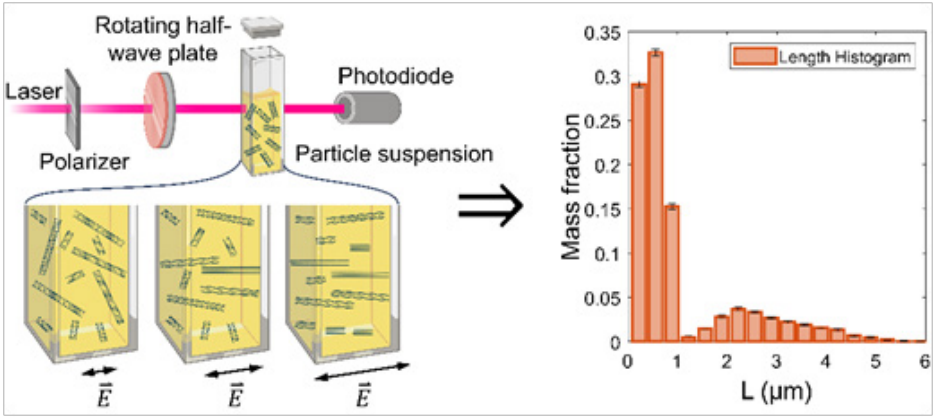
The efficient measurement of the length distribution of nanotubes, nanowires, and other 1D nanoparticles in solution is important to enable their incorporation into materials and devices, and to optimize their processing for properties of interest, such as thermal/electrical[1] conductivity or mechanical strength, in suspensions and composites. We present an electric-field (E-field) assisted optical-polarimetry technique to measure the length distribution of ensembles of high-aspect-ratio particles in dilute suspension[2]. By varying an appliedE-field strength to particles in solution and observing the relative degree of alignment, a robust computer algorithm is able to extract the length distribution histogram of particles. Following this, we comment specifically about the importance of knowing the length of carbon nanotubes forapplicationsin the fields of permeable membranes[3], conductive additives for batteries[4], and reinforcing additives for concrete[5]: “nano-rebar.”



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Metal–Organic Frameworks as Nanoscale Platforms for Solid-State Emission and Random Lasing

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Engineering light–matter interaction at the nanoscale is crucial to overcome the intrinsic limitations of fluorescent organic dyes, such as photobleaching and aggregation-caused quenching (ACQ), which restrict their application in solid-state and high-power photonics. [1] Metal–Organic Frameworks (MOFs), owing to their high porosity and large surface area, represent ideal platforms to overcome these limitations by providing spatial confinement, reduced aggregation, and enhanced photostability of embedded guests. [2]

In this work, we investigate the interaction between Rhodamine B (RhB) and Coumarin 343 (Cou) and the Zr-based MOF-808, showing how nanoscale confinement of emitting molecules within a porous matrix enhances their optical performance while providing effective shielding.

Upon encapsulation of the chromophores inside the MOF-808 cavities, we unraveled the photocycle of this novel dual-emitting nano systems through steady-state and time-resolved spectroscopy. We demonstrated the presence of an energy-transfer that populates the emissive states of RhB from initially excited MOF-808 states, clarifying the excitation dynamics of the combined system. In addition to suppressing ACQ, the MOF matrix provides photoprotection against UV and X-ray radiation, improving dye stability under harsh excitation conditions. [3]

We showed that, under high-power excitation, these systemscan exhibitRandom Laser (RL) emission, a phenomenon that arises from multiple light scattering events in disordered media and provides optical feedback without a conventional cavity. [4] Remarkably, this effect is demonstrated in the solid state, enabled by the dual role of MOF-808 as both host matrix and efficient scattering platform. In parallel, solution-based studies in water were conducted to systematically evaluate the effect of scatterer concentration. We show that MOF-808 nanoparticles act as efficient nanoscale scattering centers, significantly enhancing RL emission. [5]

Overall, these results establish MOFs as powerful platforms for stabilizing organic emitters, providing radiative shielding, and tailoring optical feedback, opening new avenues for solid-state photonics, sensing, and portable optoelectronic laser devices.

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Metastable Defect Engineering for Advanced Functional Materials

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Defects in extended solids are often viewed as imperfections to be minimized through optimizationandstructuralstabilization.However,manyhigh-performingfunctionalmaterials operateinregimeswherenon-equilibriumdefectchemistry,metastablecoordinationstates,and complex defect topologies actively influence ion transport, phase evolution, and long-range structural rearrangements. In the presentation, we will discuss how defect engineering in metastable states can serve as a unifying design principle for thin-film chalcogenides and tysonite-type fluoride-ion electrolytes. In the first part, we show how vacancies, defect complexes,andlocallydistortedcoordinationenvironmentsfacilitatedeepcationexchangeand latticereconstructioninmicrometer-thickAXmatricestowardsB_2X_3layers,whereA=Sn,Cd; B = Sb, Bi; and X = S, Se. Defect-mediated strategies allow ultrafast conversion at low concentrations of guest cations and moderate temperatures. Such routes help us to distinguish functionality from traditional thermodynamic and diffusion limits and access synthetic pathwaysthatareunavailableundernear-equilibriumconditions.Inthesecondpart,wediscuss howmechanochemicalsynthesisandcontrolledthermomechanicalprocessingoftysonite-type electrolytes can activate near single-crystal-like fluoride-ion conductivity in polycrystalline materials, using Ca-doped SmF3as a representative example. Kinetic stabilization of non-equilibrium defects enhances room-temperature conductivity and reveals slow relaxation processes.Thisisachievedthroughvacancytopology,anisotropiclatticeflexibility,andgrain-boundaryadjustment. Acrossthesedistinctsystems,weintroduceanapproachinwhichdefects, grainboundaries,interfaces,andkineticbarriersaretreatedasadjustableparametersratherthan passive constraints, thereby opening new avenues for programmable ion transport, flexible optoelectronic responses, and solid-state structures that can operate beyond conventional equilibrium-based optimization strategies.

Reconciling Dzyaloshinskii-Moriya Measurements via Spectroscopy Methods and Asymmetric Bubble Expansion in the Creep Regime

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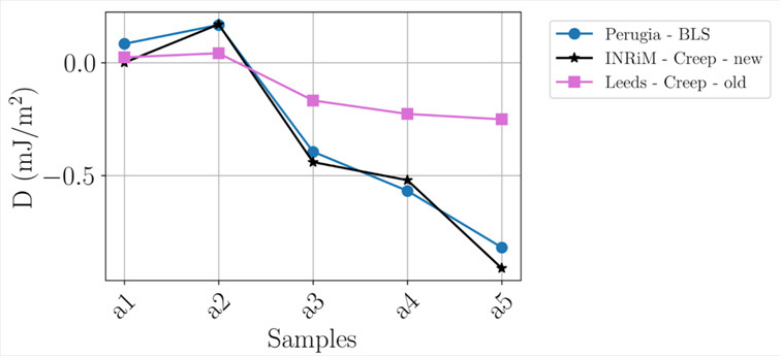
The interfacial Dzyaloshinskii-Moriya interaction (iDMI) [1-2] plays a central role in stabilizing chiral magnetic textures in heavy-metal/ferromagnet thin films and is therefore crucial for spintronic applications. Although asymmetric bubble domain expansion (ABE) measurements in the creep regime are attractive because they can be performed at room temperature and under low magnetic fields, extracting reliable iDMI values from them remains problematic, often disagreeing with Brillouin light scattering (BLS) and flow-regime measurements [3]. We hypothesize that this fundamental discrepancy arises because BLS natively disentangles chiral damping from chiral energy (iDMI) contributions [4-5], whereas ABE measurements mix them in a non-trivial way. To investigate this issue, we developed a semi-analytical model that incorporates both domain wall stiffness and chiral damping. Using symmetry decomposition [6], we derive a modified creep-velocity expression that allows these two contributions to be separated directly from Kerr microscopy creep curves. We validate the model through a comparative study combining BLS, creep, and flow measurements in perpendicular magnetic anisotropy thin films. The extracted DMI strengths are found to be in quantitative agreement with BLS and flow-regime results (see Fig.1). Our results provide a consistent framework for accurate iDMI quantification in the creep regime and help resolve a discrepancy in the spintronics literature.



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Day - 3

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Nanomaterials for Energy Applications: From Batteries to Solar Cells

Electrochemical Doping Effects in Mo(VI) doped $BiVO_4$ Photoanodes

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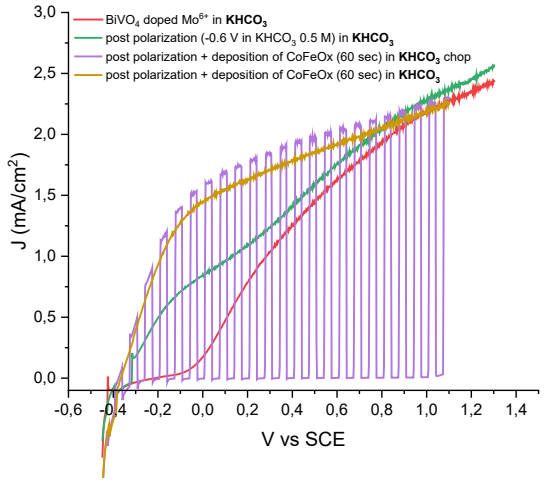
We herein report that cathodic polarization at -0.6 V vs SCE of Mo(VI) doped BiVO4[1-3] electrodes obtained via sol-gel methods causes a reversible but long lived enhancement in their photoelectrochemical response under simulated sunlight. This treatment results in a considerable anticipation of the photoanodic response of this material, whose photo-onset shifts by ca. 400 mV vs SCE. This effect persists, even amplified, in the presence of overlayers based on CoFeOx,[4,5] which are believed to enhance the interfacial charge separation. Structural investigation via XPS, XRD and Raman, coupled with EIS and IMPS measurements lead us to explain the observed photoelectrochemical behavior as due to the filling of trap states induced by Mo(VI) doping located in energetic proximity with the conduction band edge of $BiVO_4$. This leads to an improvement of $BiVO_4$ conductivity, allowing reducing the overpotential for charge collection and reducing the bulk recombination processes. This can represent a further strategy to improve the photoanodic properties of BiVO4in photoeletrochemical water splitting and a way of contrasting its photocorrosion.



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From High-Pressure Synthesis to Phonon Engineering in PbTe-Rich High-Entropy-Like Alloys

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PbTe-based thermoelectrics remain a reference platform for mid-temperature energy conversion, and multi-component alloying is a natural route to further suppress lattice thermal conductivity.WeinvestigatePbTe-rich-multicomponentchalcogenidessynthesizedunderhigh pressure, where Sn, Se and Sb are introduced at the >10% level to approach a high-entropy–like regime. High-pressure synthesis in a belt press stabilizes nominal compositions such as $Pb_{2.5}SnTe_3Se$,$Pb_{2.5}SnSbTe_3$and$Pb_{2.5}SnSbTe_3$Seintherock-saltstructure,whileGeisrejected from the main phase and forms Ge–oxide precipitates, as shown by STEM/EELS.

Synchrotron and neutron powder diffraction reveal that the average crystallographic structure remains Na-Cl-type, but with systematic trends in lattice parameter and unusually large static components of the atomic displacement parameters, pointing to strong site disorder on both cation and anion sublattices. Pair-distribution analysis can nevertheless be described to first approximation by a scaled PbTe model, implying that the disorder manifests more in force constants and local environments than in large bond-length bifurcations. Inelastic neutron scattering on a representative five-component PbTe-rich alloy provides the phonon density of states, which we compare to PbTe and to previously studied SnSe-based alloys. The spectra indicate rather harmonic phonons, suggesting that the reduced thermal conductivity observed in preliminary high-temperature measurements arises mainly from disorder-driven phonon scattering rather than extreme anharmonic softening.

We complement the experimental picture with first-principles calculations on chemically disorderedsupercells,usedtoexaminesiteoccupancypreferences(inparticularforSb)andto quantify bond-length distributions. Altogether, the combination of high-pressure synthesis, advanceddiffraction,localprobesandinelasticneutron-scatteringoffersadetailedviewofhow multicomponentdisorderinPbTe-basedalloysreshapesthephononlandscapeandimpactstheir potential as thermoelectric energy materials.

We thank the ILL, ESRF, and ALBA for facilities. Electron microscopy observations were carried out at the Centro Nacional de Microscopia Electronica (CNME-UCM). Funding was providedbyMCIN/AEI(grantnos.PID2021-122477OB-I00,PID2024-162816OA-I00, RYC2021-033518-I)andNextGenerationEU.

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Metal Oxide Nanocrystals for Light-Driven Energy Applications

Rubino A*, Martin I., Camellini A., Petrini N., Ranjan P., Squiccimarro E., Kuriyil S., Panagattil A., Kriegel I.

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Dopedmetaloxides are a versatile and fast-evolving class of materials for solar energy conversion and storage [1]. Through controlled doping, their optical and electronic properties can be finely tuned, enabling precise control over carrier concentration and plasmonic behavior. This tunability makes them particularly appealing for light-driven energy applications. Among these materials, degenerately doped metal oxide nanocrystals, such as indium tin oxide (ITO), stand out for their unique combination of optical transparency, electrical conductivity, and photochemical stability [2]. Advanced colloidal synthesis strategies allow careful engineering of the electronic band structure and charge-carrier density, leading to localized surface plasmon resonances (LSPRs)in the near-infrared region [3]. These LSPRs can be harnessed to enhance light absorption, drive photoelectrochemical reactions, and promote photocatalytic processes, thereby directly linking light harvesting with charge storage. Our research aims to elucidate how the dopant species, concentration, and spatial distribution influence the optoelectronic response of these systems, from colloidal dispersions to solid-state assemblies. Using spectroscopic techniques, we investigate the interplay between optical and electronic properties, uncovering phenomena such as multiple charge-transfer events occurring within a single nanocrystal [4]. Controlling photogenerated charges opens new pathways for direct solar energy storage and for the development of hybrid devices that integrate plasmonic materials with capacitive charge storage components. In addition, solution-based processing provides a cost-effective and flexible route for combining metal oxide nanoparticles withcomplementary materials to enhance performance or introduce new functionalities [5]. Overall, doped metal oxide nanocrystals represent promising building blocks for next-generation solar-to-electric and solar-to-chemical energy conversion technologies, offering stability, tunability, and multifunctionality within a single nanostructuredplatform.

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Tailoring Photoelectrochemical Properties with Atomic Layer

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Green hydrogen production via solar-driven water electrolysis is a cornerstone of a sustainable energy future. Photoelectrochemical (PEC) water splitting stands out as a direct and efficient pathway for solar-to-hydrogen conversion, with theoretical efficiencies comparable to photovoltaic-electrolysis combination (up to ~35%)[1]. Unlike photovoltaics, PEC systems benefit from enhanced reaction kinetics at elevated temperatures, offering a unique advantage for large-scale deployment.

Despite recent breakthroughs–such as achieving a record 19% efficiency using expensive III-V semiconductors and noble metal catalysts [2]–the cost of hydrogen production remains non-competitive. To bridge this gap, efficiency, durability, and cost-effectiveness of photoelectrodes must be significantly improved.

This presentation will explore key strategies for photoelectrode optimization, focusing on surface structuring to enhance light absorption and active surface area, co-catalyst integration to accelerate water-splitting reactions, and protective coatings to extend material lifetime under harsh operating conditions.

We will highlight the pivotal role of Atomic Layer Deposition (ALD), a versatile technique enabling conformal thin films and well-dispersed nanoparticles on nanostructured surfaces. Following an overview of PEC principles and challenges, we will present recent findings on protecting silicon-based photoelectrodes [3]. The discussion will cover corrosion mechanisms, material limitations, and how tailored ALD process parameters can enhance the functional properties of protective and catalytic layers, paving the way for more efficient and durable PEC systems.

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Mesoporous WO_3 Nanoplates: Smart Materials for Integrated Photonic Energy Storage

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We report the design and synthesis of a multifunctional transition metal oxide material engineered for next-generation photo-assisted lithium-ion batteries. Using a facile hydrothermal method, we synthesized highly crystalline, porous tungsten trioxide (WO_3) nanoplates with a monoclinic structure and an optical bandgap of approximately 2.78 eV. The material exhibits broad UV–visible light absorption as well as high thermal and chemical stability, making it a promising candidate for integrated energy storage and harvesting applications. Structural and spectroscopic analyses confirm its uniform morphology, high purity, and strong light–matter interaction. When employed as a free-standing electrode, WO_3 delivers a remarkable capacity of 1150 mAh g^{-1} at 0.1 C under illumination, far exceeding its theoretical limit, and retains 800 mAh g^{-1} at 1 C over 400 cycles. These enhancements are attributed to the synergistic effects of the material's high surface area, efficient lithium-ion diffusion, and photogenerated charge-carrier activity, as revealed by electrochemical impedance spectroscopy and photoluminescence decay analysis. These findings establish nanostructured WO_3 as a smart, dual-functional material with strong potential for advanced energy-photonic devices, in which efficient charge transport and light responsiveness are essential.

Materials Development Strategies for Low-Energy Memristors: From Halide Perovskites to Organic Electrochemical Transistors

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The design of efficient neuromorphic hardware requires memristive devices that emulate synaptic plasticity with minimal energy consumption per event. To date, metal oxides (such as TiO_2 and HfO_2) represent the most mature technology in this field.[1] However, the exploration of emerging mixed ionic-electronic conductors (MIECs) has opened new pathways to enhance performance through targeted materials development and interface engineering.This presentation provides a general guideline for designing efficient memristors for low-energy applications, focusing on two recent material breakthroughs.

First, we discuss advancements in halide perovskite memristors. We demonstrate that energy consumption can be drastically reduced by introducing lithium fluoride (LiF) interfacial layers, which serve as a source of small Li+ ions.[2] Furthermore, we highlight A-site cation engineering (e.g., Cs,Rb,K) as a strategy to control lattice distortion and ion migration barriers, allowing the optimization of the trade-off between synaptic plasticity and long-term stability.[3] We also examine the use of pre-oxidized silver (AgI) buffer layers to decouple volatile responses (ionic double-layer formation) from nonvolatile memory (Ag filament formation).[4]

Second, we present advances in organic electrochemical transistors (OECTs). Focusing on high-performance n-type conductors such as n-doped poly(benzodifurandione) (n-PBDF), we show how controlling charge carrier density through reversible doping and dedoping enables high electrical conductivity and ambient stability.[5,6] We highlight that proton (H^+) migration from the electrolyte is the primary mechanism for triggering synaptic plasticity in these devices, achieving high-quality potentiation and depression at low gate voltages (0.8 V).

Overall, these examples underscore that the synergy between compositional tuning and interface design is essential for exploiting ion migration in next-generation, energy-efficient neuro-inspired computing.

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Laser-Engineered Ag–CuO_x Composite Nanomaterials for Water Splitting Applications

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One of the central challenges in water splitting research is that the true active state of oxide electrocatalysts often emerges only under operating conditions, making structure–performance correlations fundamentally non-trivial. Copper oxides (CuO, Cu_2O, and non-stoichiometric CuO_x) are particularly attractive due to their chemical flexibility and redox-active surface states. However, their electrocatalytic behavior is highly sensitive to mixed valence ($Cu^{2+}/Cu^{+}/Cu^{0}$), defect chemistry, and dynamic structural reconstruction, rendering predictive catalyst design inherently complex.[1–3]

Here, we present a laser-driven strategy for engineering Ag–CuO_x composite nanomaterials using pulsed laser processing in liquids. Laser irradiation of suspended nanoparticles induces localized melting–solidification cycles combined with solvent-mediated redox transformations, enabling the formation of non-equilibrium multiphase architectures without surfactants or chemical reducing agents.[4,5] By systematically tuning laser fluence and solvent environment, we deliberately modulate phase distribution, oxidation states, and nanoscale interfacial organization.

Preliminary electrochemical evaluation in alkaline media confirms catalytic activity toward the hydrogen evolution reaction and reveals a clear dependence of the response on laser-defined structural parameters. The data suggest that catalytic behavior emerges from the collective interaction of metal/oxide and oxide/oxide interfaces rather than from any single dominant phase.

Ongoing investigations integrate electrochemical characterization with theoretical modeling to rationalize the role of metal/oxide and oxide/oxide interfaces in governing catalytic response. Computational insights into interfacial energetics and electronic structure complement experimental observations, enabling a more predictive framework for catalyst design.

Taken together, these results position non-equilibrium laser processing as a rational and adaptable platform for designing multiphase oxide-based catalysts, where functionality is encoded at engineered interfaces instead of isolated bulk phases.

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Emerging Chalcogenide Materials for Indoor Photovoltaics

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Chalcogenides have long been a staple of the thin film photovoltaics community, offering higher stability than their halide counterparts, but comparable facile processability. Recently, these materials have gained attention for indoor photovoltaic (IPV) applications, including Sb_2S_3, which has now reached champion indoor power conversion efficiencies (PCEi) of ~20%.[1] However, the open-circuit voltage (V_{OC}) falls well short of its radiative limit, restricting the efficiencies achievable. There are two main competing hypotheses for this V_{OC} bottleneck: self-trapping vs. defect recombination. In the former, observation of red-shifted photoluminescence led to claims that self-trapped excitons form in Sb_2S_3, restricting V_{OC}s to 800 mV under 1-sun illumination,[2] which is indeed the value the field has asymptotically approached. However, computational analyses have found no evidence of self-trapping or small polaron formation.[3] To experimentally address this debate, we reduced the grain boundary density of Sb_2S_3 thin films through use of sodium citrate additives to the precursor bath. In lowering the defect density, we achieved a VOC of 824 mV under 1-sun illumination, the highest reported value to date.[4] Further, temperature-dependent mobility measurements are consistent with large polaron formation, disproving the hypothesis of self-trapping. Our work shows that Sb2S3 can indeed be improved towards its radiative limit through defect engineering, and we identify sulfur vacancies and Sb-on-S antisites as deep traps present within our films.4

More broadly, I will conclude this talk by discussing opportunities with the broader family of chalcogenide semiconductors for indoor photovoltaics, including Se and kesterites. I will discuss current progress, challenges and future pathways to realise high performance.

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Day - 3

NanoSeries2026 Technical Session: NS (B)–II

Nanomaterials for Energy Applications: From Batteries to Solar Cells

Nanostructured Redox-Active Polymer Networks for Advanced Electrochemical Energy Storage

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The development of functional materials with controlled architectures at the nanoscale is a key challenge in nanotechnology-driven energy storage. In this contribution, we present recent advances in redox-active polymer networks with tailored nanoporosity, focusing on conjugated microporous polymers (CMPs) as model systems bridging molecular redox chemistry and nanostructured electrodes.

CMPs combine permanent microporosity, extended π-conjugation, and redox activity, enabling efficient ion and electron transport at short diffusion lengths. Through rational molecular design and polymerization strategies, CMPs with high specific surface areas (SBET > 700 $m^2\ g^{-1}$), controlled micro/mesoporosity, and robust frameworks were engineered to suppress electrode's dissolution while maximizing electrochemical accessibility.

Using anthraquinone- and phenazine-based redox units, CMPs were synthesized via Sonogashira cross-coupling polymerization and further integrated with conductive nanocarbons through miniemulsion and solvothermal routes, yielding hybrid nanostructured materials with enhanced electronic conductivity. The impact of nanoscale confinement and pore architecture is demonstrated in both non-aqueous and aqueous battery systems, where CMP-based electrodes exhibit high capacity utilization, fast redox kinetics, and exceptional cycling stability (>10,000–20,000 cycles).[1,2]

Beyond aqueous systems, CMPs and hyperbranched redox polymers were successfully implemented in lithium-, sodium-, and aluminium-based batteries, highlighting the broad applicability of redox-active nanopolymers across different electrochemical environments.[3, 4] Strategies to enhance technological relevance, including high mass loading electrodes (>30 mg cm^{-2}), reduced inactive components, and scalable processing routes, will be discussed.

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Electrocatalysis at Scale: Bridging Nanomaterials, Lab Reactors, and Industrial Electrolyzer Stacks

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Electrocatalysis is widely recognized as a key technological pillar for the energy transition, enabling the conversion of renewable electricity into fuels and chemicals(1). While tremendous progress has been achieved in the development of advanced nanostructured catalysts for reactions such as water splitting and, more in general, electroconversion ofsmall-molecules, translating these materials from laboratory discovery to industrially relevant electrochemical systems remains a major challenge. In particular, catalyst performance reported in fundamental studies often does not directly translate to practical devices operating at high current density, elevated temperature, and long-term stability(2).

In this talk, I will discuss how research at the Italian Institute of Technology (IIT) addresses this gap by integrating nanomaterials design with electrochemical engineering and electrolyzer stack development. Our work spans from the synthesis and characterization of nanostructured electrocatalysts to the development of testing protocols under industrially relevant conditions, including high current densities and continuous operation. Particular focus will be given to reactions relevant to sustainable chemical manufacturing, such as water electrolysis for green hydrogen production(3,4) and emerging electrochemical conversion pathways involving CO2(5) and nitrogen-containing molecules(6,7).

Beyond catalyst discovery, we explore how insights obtained at the nanoscale translate into practical device architectures, including membrane electrode assemblies and zero-gap electrolyzer configurations. Finally, I will present recent efforts to scale these concepts toward industrial systems through the development of AEM-based electrolyzer stacks within the startup Antares Electrolysis. Overall, the presentation will remark how the deployment of electrocatalytic technologies for sustainable energy and chemical production can only be achieved by bridging nanomaterials science and electrochemical engineering.

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Advances in (Post-)Transition Metal Nanostructures for Efficient Electrochemical CO_2 Reduction

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Electrochemical CO_2 reduction to valuable products, powered by renewable electricity, is particularly promising, as it enhances the integration of electricity into the energy mix. However, despite the potential, it faces challenges, such as slow kinetics, low product selectivity and poor durability. To overcome these obstacles, the development of highly active, selective, and stable catalysts is crucial.

Our research focuses on advancing catalyst development to enable effective CO_2 reduction. We have recently developed Cu-based, Ag-based and Bi-based materials for selective production of C_2 products, CO and HCOOH, respectively (Figure 1) [1,2].

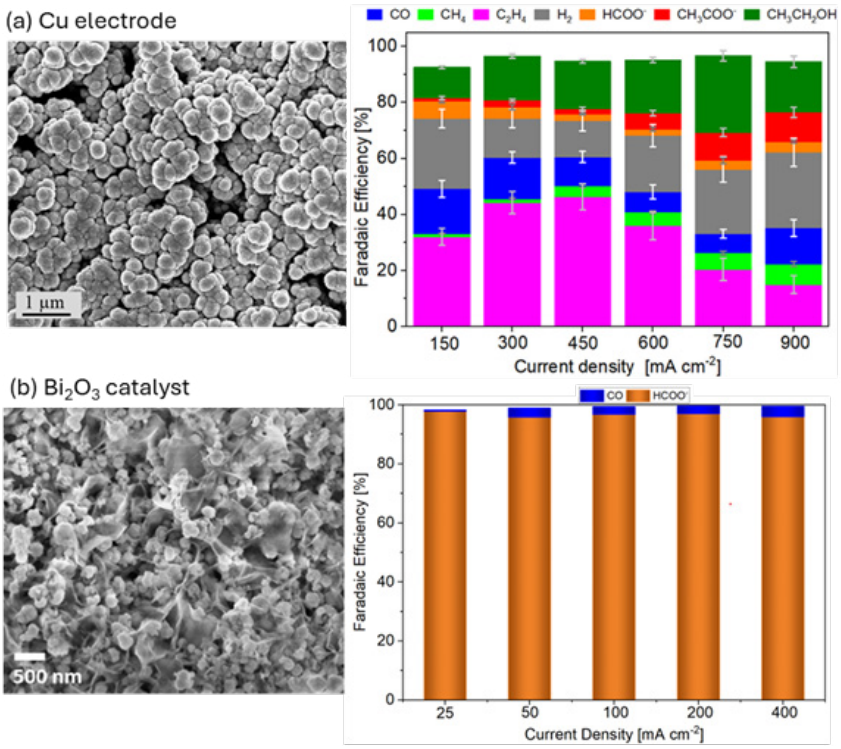

Figure 1: Sputtered Cu electrodes and microwave-assisted synthesized Bi_2O_3 catalysts.

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CeO_2Based Nanostructures Prepared by Different Synthetic Routes for Electrochemical Nitrate-to-Ammonia Conversion

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Thedevelopmentofsustainablenitrogenmanagementstrategieshasstimulatedgrowing interest in alternative pathways for ammonia production and nitrate remediation. Among these, the electrochemical nitrate reduction reaction (E-NO3RR) represents a promising approach to simultaneously remove nitrate contaminants from water streams while producing ammoniaunder mild conditions, offering a potential complement to the energy-intensive Haber–Bosch process.[1,2]

In this work, $CeO_2$and Fe-doped CeO_2nanostructures are investigated as earth-abundant electrocatalysts for the electrochemical reduction of nitrate to ammonia. The catalysts were synthesized using two different synthetic approaches, namely conventional co-precipitation and reverse micelle methods, enabling modulation of particle formation processes and nanoscale structural features. The obtained materials were characterized using complementary structural and spectroscopic techniques to investigate the relationship between synthesis method, catalyst structure and electrochemical behaviour. Preliminary electrochemical results indicate that all synthesized materials exhibit promising activity toward ammonia production. Among them, CeO_2prepared via co-precipitation shows the best performance under the investigated conditions. These findings highlight the key role of the synthetic pathway in determining the properties and catalytic behaviour of CeO_2-based nanomaterials.

Ongoing work aims to further clarify the influence of Fe incorporation and nanoscale structural characteristics on activity and selectivity in nitrateelectroreduction. Overall, this study provides insight into the structure–activity relationships governing CeO_2-based nanostructures for sustainable nitrogen valorization.

Keywords: CeO_2nanostructures, Electrochemical nitrate reduction; Green Ammonia synthesis; Synthetic pathway; Nitrogen valorization

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Applications of Two-dimensional Materials in Energy, Water, and Healthcare

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The unique physical properties of multifunctional two-dimensional (2D) materials continue to open new frontiers in fundamental and applied research across water purification, healthcare, and energy applications (Fig. 1). In this work, we expand the design space for additive electronics manufacturing by advancing the synthesis of 2D and layered-materials-based inks, enabling innovations in sensors, energy harvesting and storage devices, and flexible hybrid systems [1-3]. In water applications, we introduce a flowing electrode capacitive deionization (FE-CDI) system utilizing Ti3C2Tx MXene electrodes to efficiently remove and recover ammonia from synthetic wastewater and carbonates from simulated ocean water. This system demonstrates promising potential for managing nitrogen and carbon cycles while improving access to clean water [4]. In healthcare, the intersection of graphene and biology offers a powerful avenue for musculoskeletal tissue engineering, where graphene's exceptional physical properties contribute to fundamental biological insights [5-7].

Together, these findings highlight the transformative role of 2D materials beyond graphene in addressing critical engineering challenges and advancing sustainable solutions across diverse fields.

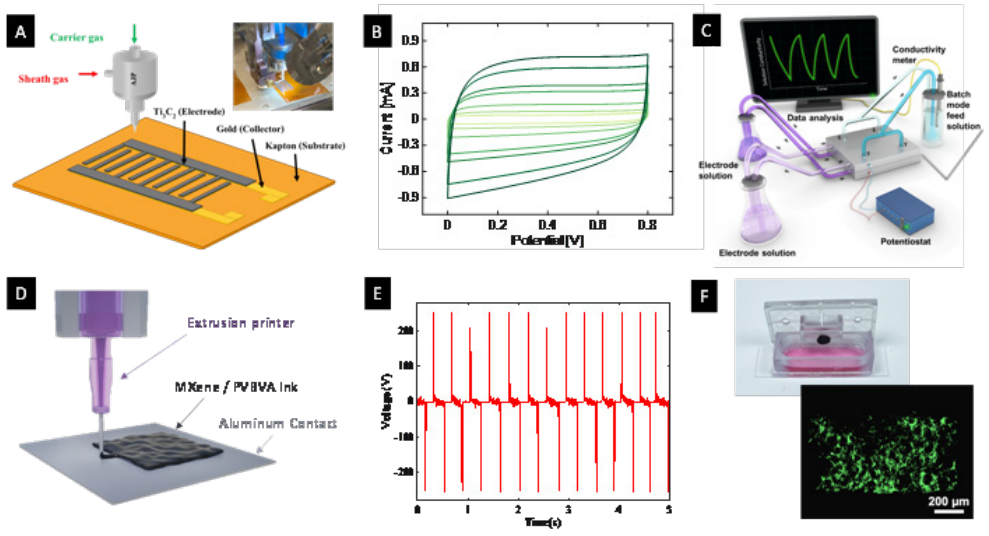

Figure 1. Overview of 2-dimensional materials in energy storage, harvesting, water purification, and tissue engineering. A,B) Schematic and optical image of aerosol jet printed Ti3C2Tx supercapacitor and its C-V performance. C) Schematic illustration of flow-electrode capacitive deionization system used with Ti3C2Tx flowing electrodes.

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Sustainable Freestanding Flow Battery Electrodes for Long-Duration Energy Storage

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Escalating greenhouse gas emissions and associated climate volatility represents an existential threat to humanity. Deep and rapid decarbonisation of the global energy systems require the replacement of fossil fuels with renewable resources (e.g., wind, solar). However, these resources are intermittent and unpredictable challenging the existing grid infrastructure which is based on the just-in-time dispatchable generation enabled by combustion of fossil fuels. As such, flexible energy management systems, including electrochemical energy storage technologies, are urgently required to enable reliable electricity delivery from the variable assets. Among them, flow batteries are excellent candidates for large-scale, long duration energy storage due to their flexible design, long service life, high reliability, and environmental friendliness. Nevertheless, this technology is still in its infancy in terms of optimisation of materials and battery design that can lead to improvement in performance and cost. Our research seeks to improve upon one of their performance-determining components: the electrodes. In my talk, I will present the work developed by our group on the manufacturing of sustainable electrodes for flow batteries using electrospinning, 3D printing and textile waste, and how mass transport and charge transfer processes are improved by effective surface functionalisation and interconnected porous structure.

Tailoring the Solid-Electrolyte Interphase with Inert Holey Nanosheets for Long-Life Sodium Metal Anodes

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Sodium metal batteries have garnered significant attention because of their superior energy storage performance over sodium ion batteries. However, the poor stability of sodium metal anode caused by dendrite formation and surface degradation frustrates the commercialization of sodium ion batteries [1]. Herein, we develop an effective means to stabilize sodium metal anode via surface deposition of two-dimensional holey inorganic monolayers [2,3]. The sodium metal batteries with holey-nanosheet-coated metal anode delivered excellent electrode performances with larger discharge capacity and better rate characteristics with respect to the conventional sodium metal batteries, underscoring the usefulness of holey nanosheets as coating layers. The benefit of holey inorganic nanosheets as coating layers was further evidenced by the excellent performance of full cells. The coating with holey inorganic nanosheets enabled to promote the reversible and stable Na deposition and stripping on the sodium metal surface and to prevent the formation of sodium dendrite. Microscopic analysis and theoretical calculation revealed that the stable and efficient migration of Na^+ ions through holey monolayers was responsible for the benefit of nanosheet coating in achieving the reversible charge-discharge process of sodium metal batteries. The present holey nanosheet coating approach paves an efficient route to the rational design and fabrication of sodium metal batteries.

Keywords: Sodium metal battery, Holey inorganic nanosheet, Dendrite prevention, Surface deposition/coating, Ion migration

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Interfacial Regulation via 2D Crystalline Polymer in Sustainable Batteries

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The solid electrolyte interphase (SEI) on the anode in Li-ion batteries (LIBs) plays a critical role in regulating interfacial Li-ion transport and has been pivotal to their commercial success. However, emerging sustainable battery systems often struggle to form effective SEIs, leading to significant interfacial charge-transfer limitations. Inspired by the fundamental principles governing SEIs, we propose that stable, electron-insulating, ion-conductive, and ion-selective interphases represent a universal strategy for addressing interfacial challenges in next-generation energy storage devices. In this talk, I will present the use of two-dimensional crystalline polymers (2DCPs) as artificial interphases to overcome these limitations. For example, we employ an ultrathin poly(pyridinium salt)-based 2DCP membrane as a conformal coating on graphite electrodes to enable selective anion intercalation. This membrane effectively regulates the transport of anions (e.g., PF_6^-, FSI^-, $TFSI^-$), while suppressing the undesired co-intercalation of solvent molecules and cations into the graphite lattice. As a result, the durability of anion intercalation chemistry in graphite is significantly enhanced.We further demonstrate the broader applicability of 2DCP interphases in Zn//graphite batteries. In addition, by introducing a polyimine-based 2DCP membrane as an interfacial coating, we achieve a distinctive electrochemical transition—from sluggish Zn^{2+}-dominated processes to fast-kinetics H^+-dominated Faradaic reactions,even at high mass loadings.These results highlight the potential of 2DCPs as conformal, ultrathin interfacial coatings that enable selective ion transport at electrode/electrolyte interfaces. Their well-defined nanochannels and minimal thickness ensure efficient ion flux while maintaining interfacial stability, offering a promising platform for advancing sustainable battery technologies.

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Design of Hybrid Nanostructured Electrodes for Sustainable Batteries

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In the context of the green energy transition, the development of innovative battery technologies based on sustainable materials with a reduced environmental footprint is essential.

Although lithium-ion batteries offer high efficiency and long cycle life, the rapid expansion of their market has raised increasing concerns about the availability and sustainability of critical raw materials, with current projections predicting potential shortages within the next decade [1].

A promising alternative for electrochemical energy storage is offered by organic redox molecules, which, thanks to their tunable electrochemical properties, can operate efficiently in battery systems. In addition, these compounds can be derived from renewable biomass or synthesized through environmentally friendly processes [2].

This work focuses on the development of hybrid electrodes that combine organic molecules capable of efficiently storing and releasing electrons with tailored nanostructures designed to maximize electron and ion transport, improve stability, and reduce environmental impact.

Initial results from this research, obtained within the ERC Consolidator Grant project 'Hynanostore', will be presented to illustrate the operating principles of this bio-inspired strategy.

By bridging organic chemistry and advanced nanomaterials, this interdisciplinary approach may contribute to the development of next-generation energy storage technologies designed to address future sustainability challenges.

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Solar Redox Flow Cells: Bridging Solar Energy Conversion and Electrochemical Storage

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A solar redox flow cell (SRFC), also known as a solar redox flow battery, is an emerging technology capable of solar energy collection, storage and conversion to dispatchable electricity and heat [1]. In an SRFC, a photoelectrochemical (PEC) cell is used to charge a pair of redox electrolytes, which subsequently release the stored energy at a redox flow battery (RFB) as electrical power. The PEC approach is particularly attractive due to its simple semiconductor–liquid junction (SCLJ) configuration at the photoelectrode. However, SCLJ-based SRFCs still face significant limitations, with only a few demonstrations achieving solar-to-output electricity efficiencies (SOEE) above 1–2 % [2]. These limitations have driven the development of alternative architectures and materials. Consequently, recent research has shifted from conventional metal-oxide SCLJs toward high-performance photoelectrodes based on tantalum nitride [3], as well as employing highly efficient photovoltaic (PV) cells as photoelectrodes toward a buried-junction (BJ) design. In parallel, several additional challenges remain to be addressed, including electrolyte cost reduction, long-term operational stability, and system scalability [4]. Recent advances in low-cost and highly stable redox couples originally developed for RFB technologies have also opened new opportunities for their integration into SRFC systems The present communication will discuss recent progress in SRFC design, including advanced photoelectrode materials, architectures, and emerging redox electrolytes, highlighting promising strategies to overcome current efficiency, stability, and scalability barriers and accelerate the commercialization of SRFC technologies.

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Day - 3

NanoSeries2026 Technical Session: NS (G)

Nanoscale Engineering for Sustainability

Controlling Structures of Carbon-Based Nanomaterials and Their Physical and Catalytic Properties

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Chemical designing on nano-materials in molecular level would be a promising route to create new hybrid materials and to control various properties of nano- and molecular materials.In this presentation, I will discuss two topics on the fundamental chemistry of carbon-based nano-materials as well as physical and electrochemical properties.

(i) Organometallic compounds have been a center of molecular catalysts with preeminent catalytic activity and selectivity in a wide range of chemical transformations. As carbon-based nanomaterials, such as graphene-based materials, carbon nanotubes, and carbon nitrides, are sterically bulky, and they exhibit a wide spectrum of electrical properties, they can dramatically tune the catalytic behavior of transition metal-based active species. Hybridization of organometallic complexes with graphene-based materials can give rise to enhance catalytic performance.

(ii) Carbon nitride (C3N4) exhibits significant potential as a metal-free photocatalyst for various reactions under the irradiation of visible light. Polymeric C_3N_4 (p-C_3N_4), also known as graphitic carbon nitride (g-C_3N_4), is the most stable carbon nitride structure and contains the C, N alternating tri-s-triazine ring as a basic intralayer building unit. The photophysical and photocatalytic properties of the three dimensional (3D) C_3N_4 significantly depend on the chemical and morphological structures. This talk will include several routes to control the structures of C_3N_4 materials and understanding their photocatalytic properties associated with the structures.

A Low-Cost Miniature Optical Sensor for Detection of Heavy Metals in Water

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Continuously monitoring heavy metal contamination in water is crucial for environmental protection and public health, particularly in economically less developed regions where international safety limits are frequently exceeded. Despite significant advances in analytical techniques, commercially available systems remain expensive and laboratory-bound, and developing portable and affordable devices for rapid, on-site measurements is of immense interest.

We present the development of a portable and low-cost sensor based on luminescent quantum dots (QDs) that are sensitive to heavy metals at low concentrations. In these measurements, we calibrate the sensor by characterizing changes in the fluorescence emission of two types of QDs, $CuInS_2$ and ZnS, upon exposure to water samples contaminated with different metal ions. In a first stage, we evaluated the effects of Ca^{2+}, Mg^{2+}, Zn^{2+}, Cd^{2+}, Co^{2+}, and Pb^{2+} in dispersion, which present different variations in fluorescence intensity emission wavelength. These responses enable quantitative detection of metal contamination in the sample.

Finally, we report on the development of consumable sensing elements by immobilizing the QDs in gelatin matrices, which provide a suitable environment to preserve their optical properties and allow direct use with water samples. For economical implementation in low-resource settings, we developed a portable and inexpensive detection system based on a homemade spectrometer built using 3D-printed components, a webcam, and a DVD as a diffraction grating, with data acquisition and analysis performed in Python. This combination of technologies aims to deliver a portable, affordable, and easy-to-use sensor for rapid heavy metal detection in water.

Zeolitic Imidazolate Frameworks (ZIFs): Metal–Organic Framework Nanomaterials for Selective Adsorption and Recovery of Polyphenols from Water

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Water contamination from industrial and agro-industrial effluents remains a pressing environmental challenge. Among the diverse pollutants detected in wastewater, polyphenols present a distinctive dual characteristic: while elevated concentrations can disrupt aquatic ecosystems [1], they are highly valued for their antioxidant, antimicrobial, and nutraceutical properties [2]. Therefore, their selective recovery from water represents not only an environmental imperative, but also a strategic opportunity for resource valorisationfrom a circular economy perspective [3, 4].

In this context, Zeolitic Imidazolate Frameworks (ZIFs), a subclass of porous metal–organic framework (MOF) nanomaterials, were explored as advanced adsorbents for polyphenol recovery [5].

Three materials were synthesized and comparatively assessed: ZIF-8 (Zn-based), ZIF-67 (Co-based), and a hybrid bimetallic ZIF-67/8. Comprehensive physicochemical characterization (XRD, XPS, HRTEM, FESEM-EDS, N_2 physisorption, and TGA) was performed and correlated with adsorption performance using gallic acid as a model compound, alongside withstructurally related polyphenols to elucidate structure–affinity relationships (Figure 1A).

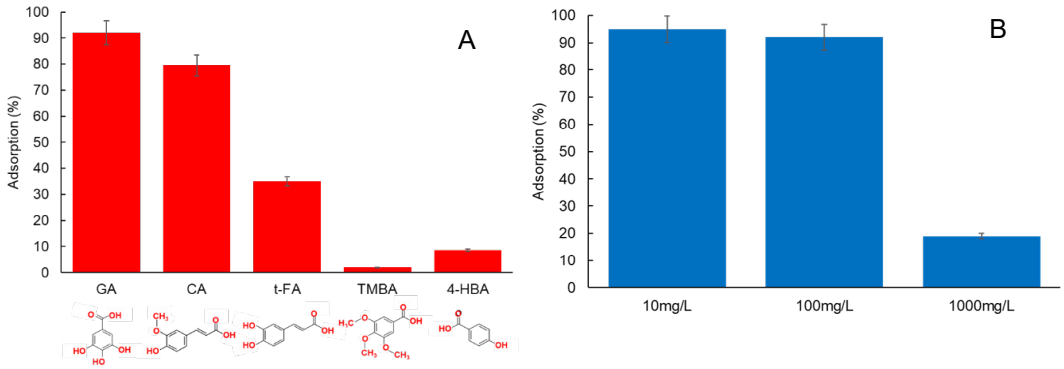

Figure 1:A) Percentage of polyphenols adsorption on ZIF-67/8. Experimentalconditions: 50 mg of MOF (0.5g/L), 100 mL of 100 mg/L polyphenols solution, room temperature, 15 min of contact time. B) Initial concentration of gallic acid (model polyphenol) on ZIF-67/8 adsorption capacity. Operative conditions: 50 mg of MOF (0.5g/L), in 100 mL of GA solutions at different initial concentrations, room temperature, 15 min of contact time.

Adsorption was predominantly governed by hydrogen bonding and coordination interactions, as evidenced by the strong dependence on polyphenol functional groups.

All ZIFs exhibited remarkably fast adsorption kinetics at low and moderate concentrations (10–100 mg/L), achieving complete removal within minutes. However, performance declined with higher pollutant loads (Figure 1B).Stability investigations revealed a critical limitation. The crystal structure of ZIF-67 undergoes complete structural collapseuponprolongedexposureto water (more than 5 h), as displayed in Figure 2A. Moreover, despite the comparatively higher water resistance of ZIF-8, all frameworks underwent partial structural degradation during adsorption, accompanied by loss of crystallinity and microporosity. The hybrid ZIF-67/8 displayed intermediate behaviors, balancing adsorption efficiency with improved aqueous stability (Figure 2 B).

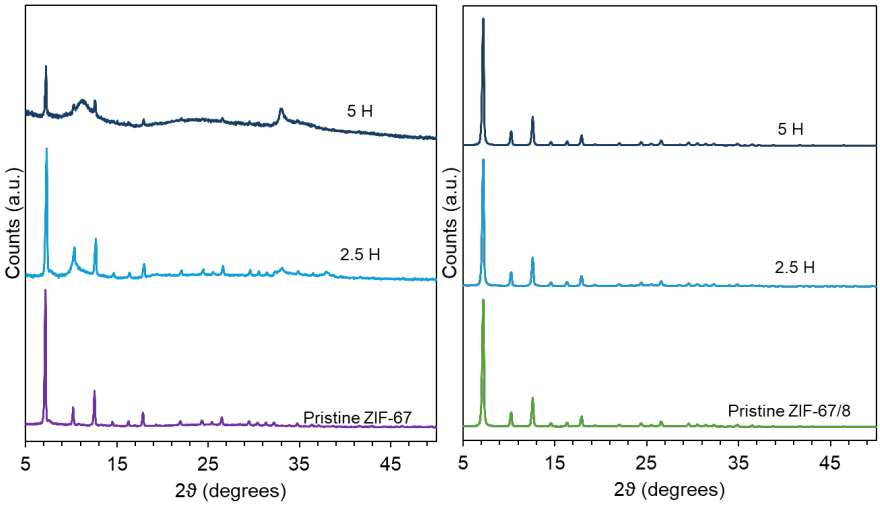

Figure 2: XRD patterns of A) ZIF-67 and B) ZIF-67/8. Operative conditions: 50 mg ZIF (0.5 g/L) in 100 mL deionized water at spontaneous pHat different contact time.

These results emphasize that high performance must be accompanied by long-term structural resilience, guiding future efforts toward more water-stable MOF systems and hybrid materials for scalable and sustainable polyphenol recovery.

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Tailoring Nanodiamonds for Photocatalytic Degradation of Fluorinated Pollutants

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At present, per- and polyfluoroalkyl substances (PFAS) pose a major environmental concern due to their extreme persistence, widespread occurrence, and toxic and carcinogenic nature, driving the urgent development of effective degradation technologies. Advanced reduction processes, exploiting highly reducing hydrated electrons (eaq^-) generated under UV irradiation, have recently emerged as promising strategies for PFAS abatement [1]. In this context, hydrogen-terminated nanodiamonds (HND) are attractive photoactive materials for eaq^- generation, combining efficient UV-driven activity with intrinsic biocompatibility and environmental friendliness. Owing to their negative electron affinity, HND exhibit a conduction band edge above the vacuum level, enabling efficient electron emission into water upon UV photoexcitation. Furthermore, surface sp^2-hybridized carbon states introduce sub bandgap absorption pathways, allowing production of eaq^- under extended UVC irradiation [2,3].

In this work, we investigated the PFAS degradation potential of 18 nm ND subjected to various thermal treatments, including annealing ininert atmosphere, air oxidation, and hydrogenation, aiming to correlate their physico-chemical properties with catalytic performance. The ND were characterized by transmission electron microscopy, infrared, Raman, and UV-vis spectroscopies to assess their morphology, surface chemistry, structural features, and optical properties. In parallel, UV-driven photocatalytic degradation and defluorination tests were carried out on representative fluorinated compounds, including perfluorooctanoic, perfluorobutanoic, and trifluoroacetic acids. ND subjected to hydrogenation showed consistently the highest PFAS abatement efficiency, with catalytic activity strongly influenced by the processing steps applied beforehand and by the chemical nature of the fluorinated compounds. Our results evidence a clear influence of ND structural integrity and surface characteristics on the degradation of fluorinated pollutants, simultaneously highlighting their suitability as environmentally friendly and effective materials for PFAS remediation.

Keywords: nanodiamonds, surface engineering, hydrogen terminations, fluorinated pollutants remediation, photocatalysis

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Rheology and Interfacial Properties of Concentrated Bulk Nanobubbles

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Bulk nanobubbles (BNBs), unlike macroscopic bubbles, display extraordinary longevity in aqueous environments, defying classical expectations of gas dissolution. Although their exceptional stability is now widely recognized, the rheological response of BNB–water systems remains largely unexplored at the nanoscale. Here, we combine molecular dynamics simulations and experimental measurements to elucidate the flow behaviour of nitrogen- and air-filled bulk nanobubbles dispersed in water.

By systematically varying the nanobubble volume fraction (nominal diameter ~1.9 nm) in simulations, we quantified the zero-shear viscosity and uncovered the mechanisms governing nanoscale rheology. Contrary to the trends observed in microbubble suspensions, BNB dispersions exhibit a pronounced viscosity enhancement, with the zero-shear viscosity exceeding that of pure water and increasing sharply with nanobubble concentration. While the qualitative rheological response resembles that of microbubble systems, the magnitude of the effect is significantly amplified at the nanoscale.

This anomalous behaviour originates from the unique physicochemical nature of nanobubble interfaces. The gas–liquid interface carries an effective negative surface charge arising from enhanced structuring of interfacial water molecules and a high internal gas density. These features generate strong electrostatic repulsion between neighbouring nanobubbles, producing dynamics analogous to dilute dispersions of charged colloids and substantially increasing the effective viscosity of the suspension.

To rationalize these observations, we developed a modified relative-viscosity model that extends classical suspension theory to incorporate nanoscale interfacial effects explicitly. Under Couette flow, nanobubbles exhibited shear-dependent stability, remaining intact at low shear but coalescing into larger bubbles at elevated shear rates. Prior to coalescence, the shear viscosity increased monotonically with volume fraction, consistent with zero-shear behaviour.

Experimental validation was performed using bulk nanobubbles with an average radius of ~70 nm at a concentration of 4.0×10^{13} bubbles mL^{-1}. The measured viscosities closely matched simulation predictions: enhanced viscosity relative to pure water at low shear rates, followed by a return to baseline values at high shear due to bubble coalescence and gas release. The proposed model predicts the zero-shear viscosity within 8.93% of experimental values, demonstrating strong quantitative agreement. We have investigated the interfacial and internal properties of these bulk nanobubbles to understand how they remain stable under significantly high internal pressures.

Multifunctional Nanosorbents for the SERS Detection of Water Contaminants

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Surface Enhanced Raman Spectroscopy (SERS) is a powerful tool for environmental monitoring, enabling the detection of trace-level molecules through portable equipment for on-site chemical analysis. Recent advancements in surface chemistry play a crucial role in developing effective SERS substrates, particularly with respect to innovative multifunctional analytical platforms. This presentation summarizes our recent studies on magneto-plasmonic nanosystems designed to fabricate SERS substrates for detecting water contaminants.[1,2]It will includea few examples that demonstrate the effectiveness of these nanostructures in contaminant removal and detection, emphasizing their suitability for analytical protocols using either conventional Raman intrumentation or for on-site applications with portable equipment. The selected nanostructures highlight their role as sorbents in magnetic-assisted technologies for water quality monitoring, including magnetic iron oxides coated with hybrid shells decorated with plasmonic nanometals. The latter function as antennas for SERS, while the magnetic cores enable magnetic separation of the sorbents used as substrates for optical detection. Finally, Iwill share insights into the latest advancements in this field while mentioning challenges that lie ahead.

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A New Lattice-Engineering Strategy for Waste-to-Value Reactions: The Thermal Stimulated Polarization Treatment and its Applications in Permanently Polarized Hydroxyapatite

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In the context of waste-to-value reactions, developing industrially feasible catalysts with low environmental impact has become a priority. Herein, we present a novel lattice engineering strategy: the Thermal Stimulated Polarization (TSP) treatment. TSP consists of exposing the samples to an electrostatic force (i.e., constant voltage application) at a high temperature; causing a refinement of the crystal lattice showing a priority direction (i.e., polarization). In this sense, the specific new ordination, with customized photo-, electro- and thermal-properties, is maintained after the TSP treatment without the need to apply any external stimuli. Hence, the material presenting a new meta-stable state is referred as "permanently polarized".

TSP has shown successful results when applied to hydroxyapatite (HAp, $Ca_5(PO_4)_3OH$) an abundant and biocompatible ceramic. The TSP induces controlled: 1) OH- vacancies, 2) specific re-orientation and alignment of the remaining OH^- (acting as quantum pathways); and 3) new calcium phosphate co-existing phases. As a result, permanently polarized HAp (2P-HAp) transition from a passive support to an active catalytic material with: 1) enhanced conductivity (from >500 $M\Omega \bullet cm^{-2}$ to 10 $M\Omega \bullet cm^{-2}$), 2) enhanced photo-absorption response (presence of trap states Eg= 2.85 eV); and 3) superior catalytic activity. Overall, TSP unveils the possibility to carry out waste-to-vale reactions such us CO_2-valorization and/or microplastic-valorization reactions under mild conditions.

A part from the results obtained for 2P-HAp, herein we aim to present the potential of a generalized lattice-engineering strategy for the development of a new generation of abundant catalysts. Currently we propose (from a theoretical point of view) the extension of the TSP towards other materials, highlighting the different polarization mechanisms which depend on the "starting" lattice structure. TSP proposes re-visiting already existing materials to improve their properties, rather than relying on the development of rare or exotic systems.

Sustainable Multi-Stack Printed Heaters on Paper for Energy-Efficient Thermal Distribution

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"Printed heating elements are gaining increasing attention as lightweight, flexible, and sustainable alternatives for next-generation thermal management systems, spanning applications from wearable therapeutics to automotive components. In this work, we tackle the persistent challenges of temperature homogeneity and mechanical robustness through a fully screen-printed approach that combines water-based inks with biodegradable paper substrates.

A multi-layer architecture composed of carbon, silver, and aluminum oxide (C/Ag/AlOx) was developed to enhance both electrical performance and structural stability. The optimized heater reaches temperatures up to 120 °C at 5 V, while maintaining remarkable spatial uniformity with temperature variations confined to ±3°C. In contrast, reference configurations (Ag and Ag/AlOx) exhibit temperature gradients of up to 10°C, highlighting the effectiveness of the multi-stack design.

The devices demonstrate strong operational reliability, sustaining 6 hours of continuous 5 V cycling with negligible resistance drift, and maintaining stability under accelerated environmental conditions (80°C, 80% RH). Adhesion tests further confirm the protective role of the AlOx layer, with the C/Ag/AlOx structure preserving its electrical integrity after multiple tape-peel cycles.

Importantly, the multi-stack heater is produced at an ultralow cost of approximately 0.20 € per unit. When integrated into a skin bandage platform, it delivers controlled heating up to 50°C at 3.5 V with a power density of 0.08 W/cm², demonstrating its suitability for homogeneous, low-voltage thermotherapy applications. These results position the proposed architecture as a scalable and environmentally responsible solution for precise and reliable printed heating technologies."

An Ultrathin Compact Transformable RFID Tag for Lightweight Wireless Motes

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Distributed wireless tags, sensors, and data acquisition systems, referred to as “motes,” have become integral elements of contemporary living. This talk presents an optimised meander dipole antenna structure on a flexible substrate suitable for implementing printed radio frequency identification (RFID) tags. Our antenna has a unique capability to transform into the Swiss-roll architecture from a planar state for easy handling, allowing easy handling without compromising structural integrity. The hydrogel polymeric layer is used to create the volumetric stress, thus leading to the rolling process and creation of a compact antenna. The simulations with Ansys demonstrate conjugate impedance matching between the tag antenna and RFID tag chip. This compact tag antenna achieves the maximum read ranges of 77 cm in passive regime and 113 cm in semiactive regime, when connected to the external power supply.

Keywords: Flexible antenna, RFID tag, meander dipole, Swiss-roll antenna, hydrogel polymer

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Day - 3

NanoSeries2026 Technical Session: NS (E)

2D Materials Research: Graphene and Beyond

Sensing Toxic Gases and Producing Dihydrogen With 2D Materials : A Theoretical Perspective

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Monosheets of 2D material such as Transition Metal Dichalcogenide (TMDs such as MoS_2, WS_2,..) offer a great potential as gas sensor due to their huge surface-to-volume-ratio. Gas sensing is typically probed in Chemristor by measuring the change in the electrical resistance of the monolayer upon exposure to the gas. In a recent experimental/theoretical study, we have extended this approach by combining electrical measurements to Ambient Pressure XPS measurements allowing to measure the binding energy shifts of key orbitals upon exposure to gases such as NO_2 and NH_3 [1]. When coupled to DFT calculations of these shifts, this approach allows for a detailed analysis of the detection mechanisms and points to the key role played by sulfur vacancies. In parallel, TMDs are also attractive to be used as cathode for photocatalytic hydrogen production by water splitting. However, pristine surfaces behave as poor catalyst and requires strategies to balance energetically the adhesion of two hydrogen atoms and the bond formation of H_2. We will show that DFT calculations can provide useful guidelines to reach this target.

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Hexagonal Boron Nitride Bio-Interfacing the Skin: Safety Insights From Advanced Skin Models

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Safety issues of 2D materials (2DM) for human health are mainly related to occupational exposure during their manufacturing as well as to consumer exposure in case of 2DM-based technologies.Inthiscontext,cutaneous-contactandinhalationarecertainlythemostimportant exposure routes for humans. In particular, hexagonal boron nitride (hBN) is attracting great interest in scientific and industrial fields thanks to its chemical inertness, unique mechanical and electric properties, superb thermal conductivity and oxidation stability.

Hence, in this study the toxicological potential of hBN at the skin level has been evaluated in compliance-withthe3R'sprincipletoavoidtheuseoflaboratoryanimals.Aninvitroapproach was followed considering twomodels with different levels of complexity. Initially, asimplified one, constituted of HaCaT epidermal keratinocytes, was used to assess hBN toxicity and to studyitsmechanismofaction.Despiteitssignificantuptakebykeratinocytes,hBNcausedonly weak adverse effects, such as slight alterations of cells parameters indices of cytotoxicity and mitochondrial-related dysfunctions, detectable only at high concentrations (>25 µg/mL) and mainly after long exposure times. Secondly, a more predictive and complete model of 3D reconstructedhumanepidermiswasusedtoassessskincorrosiveandirritantpropertiesofhBN according to the relevant test guidelines given bythe Organization for Economic Cooperation and Development. On the same model, further analysis studied the interaction with the epidermis and demonstrated an extremely low pro-inflammatory potential [1]. These results showedalowtoxicpotentialofhBN,thatmaybealteredbysomephysico-chemicalproperties of the material, such as shape and size of the flakes.

On the whole, these data elucidate the biocompatibility of hBN at the cutaneous level, with particular relevance for the characterization of its safety profile.

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Optomechanical Characterization and Control of Physical Properties in Suspended 2D Materials

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The introduction of suspended two-dimensional (2D) materials by transferring single-atom (or few-atom) thick flakes onto substrates containing cavities openedan innovative approach either for the study physical phenomena in these materials as well as for the application of these materials in different fields as sensing, actuators or metrology. Suspended 2D membranes present two important features: their mechanical resonance, which allows transducing different phenomena, and the fact that their properties are not perturbed by the substrate. These featureshave allowed the characterization ofinteresting phenomena in condensed matter physics as phase transitions[1] or photon absorption [2] as well as the implementation of these systems as ultrasensitive sensors[3].

Nevertheless, the full potential of this technique has not been fully released due to reproducibility problems. On one hand, limitations in their fabrication processes produce a wide variability in parameters like pre-tension or density. On the other hand, some of the mechanical properties determining the resonance of the membrane can even depend on the transduction mechanisms used for actuation and readout (laser power, electrical current, etc.). These limitations impede in many cases comparing results as well as well as quantifying some physical magnitudes. For these reasons finding techniques that allow robust and reproducible characterization of 2D material-based nanomechanical resonators has become essential.

In this work we explore how mechanical properties, as stiffness, can be controlled in these membranes though the injection of light. We eventually use this optomechanical control of the stiffness to characterize the membrane, extracting intrinsic properties as mass, initial pretension and photothermal heating rate. The proposed method represents a step forward in the development of 2D material-based resonators as it is robust and interoperable.

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Surface-Engineered $Ti_3C_2T_x$ and Nb_2CT_x MXenes for Nitric Oxide Detection

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The development of compact and low-cost gas sensors for breath analysis is attracting increasing attention as a non-invasive strategy for diagnosing and monitoring respiratory diseases [1,2]. Nitric oxide (NO) is a clinically validated biomarker of airway inflammation, while relative humidity (RH) strongly influences sensing performance in exhaled breath. Two-dimensional transition metal carbides (MXenes) are promising chemoresistive materials due to their high electrical conductivity, tunable surface terminations, and layered architecture enabling interfacial transport modulation [3,4].

Here, $Ti_3C_2T_x$ and Nb_2CT_x were synthesized via HF-based selective etching and functionalized with 3-mercaptopropyltrimethoxysilane (MPTMS). MPTMS was selected because sulfur-based terminations are theoretically predicted to enhance interaction with nitrogen-containing species such as NO, potentially promoting adsorption and interfacial charge redistribution [5]. Structural and chemical characterizations (XRPD, FTIR, SEM/TEM, EDX) confirmed successful MXene formation and effective silane grafting without structural degradation. Chemoresistive devices were fabricated by spray-coating identical amounts of stable suspensions onto interdigitated electrodes, enabling nominally comparable film thicknesses, and tested at room temperature under controlled RH and NO concentrations (ppm to ppb level).

Pristine $Ti_3C_2T_x$ exhibited a decrease in current upon NO exposure. Considering NO as an oxidizing radical [6], electron withdrawal from the metallic MXene reduces carrier density, therefore causing a resistance increase.

Conversely, Nb_2CT_x-based sensors displayed a resistance decrease under NO exposure. Despite identical deposition mass, the smaller flake size (around 200 nm by TEM) and distinct electronic structure of Nb_2CT_x likely promote stronger interfacial coupling among flakes, and more effective junction-barrier lowering upon NO adsorption. In this case, interfacial charge redistribution and barrier modulation dominate over carrier depletion, resulting in net conductivity enhancement. MPTMS functionalization further improves NO response for both MXenes thanks to the possible establishment of S---N interactions [5].

These findings highlight that MXene sensing behaviour arises from the interplay between intrinsic electronic structure, morphology, and surface properties.

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Photonic Crystal Grating for k-Space Shaping of 2D Material Emission

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Photonic crystal gratings (PhCGs) are dielectric metasurfaces in which a one-dimensional subwavelength modulation of the dielectric permittivity enables precise control of light propagation and light-matter interactions. [1,2] Such control is especially relevant for two-dimensional materials, whose atomically thin nature limits light extraction, weakens radiative out-coupling, and provides little intrinsic control over emission directionality.

Here,werealizeametasurfacebypatterningathintransitionmetaldichalcogenide(TMD)flake into a photonic crystal grating supporting a quasi-bound state in the continuum (qBIC), which acts as a momentum-selective cavity. Because the patterned TMD also hosts strong excitonic resonances, the grating exhibits a self-hybridized exciton-photonic mode. A second TMD monolayeristransferredontop,withitsmainexcitontunedtotheqBICbranchwhileremaining intheweak-couplingregimewiththecavityfield.Fouriermicro-spectroscopyrevealstheself-hybridized response of the TMD PhCG together with a pronounced redistribution of the monolayer emission into directional angular lobes engineered by the grating geometry.

These results indicate that TMD photonic crystal gratings can serve as a compact platform for k-space engineering, directional emission control, and integrated nanophotonic functionalities in layered semiconductors.

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Single-Atom Catalysts: Unveiling Synthesis Strategies and Catalytic Potential

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Heterogeneous catalysis plays an indispensable tool in modern industrial processes. When supported nanoparticles are downsized to the single-atom limit, the resulting single-atom catalysts (SACs) have proven special value1. These individually dispersed metal sites possess defined coordination structures and enabled reaction pathways that differ from traditional heterogeneous catalysis. While offering high stability even in harsh environments, and maximum utilization of catalytic metals, SACs also satisfy the key goals of a sustainable chemistry. Nevertheless, limited reproducibility and scalability of SAC preparation hinder their further practical applications, and efficient methods of SAC synthesis are urgently needed. A major challenge is to prepare single-atom sites on the catalyst support with high density while avoiding aggregation of metal atoms. This challenge can be traced to the trade-off between diffusion and stabilization of metal atoms during the pyrolysis process. In this talk, several approaches will be presented2,3. These methods will discuss how the metal resources including ions, organometallic complexes, and particles are transformed into single atoms and their possible mechanisms. This work is a critical step forward toward a scalable synthesis and widespread application of dense SACs and pavs the way for the development of further economically feasible catalyst systems4.

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Engineering Atomically Precise Hybrid Architectures with Transition-Metal Centers and Graphene Nanoribbons

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On-surface reactions based on the programmed interactions of molecular building blocks have recently emerged as a powerful strategy for the bottom-up synthesis of atomically precise materials. This approach enables exquisite atomic-scale control over structure and chemical functionalization, opening access to a broad range of carbon-based nanoarchitectures that cannot be achieved through conventional solution chemistry or top-down fabrication methods.

In this talk, I will present our recent advances in the synthesis of atomically precise nanoporous graphene [1] and graphene nanoribbons, including their chemical functionalization and their assembly into atomically sharp heterojunctions [2]. I will further discuss molecular bridge engineering as a strategy to tune quantum electronic transport and anisotropy in nanoporous graphene [3]. Building on these results, I will introduce recent progress toward more complex architectures that integrate graphene nanoribbons with transition-metal complexes via lateral covalent linking.

Finally, I will demonstrate the complete pathway toward a semiconducting graphene material exhibiting a silicon-like bandgap, from atomic-scale synthesis and characterization to implementation in a three-terminal electronic device, as well as its integration into photonic biosensors [4].

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Metrological Interlaboratory Comparison (ILC): Raman Spectroscopy as a Standard for Graphene Layer Number Measurement and Commercial GR2M Characterization

Sacco A.*[1], Bissett M.[2], Kinloch I.[2], Delvallée A.[3], Ducourtieux S.[3], Paton K.[4], Subhedar, K.[5], All Participants to the ILC[6], Pollard A.[4], Clifford C.[4], Portesi C.[1] and Rossi A.M.[1]

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Graphene has potential industrial applications in many fields, including flexible electronics, energy, and biosensors. However, technological integration and commercial viability of graphene and related 2D materials (GR2M) are hindered by a lack of standardized methods and consistent quality control protocols, leading to significant variability and often misclassification. This inconsistency undermines their adoption as commercial products. Addressing this issue requires the development of standard characterization methods, especially for industrially scalable products such as GR2M powders: these must be validated through comprehensive interlaboratory comparisons (ILCs).

This work presents the outcomes of an international ILC that tackles this requirement, conducted within the Versailles Project on Advanced Materials and Standards (VAMAS).[1] Over twelve laboratories participated, validating methods for characterizing graphene nano-platelets using Raman microspectroscopy. Raman was selected because it is fast, non-destructive, and widespread in graphene production facilities, thus a perfect fit for industrial quality control and harmonization. Raman spectroscopy provides a fingerprint of graphene for the assessment of defectivity, strain and layer number, which is often a foremost parameter for both industrial and research purposes.

The ILC approach was twofold: first, commercially available graphene powders were used to test robust protocols for nano-platelet localization and Raman mapping on a specifically designed substrate; moreover, high-quality mechanically exfoliated graphene was employed to assess a simplified Raman-based method for quantifying the number of layers, which was previously verified independently using atomic force microscopy (AFM). These procedures were designed to be simple and unambiguous, making them excellent candidates for dissemination and adoption as global standards.

These findings will greatly impact the graphene supply chain, encompassing all stakeholders, from producers to consumers: they will facilitate the establishment of globally recognized characterization methodologies, thereby defining accepted material specifications. The outcomes derived from this ILC will directly inform the forthcoming revision of the ISO/TS 21356-1 standard — "Structural Characterization of Graphene".[2]

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Unveiling the Drug Delivery Mechanism of Graphene Oxide Dots at the Atomic Scale

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In the context of nanomedicine, understanding the interplay between nanomaterials and drugs is fundamental to the development of targeted drug delivery nanocarriers, with the aim of administering drugs in a spatially and temporally controlled manner.Graphene oxide (GO) is an amphiphilic and versatile graphene-based nanomaterial that is extremely promising for carrying drugs. However, capturing the interactions of GO with drug molecules at the atomic scale remains a major challenge for experimental techniques.

In this work [1], we present a computational strategy that combines atomistic metadynamics simulations with unsupervised machine learning to investigate drug loading on realistic GO nanocarriers (Figure 1).

The GO-based nanocarriers were modeled as homogeneously or inhomogeneously oxidized GO dots coated with stealth polymer chains and conjugated to an active targeting ligand, thereby reproducingrepresentative experimental designs [2]. The adsorption of a model chemotherapeutic drug – doxorubicin or DOX – was investigated by metadynamics simulations for accelerated loading/release events. Drug/nanocarrier adsorption modes were clustered through machine learning-based analysis, revealing mechanistic details not easily accessible by experimental techniques.

We find that while the coating does not significantly affect DOX adsorption, the homogeneity of GO oxidation plays a crucial role. We also prove that a pH change towards acidic conditions reduces DOX/GO affinity, in line with a pH-triggered drug release mechanism. Based on this study, the ideal GO-based DOX carrier is identified as a highly and homogeneously oxidized GO dot coated with polymers. Our findings provide atomistic-level insights to the experimental community to further develop successful drug delivery systems. Moreover, the metadynamics protocol employed in this study [1,3] can be applied for studying adsorption mechanisms of other clinically relevant drugs on graphene-based nanomaterials.

Keywords: Nanomedicine, Controlled release, Active targeting, Metadynamics, Doxorubicin.

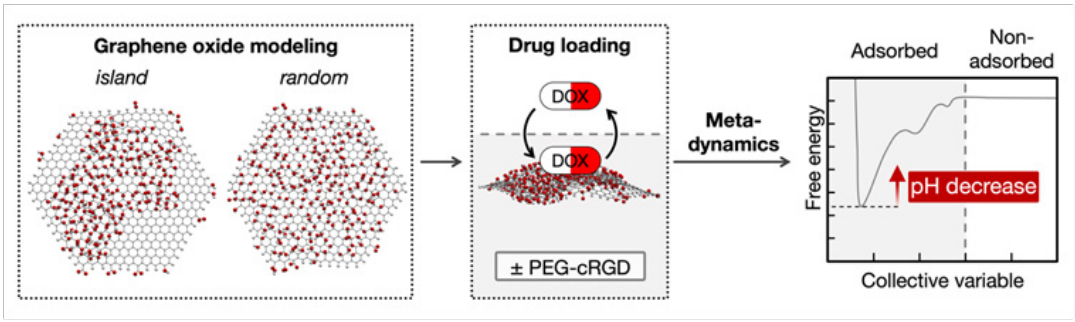

Figure 1. Schematic representation of the workflow of this study and its main findings. PEG-cRGD indicates the polyethylene glycol-cyclic RGD coating.

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Probing Inversion Symmetry Breaking and Related Electronic Properties in Ultrathin Tellurides

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Crystalline tellurides characterized by an atomic arrangement with an inversion symmetry breaking such as α-SnTe, α-GeTe or Td-WTe2 show multi-functional properties including ferroelectricity, a Rashba spin-split band structure, topological electronic states, …[1–4]. This is of significant importance in the perspective of all-electrically controlled and low-power spin-orbitronic applications [5–7]. In this context, device downscaling raises fundamental questions about the persistence of the targeted properties in ultrathin films. For instance, X. Yang et al. evidenced a reductionoftheRashbaeffectinα-GeTe(111)filmsbelow5nmandextrapolatedacriticalthicknessof 2nm, below which the Rashba spin splitting of the electronic band structure vanishes [8].

By appropriately analyzing and optimizing the growth conditions, we will show that Rashba spin-splittingandrelatedelectronicpropertiescanbepreservedintheultrathinregimeinα-GeTeand Td-WTe2films[9,10].Ourresultsbasedonphotoemissionspectroscopytechniques(ARPES, SR-ARPES,…),microscopies(TEM,STM)andastrongtheoreticalsupportfromDFTcalculationssuggest to further investigate the limit of physical properties in the ultrathin film regime.

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Day - 3

NanoSeries2026 Technical Session: NS (C)

Nano-Bioengineering for Medicine: Therapeutics, Diagnostics, and Regeneration

Self-Assembled Conductive Fibres in Live Cells

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Self-assembly of molecular components is a naturally occurring process in cells (e.g., cytoskeletal dynamics, organelle formation). Here, we report on the intentional design and harnessing of such processes for therapeutic and technological applications. A small hydrophobic thiophene derivative, DTTO, can bio-generate nanofibers through intracellular self-assembly. We investigated the electronic structure of these fibers using steady-state and time-resolved photoluminescence, as well as transmission spectroscopy. Our results indicate that DTTO monomers within fibers exhibit weak J-type intermolecular coupling. The observation of stimulated emission suggests the possibility of achieving optical gain in these systems. Biological assays on *Escherichia coli* exposed to DTTO provide insights into the stability and biocompatibility of the material. Electrical characterization further demonstrates that these nanofibers display p-type conductivity on the order of 10^{-5} S/cm. Such properties highlight potential applications that will be discussed. Overall, our findings support the emerging concept of self-assembled nanodevices—functional structures generated in situ through the simple injection of monomers into living cells, tissues, or organisms.

Molecular Engineering of Nanographenes for Super-Resolution Bioimaging and Other Bioapplications

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Nanostructures of graphene, i.e., nanographenes, exhibittunable electronic and opticalproperties depending on their size and chemical structures, attracting attention as next-generation carbon-based materials for nanoelectronics, photonics, bioimaging, and other bioapplications. Whereas it is challenging to accurately control the chemical structures while “cutting” graphene into nanostructures, molecular nanographenes can be synthesized with atomic precision through the methods of organic chemistry [1]. Notably, molecular nanographenes can serve as self-blinking fluorophores, enabling buffer-free single-molecule localization microscopy (SMLM)under variousenvironments [2].We have explored the functionalization of a highly stable,red-emissive nanographene which can be named as dibenzo[hi,st]ovalene (DBOV), toward super-resolution bioimaging and other bioapplications [2,3,4]. By installing hydrophilic chain and azide groups on the edges of DBOV, we have for example achieved single-molecule labeling and super-resolution SMLM imaging of nascent proteins in neurons [3]. Moreover, we have demonstrated that molecular nanographenes can be solubilized in water as polymeric nanoparticles, using conventional amphiphilic polymers, and utilized as neuronal tracers [5] as well as phototheranostic agents towards cancer phototherapy [6].

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Materials-driven Phototaming of Bacterial Bioelectricity

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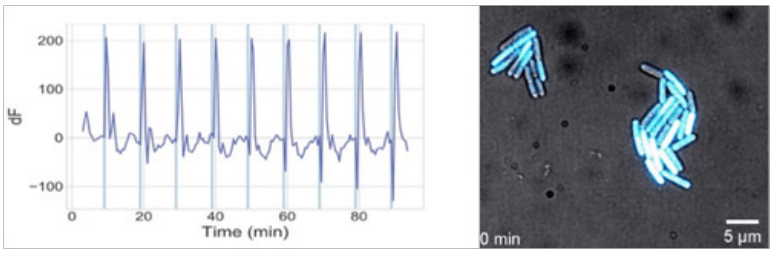
Engineering living matter aims to confer organisms with controllable functions by coupling biological specificity with designed inputs. A powerful, yet underexploited, axis for such control is cellular bioelectricity: the membrane potential (MP) that links redox chemistry, transport and metabolism to signalling and behaviour. In bacteria this link is particularly intimate because ATP synthesis and many ion fluxes occur at the membrane; recent work shows that MP is dynamic and participates in cell-to-cell communication, shaping metabolism, motility, dormancy towards antibiotics and community behaviours such as biofilm formation.

Here, we demonstrate that membrane-localized photoactive molecules can produce reliable optical control of bacterial MP.[1] Membrane isomerization at the site of action drives either hyperpolarisation or depolarisation depending on the excited-state relaxation pathway (optomechanical versus dipolar), a biomimetic mechanism reminiscent of retinal photochemistry. Such control can evoke neuron-like bioelectric responses in bacteria and reveal the functional involvement of ion channels previously uncharacterised in microbial electrophysiology. Finally, we show how light-driven MP modulation can be used to influence antibiotic uptake and efficacy,[2] and to steer motility— opening routes to both fundamental insight and translational applications in diagnostics and antimicrobial strategies.

Keywords: Bacterial bioelectricity; synthetic photobiology; biomimetic materials



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Synergistic Zwitterionic–Phytochemical Nano-Enabled Coating to Prevent Biofilm Formation in Urinary Catheters

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Hospital-acquired infections and antimicrobial-resistant bacteria pose an escalating challenge to modern healthcare, contributing significantly to patient morbidity and mortality. The ability of bacteria to colonise indwelling medical devices, such as catheters, and to form drug-resistant biofilms on their surfaces accounts for up to 60% of healthcare-associated infections. These infections are associated with prolonged hospital stays and impose a substantial economic burden on healthcare systems worldwide. Therefore, there is an urgent need for innovative and effective strategies to prevent biofilm formation on catheter surfaces and reduce the incidence of device-associated infections.

In this study, durable nano-enabled hydrogel coatings were engineered onto silicone urinary catheters through a single-step sonochemical process[1]. The coatings incorporate an antimicrobial and antifouling polycationic zwitterionic polymer (2N+) together with antibiofilm carbon dots derived from *Rosmarinus officinalis* extracts via hydrothermal synthesis (CRONPs). The bioactive layer was deposited directly onto catheter surfaces without prior substrate modification or the use of harsh chemical treatments, providing a simple and environmentally sustainable fabrication approach.

The functionalised catheters exhibited sustained antimicrobial and antibiofilm activity for up to seven days of catheterisation in an artificial hydrodynamic bladder model[2], while maintaining excellent biocompatibility with mammalian cells. Overall, these findings demonstrate the potential of ultrasound-assisted fabrication of 2N+/CRONPs nano-enabled hydrogel coatings as an effective and durable strategy for antimicrobial and antibiofilm functionalisation of urinary catheters.

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Aqueous Phase Separation in Biomolecular Coacervate Systems

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Inthistalk, Iwillsharesomeof myworkrelatedtothestudyof aqueousphase separation, where an aqueous solution separates into immiscible aqueous phases. In particular, I will discuss studies of coacervate systems formed between nucleic acids and polypeptides. As the sequences of the constituent molecules change, the macroscopic properties of the coacervates are also observably different [1]. This suggests that the molecular sequence can be used as a parameter to tune not just biochemical properties, but also physical and material properties [2, 3, 4]. Such control can potentially be used in designingstructuresforavarietyofapplications,suchasbiopharmaceuticals.

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One-Pot Synthesis of Hydrophilic Magnetite Octahedral Nanoparticles with Enhanced Colloidal Stability and Magnetic Heating Efficiency

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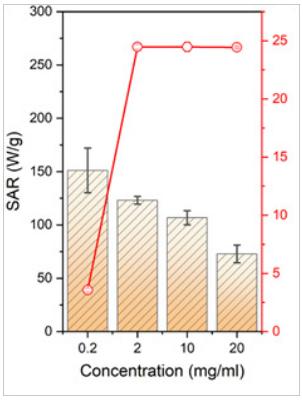
Magnetite nanoparticles (MNPs) are key nanomaterials for magnetic resonance imaging (MRI), tracers for magnetic particle imaging (MPI), drug-delivery platforms, and therapies such as magnetic hyperthermia (MH), either alone or in combination with chemotherapy [1]. Their broad applicability arises from their superparamagnetic properties and low toxicity. For biomedical applications, MNPs need to be hydrophilic; however, producing hydrophilic magnetite nanoparticles with controlled size and shape remains challenging. One common synthesis method that allows precise control over shape and size is the thermal decomposition of iron-based precursors in high-boiling media [2]. Unfortunately, this produces hydrophobic MNPs that cannot be used directly in biomedical applications. Therefore, ligand exchange techniques or hydrophilization using amphiphilic polymers, such as PMAO, have been proposed [3,4]. Both methods are well-established but add extra steps and require specific reagents to prepare stable dispersions.

In this study, hydrophilic octahedral MNPswere synthesized in benzyl ether via thermal decomposition of Fe(acac)3, using homoproline as a surface-stabilizing agent. These particles were tested for biomedical applications, with a focus on MH. Thermogravimetric analysis showed an organic phase weight of 15%. The synthesized MNPs exhibited a high saturation magnetization (>75 emu/g at 300 K) and a low coercivity (<20 Oe). Water-based dispersions showed high stability and a high specific absorption rate (SAR) of 123.1 ± 3.6 W/g at a 2 mg/ml concentration, with a temperature increase of 24.5°C after 16 minutes. At a higher concentration of 10 mg/ml, the same temperature rise was achieved in just 1.5 minutes (Fig. 1). Finally, surface modification was performed to reduce uncontrolled iron-ion leaching and particle aggregation in biological media, mainly by reducing nonspecific protein adsorption. The proposed strategy enables direct formation of hydrophilic, shape-controlled magnetite nanoparticles without post-synthetic ligand exchange, highlighting the potential of this approach for simplified preparation of biomedical-grade magnetite nanoparticles.



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Nanoengineered Pro-Degradative Coating for Bioresorbable Iron Cardiovascular Stents

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Controlling both the resorption rate and the formation of reactive oxygen species (ROS) of biodegradable iron (Fe) remains a central challenge for bioresorbable cardiovascular stents. Here, we introduce an innovative, nanoengineered surface coating strategy to simultaneously accelerate Fe corrosion and suppress ROS generation without altering the bulk Fe materials. Aryl-diazonium salt chemistry (4-cyanobenzene diazonium tetrafluoroborate, DCN) was used to creates robust polyaryl interphases that can immobilize gold nanoparticles (Au NPs) on Fe, establishing nanoscale microgalvanic and catalytic sites. Electrochemical analysis reveals that the coating increases the overall Fe corrosion rate while biasing cathodic oxygen reduction reaction towards the four-electron pathway, thereby reducing peroxide/hydroxyl radicals (OH•) formation. This mechanism is supported by the remarkably reduced OH• content detected by terephthalate-probe assay. Corrosion metrics show a pronounced, controllable rate enhancement relative to bare Fe, and the post-corrosion exposure interfacial spectroscopy/microscopy verify the persistence of Au NPs, attributed to atomic Fe–FeO-Au interactions and anchoring by the DCN-derived polyaryl layer. Endothelial cells culture indicates favorable adhesion and viability, supporting cytocompatibility of the modified surface. This surface-chemistry–driven mechanism establishes a general interfacial principle for rate- and pathway-control of iron biodegradation, offering a concise route to safer, faster-resorbing Fe-based stents [1].

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Interface-Engineered MoS_2 Photo-Nanozymes as Multifunctional Materials for Precision Catalytic Cancer Therapy

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Tumor hypoxia remains a critical barrier limiting the efficacy of conventional cancer therapies by reducing ROS-mediated cytotoxicity and photothermal treatment. Catalytic nanomaterials, particularly photo-nanozymes, provide a multifunctional strategy to overcome these limitations by integrating enzymatic mimicry with light-triggered photothermal effects.[1,2] Here, we present interface-engineered MoS_2-based photo-nanozymes as a precision platform for catalytic cancer therapy.

Hydrothermally synthesized MoS_2 nanoflowers (~200 nm) exhibit intrinsic peroxidase (POD) and catalase (CAT)-like activities, efficiently converting endogenous hydrogen peroxide into reactive oxygen species (ROS) and oxygen, thereby alleviating tumor hypoxia.[3] C_3N_4@MoS_2 heterojunctions were engineered to enhance optical absorption, improve charge separation, and enable cascade catalytic activity. By adjusting MoS_2 content (5–40 wt%), near-infrared (808 nm) irradiation allowed tunable photothermal heating ($\Delta T \approx 10$ °C). In vitro studies using 2D FaDu cells and 3D tumor spheroids demonstrated minimal dark toxicity, while synergistic ROS amplification and localized photothermal heating induced potent cytotoxicity, reducing spheroid viability. he integrated design enables precise modulation of the tumor microenvironment, transforming hypoxia from a therapeutic barrier into a targetable feature.[4] Interface engineering further improves multifunctionality, catalytic performance, and NIR responsiveness.

MoS_2-based photo-nanozymes constitute a robust, multifunctional platform for precision catalytic cancer therapy, uniting enzymatic mimicry with photothermal functionality. This work highlights their potential as next-generation nanomaterials for translational oncology, offering a pathway toward clinically relevant, controllable, and highly effective cancer therapeutics.

This project received financial support from the CNRS through the MITI interdisciplinary programs and from Lorraine Université d'Excellence as part of the France 2030 Program (reference ANR-15-IDEX-04-LUE).

Keywords: MoS_2, photo-nanozyme, catalytic therapy, tumor hypoxia, photothermal therapy

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Engineering Selective Peptide Ligands for the Development of Nanoparticles Targeting the Metabolic-Immune Interface

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Major histocompatibility complex (MHC) class I–related protein (MR1) is a highly conserved, low-polymorphic antigen-presenting molecule that links metabolism to immune surveillance by presenting small metabolites to MR1-restricted T (MR1T) cells. Its distinctive “presentation-on-demand” mechanism relies on metabolite binding in the endoplasmic reticulum, which stabilises the MR1–β2-microglobulin (β2m) complex and promotes its maturation and surface expression. The nature of the presented metabolite determines the immune response: activating ligands induce rapid T cell activation, whereas inhibitory ligands suppress responses and maintain immune homeostasis.

We hypothesised that MR1 can be targeted using peptide binders that engage the complex in a manner analogous to T cell receptor (TCR) recognition. To test this, we screened for peptides binding specifically to MR1 loaded with acetyl-6-formylpterin (Ac-6-FP), a stable antigen known to enhance MR1 surface expression.

Human MR1 ectodomain (MR1_ED)–β2m heterodimers loaded with Ac-6-FP, were expressed in E. coli, purified by fast protein liquid chromatography, and characterised by native mass spectrometry and circular dichroism. These complexes were used as targets in phage display screening. Selected clones were Sanger sequenced, and binding specificity was assessed by ELISA. We identified three peptides (VHLA, ISWG, NNMG; representing the C-terminal residues of 12-mer sequences) with selective binding to MR1 complexes over controls.

This study provides the first demonstration of MR1 targeting using non-TCR-derived peptide binders, establishing a proof-of-concept for MR1-directed recognition. These peptides represent a versatile platform for targeted therapeutic development and can be readily conjugated to nanoparticles to enable selective delivery strategies.

Iron-doped CeO_2 Nanoparticles Trigger Eryptosis: Is Iron Critically Involved?

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Iron doping is a feasible strategy to modulate toxicity and biological effects of nanomaterials. In particular, iron-doped metal oxide nanoparticles (NPs) are considered promising anti-cancer agents due to their enhanced ability to trigger ferroptosis, an iron-driven regulated cell death. In this study, blood compatibility of iron-doped and non-doped CeO_2NPs was evaluated focusing on their ability to trigger eryptosis, a regulated cell death of mature erythrocytes. Eryptosis is increasingly recognized as a nanotoxicological endpoint in the overall assessment of nanomaterial hemocompatibility. State-of-the-art flow cytometry-based techniques were applied to evaluate the eryptosis-triggering capacity of Fe^{3+}-doped CeO_2 NPs with the varying content of Fe^{3+} ions (3, 5, and 10 at.%) and non-doped NPs.

Iron-doped NPs showed the dose-dependent ability to trigger hemolysis, enhance osmotic fragility of erythrocytes, promote phosphatidylserine externalization (annexin V-FITC staining), reactive oxygen species (ROS) generation (2',7'-dichlorodihydrofluorescein diacetate assay), lipid peroxidation (BODIPY 581/591 C11 staining), as well as increase intracellular Ca^{2+} and Fe^{2+} levels (Fluo 3-AM and BioTracker Far-red Fe^{2+}probes, respectively) in rat erythrocytes. Thus, eryptosis triggered by all iron-doped CeO_2NPs was found to be oxidative stress-driven and cation channel (Ca^{2+} influx)-dependent. Importantly, eryptosis was shown to be triggered by lower concentrations of NPs than hemolysis, confirming its higher sensitivity in nanotoxicological studies. Non-doped NPs did not trigger eryptosis and oxidative stress in erythrocytes at concentrations that were eryptosis-promoting for Fe^{3+}-doped NPs, suggesting the crucial role played by iron doping. Moreover, an increase in the content of Fe^{2+} in erythrocytes exposed to iron-doped CeO_2 NPs indicates that they can be potentially tested as ferroptosis-inducing agents in cancer cell lines, since $Fe^{2+}$is a major driving force of ferroptosis.

To conclude, iron doping ofCeO_2NPs modulates nano-bio interactions of CeO_2 NPs,increasing their toxicity against erythrocytes, which results in the promotion of oxidative stress-driven and cation channel-dependent eryptosis.

The study was supported by the DonatioUniversitatisCarolinae Chair grant provided by Charles University, Czech Republic.

Keywords: eryptosis, nanoceria, nanotoxicity, regulated cell death

Day - 3

NanoSeries2026 Technical Session: NS (F)

Next-Generation Light-Matter Interactions at the Nanoscale: Photonics and Optoelectronics

Theoretical Modeling of Ultrafast Phase Transitions from the Femtosecond to the Picosecond Scale

S. Mocatti, A. Corradini, G. Volpato, X. Zhu, P. Cudazzo, G. Marini and M. Calandra*

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In this talk, I will introduce a theoretical approach [1,2] to ultrafast phase transitions that captures both electron/hole and phonon dynamics following laser pumping, on time scales ranging from a few femtoseconds to hundreds of picoseconds after the action of the pulse.

At short times, the method relies on solving the manybody Bloch equations coupled to Ehrenfrest dynamics in the space of maximally localized Wannier functions. It includes the electric field of the pump explicitly, as well as carrier-carrier, carrier-phonon, and phonon-phonon scattering, treated entirely from first principles [1].

At longer times before recombination, when carrier-carrier interactions generate a photoexcited quasi-equilibrium electron-hole plasma, the approach is based on a constrained density-functional perturbation theory (cDFPT) scheme that accounts for the presence of holes in the valence band and electrons in the conduction band (two-Fermi-level approach) [2]. In this framework, the calculation of forces, phonon dispersion, and carrier-phonon coupling becomes possible, as well as molecular dynamics with machine-learning potentials in the presence of an electron-hole plasma [3].

I will showcase relevant applications of the method to ultrafast transitions in 2D materials andnanosystems [1,3,4].

This work is funded by the European Union (ERC, DELIGHT, 101052708).

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Chiral Sensing With Silicon Nanophotonics

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Chirality is omnipresent in biochemistry, where molecules with opposite handedness can have markedly different biological functionalities. Detecting molecular chirality, however, is plagued by low sensitivity, limiting its use to high concentrations and large volumes. In this presentation, we introduce two examples of dielectric nanophotonic structures for chiral sensing, in particular, silicon metasurfaces.

By sustaining optical resonances of electric and magnetic dipole origin, high-index metasurfaces can strongly enhance the sensitivity of chiral molecular detection in small volumes [1-3]. First, we will discuss our experimental results on enhancing circularly polarized luminescence from chiral molecules using crystalline silicon metasurfaces. Our results combine fluorescence enhancement [4] with controlled circular polarization. To this end, we developed a microscope with polarization modulation and photon-counting capabilities to measure smaller chiral analyte volumes than are possible with commercial systems.Second, we will present enhanced circularly polarized Raman scattering in silicon metasurfaces. Our experimental results agree with a tensorial theory of polarized Raman scattering, demonstrating the relevance of the multipolar Mie resonances in metasurfaces for controlling excitation and emitted polarizations.

Metasurfaces open exciting paths to reach previously unmeasurable sensitivities for chiral optical spectroscopies at lower molecular concentrations and smaller analyte volumes.

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Spin-Selective Photophysical Pathways in Chiral Donor–Acceptor Dyads

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Photoinduced spin interactions play a fundamental role in fields ranging from optoelectronics to quantum technologies.1 In this framework, chiral molecules offer an exciting route to control the spin degree of freedom via the chirality-induced spin selectivity (CISS) effect.2Recent breakthroughs have enabled the direct detection of CISS in electron donor-acceptor dyads.3These studies show that CISS governs the spin dynamics of photoinduced charge transfer through chiral bridges at the molecular level.Understanding the molecular origin of CISS and identifying its key molecular parameters are now pressing priorities.4

Here, we present new systems consisting of a thiabridged[4]helicene donor covalently linked to a perylenediimide (PDI) acceptor through bridges of variable length. Transient absorption and time-resolved electron paramagnetic resonance (TREPR) spectroscopies reveal that the spin selectivity of charge transfer and triplet formation pathways strongly depends on the bridge design. Orientation-dependent TREPR experiments of the longer chiral dyad and its achiral analogue disclose the generation of distinct spin-polarized radical pair signals. Complementary theoretical simulations clarify the molecular origin of the CISS effect and show that the electron motion through the chiral bridge is essential for its observation.

These results add another piece to the puzzle of chirality in donor-acceptor dyads, with the final aim of exploiting CISS to control electron spin states for applications in photovoltaics and quantum information science. Supported by the Italian Ministry of University and Research through the Fondo Italiano per la Scienza project SPIROχ (FIS-2023-01975).

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Electrostatic Repulsion as a Governing Mechanism in Near- and Far-Field Optical Binding of Gold Nanoparticles

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The dynamics and equilibrium configurations of optically bound particles immersed in a fluid arise from the interplay of multiple physical mechanisms, including optical forces, electrostatic interactions, and hydrodynamic effects [1]. From a theoretical perspective, a key challenge lies in disentangling the relative contribution of these interactions across different length scales. In this work, we combine experiments with a theoretical and numerical framework to demonstrate that short-range electrostatic forces play a central role in determining the observed optical binding configurations. Within our model, electrostatic repulsion between gold nanoparticles is explicitly incorporated and systematically tuned to mimic variations in salt concentration. The theoretical analysis reveals that reducing the strength of the electrostatic interaction favors near-field optical binding, leading to particle arrangements aligned along the polarization direction of the incident field. Conversely, when electrostatic repulsion is dominant, the balance of forces shifts toward far-field optical binding, resulting in equilibrium configurations oriented perpendicular to the polarization direction.Numerical simulations based on this model quantitatively reproduce the experimentally observed particle configurations across the explored parameter space [2]. These results underscore the decisive influence of electrostatic interactions in shaping the energy landscape of optically bound systems, particularly in the regime of far-field optical binding, where repulsive forces critically determine both stability and orientation of the particle assemblies.

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Nanoscale Reshaping of Molecular Excitation via Plasmonic Hot-Spots

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Plasmon–fluorophore interactions are most often described in terms of overall fluorescence enhancement or quenching. Yet, beyond intensity modulation, plasmonic near-fields offer the possibility to redistribute how different electronic transitions contribute to excitation and emission[1]. In this work, we show that plasmonic hot-spots can reshape the excitation profile of tetraphenylporphyrin (H_2TPP), increasing the relative contribution of the Q-bands compared to the dominant Soret band.

To explore this effect, wavelength-dependent near-field enhancements were calculated using Boundary Element Method simulations[2] for plasmonic architectures with progressively stronger confinement, including Au and Ag nanosphere aggregates, Au nanorods, and Au nanostars[3]. The simulations reveal morphology-specific amplification patterns, with selective reinforcement of spectral regions that overlap with plasmonic resonances.

Based on these predictions, H_2TPP was covalently positioned at a defined separation (~1.8 nm) from the metal surface using a rigid α-helical peptide spacer[4], enabling controlled coupling across nanostructures. Normalized excitation and emission spectra reveal reproducible spectral reshaping: Q-band excitation becomes relatively more prominent, with the extent of redistribution governed by the spectral overlap between porphyrin transitions and plasmonic resonances. The experimental trends follow the wavelength-dependent field enhancements obtained from electromagnetic modeling, highlighting the role of localized confinement in steering the interaction.

Rather than solely amplifying emission intensity, these results illustrate how plasmonic nanostructures can redistribute the spectral weight of molecular transitions. Such control over excitation pathways expands the usable spectral window of chromophores without chemical modification, opening new directions for nanoscale photonic and optoelectronic design.

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Origin of the Temperature-Induced Gap Bowing of $FA_xMA_{1-x}PbI_3$ Perovskites: Role of Cationic Rattlers

Xu K.[1], Francisco-López A.[1], Charles B.L.[2,3], Alonso M.I.[1], Garriga M.[1], Weller M.T.[2,4] and Goñi A.R.*[1,5]

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A thorough understanding of the temperature dependence of semiconductor band gaps is essential for optimizing optoelectronic devices. In this respect, the origin of the pronounced temperature-induced gap bowing observed in low-temperature phases of formamidinium-methylammonium (FA-MA) lead iodide perovskites [1] has remained elusive until now. By combining temperature and pressure-dependent photoluminescence measurements on a series of FAxMA1-xPbI3 mixed-cation single crystals with eleven compositions from 0 to 1, we unravel the origin of this bowing. Both thermal expansion as well as electron-phonon interaction effects are responsible [2,3]. However, the latter is the leading term, driven by the activation of an anomalous electron-phonon coupling mechanism linked to mixed vibrational modes [4], which combine inorganic-cage phonons involving octahedral tilting with low-frequency FA librations, i.e., FA rattler modes. This occurs mainly in a low-temperature (pseudo)tetragonal phase, presumably featuring stripe domains with alternating octahedral tilt patterns for FA concentrations between 20% and 90% [5]. In this way, we have shed light on an intriguing behavior of lead halide perovskites that directly affects their optoelectronic properties.

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Exploring Correlated Disorder Photonic Materials With Scanning Near-Field Optical Microscopy

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Hyperuniform disordered (HuD) photonic structures represent a novel class of materials that bridge the gap between periodic photonic crystals and random media, combining the advantages of both worlds [1]. By leveraging correlated disorder, they exhibit large, isotropic photonic band gaps and can host both Anderson-localized modes and delocalized, diffusive states within the same platform [1,2]. This makes them ideal for investigating fundamental light transport phenomena and for applications in integrated photonics and quantum optics.

In this talk, I will showcase the potential of Scanning Near-Field Optical Microscopy (SNOM) to investigate the fundamental properties of HuD photonic materials. Exploiting its subwavelength resolution and hyperspectral capabilities, we reveal that Anderson-localized modes follow conventional photonic scaling laws [3]: systematic variations of length scale and filling fraction produce predictable spectral shifts, while mode spatial profiles remain robust. This demonstrates that HuD materials combine the spectral predictability of periodic systems with the isotropy and fabrication tolerance typical of disordered architectures [2,3].

Through autocorrelation analysis of spatially-resolved spectra [4], we provide the first experimental evidence of level repulsion among delocalized modes, a universal signature of modal interaction, rigorously distinguishing them from uncorrelated Anderson-localized states [5]. Interestingly, beyond conventional localization, we discover that topological defects encoded within the hyperuniform architecture host a peculiar class of highly confined resonances. Their spatial and spectral fingerprints reveal striking similarities with Lifshitz states known from electronic systems [6]: rare, disorder-induced modes emerging near the band edge with the tightest spatial confinement. When such defects lie in close proximity, their modes hybridize into coupled “photonic molecules” with bonding and antibonding character [5].

Our results establish HuD materials as a versatile platform where disorder becomes a tunable design parameter, enabling simultaneous control over localization, spectral correlations, and mode coupling for applications in nanophotonics and quantum technologies.

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Low-Power Operable, Ultrathin Reflective Displays Based on Reconfigurable Gires–Tournois Resonators

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Achieving uniform colour and efficiency at micrometre-scale pixels remains challenging for near-eye displays. LCoS offers high resolution but requires high voltage and suffers from light loss and scalability limits, while PCM and EO materials face issues such as heat, high voltage, or limited modulation. We introduce a PANI-integrated electrically reconfigurable Gires–Tournois (r-GT) resonator that enables full-colour modulation at CMOS-compatible low voltages (−0.2 to 0.8 V) with ultra-low power (90 µW/cm²). It operates from 1.5 µm micro-pixels to large areas and supports memory-in-pixel functionality, significantly reducing energy consumption.

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Stimulated Terahertz Emission from CMOS-Compatible α-Sn Nanoparticles Integrated on Silicon

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The realization of efficient solid-state emitters in the far-infrared/terahertz spectral range remains a major technological challenge due to the limited performance of both electronic and photonic devices at these energies [1]. In this work we investigate the potential of semiconducting α-Sn nanoparticles integrated on silicon as a CMOS-compatible platform for tunable THz emission. Recent studies demonstrated that microwave-assisted processing enables stabilization of α-Sn nanocrystals on silicon substrates with a size-dependent direct bandgap spanning the THz region [2,3], making this material a promising candidate for integrated photonic applications.

Here we report the first experimental investigation aimed at detecting stimulated emission from α-Sn nanoparticles. Nanoparticles were obtained by Sn thin-film deposition followed by annealing and microwave irradiation, producing core–shell nanostructures with controllable diameters and bandgap energies. To enhance light–matter interaction, a resonant chromium slab-antenna array was designed through electromagnetic simulations and fabricated by electron-beam lithography, allowing nanoparticles to remain in contact with silicon while benefiting from resonant field enhancement.

Optical characterization was performed using a customized FTIR configuration capable of detecting emission contributions from the sample. Transmission measurements at different fabrication stages show that only microwave-irradiated nanoparticles yield an additional spectral contribution. After normalization, a broad emission peak appears near the expected bandgap wavelength, consistent with stimulated emission from α-Sn nanostructures.

These results provide the first experimental indication of stimulated emission from silicon-integrated α-Sn nanoparticles and highlight their potential for CMOS-compatible THz sources and photonic devices relevant to next-generation communication, sensing, and quantum technologies [4,5].

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Exploring Defects in Group IV Heterostructures as Advanced Light–Matter Interfaces

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The advent of a future quantum internet promises a revolutionary leap in communication technologies by enabling generation, global distribution, storage, and processing of quantum bits [1]. Central to this vision is the need to connect quantum nodes via quantum states of light. In this context,defects in semiconductorsshow exceptional promise as non-classical light sources and as spin-photon interfaces [2]. However, the operational wavelength of these systems currently lies at the border of the infrared, which poses significant challenges for long-distance quantum communications.

This work aims to create and study point defects in group IV heterostructures, specifically focusing on their optical characteristics and the mechanisms leading to the formation and efficiency of these defects. To this purpose, we primarily employ protons and helium ions and high-quality Ge-on-Si heterostructures, followed by detailed analysis using photoluminescence spectroscopy [3]. This work explores an uncharted territory in the realm of quantum repeaters, leveraging the unique properties of Ge-on-Si heterostructures to advance our understanding of quantum architectures in the telecom range. Indeed,we unveil the emergence of the so-called C-centre, a quantum emitter based on interstitial oxygen-carbon complexes whose zero-phonon linefalls at 1569 nm in the telecom L band[3].

We then further our knowledge by exploring the possibility of optically injecting and reading spin states at extended defects that naturally develop in Ge-based heterostructures as a result of the lattice mismatch. This unrivalled possibility can open novel routes to realize light-matter interfaces and to manipulate spin-based phenomena such as spin-to-charge interconversion.

In conclusion, through meticulous irradiation experiments and optical spin orientation investigations, we aim to uncover new opportunities to realize quantum photonics in group IV materials via defect states. All these findings are expected to contribute to the advancement of critical technological areas in the context of quantum information science and technology.

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Day - 3

NanoSeries2026 Technical Session: NS (C1)

Bionanosensors and Bioelectronics: In Vitro and In Vivo Applications

Heterogeneously-Integrated Deformable Optoelectronic Systems for Biostimulation and Biosensing

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With the advent of the IoT era, wearable smart devices, particularly electronic skins (e-skins), have emerged as critical tools for novel human-machine interfaces (HMIs). However, conventional approaches utilizing organic materials or rigid bulk chips often face limitations in optoelectronic performance and mechanical conformability, restricting their stability in dynamic biological environments.

In this talk, I will introduce recent advancements in heterogeneously-integrated deformable optoelectronic systems designed for precise biostimulation and biosensing. By utilizing high-performance inorganic semiconductors on functional substrates, we address the limitations of existing soft electronics. The presentation will cover the fabrication of high-performance active components, specifically flexible microLEDs for effective biostimulation and Transition Metal Dichalcogenide (TMD)-based photodetectors for high-sensitivity sensing. Furthermore, I will demonstrate a fully integrated wearable system realized through the heterogeneous integration of these technologies, offering a robust and high-performance solution for next-generation bio-integrated electronics.

Keywords: Electronic skin, Heterogeneous integration, flexible optoelectronics, Human-machine interface

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Calorimetric Lateral Flow Immunoassays (CLFIA). Next-generation Point-of-Care (POC) Biosensors Targeting Tumor-Related Extracellular Vesicles (EVs) and Their microRNA (miRNA) Content

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Pancreatic ductal adenocarcinoma (PDAC) stands as one of the leading causes of cancer-related deaths, driven by late diagnosis, limited treatments, and poor therapeutic responses. Neurodegenerative diseases (NDs), including Alzheimer's and Parkinson's, similarly pose major health challenges due to their progressive nature and the absence of early diagnostic tools and curative options. Extracellular vesicles (EVs) serve as key intercellular messengers in both pathologies, carrying biomolecules that reflect tumor progression, metastasis, chemoresistance, neuroinflammation, and protein misfolding [1,2,3,4].

Biomarkers within EVs, such as miRNAs and membrane-based proteins, enable early detection and therapy monitoring for PDAC and neurodegenerative conditions. Our team exploits inorganic Gold nanomaterials (AuNMs), specifically Gold Nanoprisms (AuNPris, λ_max = 1100 nm), with tailored physicochemical and opto-thermal properties for next-generation temperature-based POC biosensors.

Here, we present variousrapid Lateral Flow diagnostic tests formats integrated with Calorimetric amplification due to the mentioned optothermal properties of AuNPris. One of them employs 150 nm AuNMs biofunctionalized with PDAC- and neurodegeneration-associated miRNA-specific DNA probes. These nanoconjugates, acting as signal enhancers and thermal transducers, generate heat under NIR laser irradiation[5-7].Target miRNA binding triggers antibody recognition on a nitrocellulose strip, producing a quantifiable visible dark spot on a backside-attached thermosensitive paper (LoDcalorimetric = 0.5 fmol miRNA/µL sample). Validation against qRT-PCR on EVs from pancreatic cell lines and neurodegenerative models shows strong concordance, with advantages in cost, speed, and simplicity. Furthermore,a second CLFIA detects intact EVs via sandwich conformation using anti-tetraspanin antibodies (as CD63 or CD9) and PDAC-specific markers like Glypican-1 (GPC1) or EpCAM. Following immunoaffinity column purification, our group was able to achieve a detection of tumor-related EVs down to 10^3 EVs/mL. This opto-thermal platform holds promise for neurodegenerative EVs using shared membrane-based biomarkers, pending deeper validation.

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Dual-Emission Fluorescent Molecularly Imprinted Polymer-Based Test Strips for Memantine Detection

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In medical theranostics, there is an increasing demand for paper-based assays capable of detecting physiologically relevant analytes with rapid and visual readout. Such platforms are particularly advantageous for point-of-care testing and routine monitoring. Memantine (MEM), an N-methyl-D-aspartate (NMDA) receptor antagonist, is widely used for the treatment of moderate to severe Alzheimer's disease by modulating glutamatergic signaling and slowing disease progression [1].

Herein, we report a dual-emission fluorescent molecularly imprinted polymer (DE-MIP)-based test strip for the rapid and visual detection of MEM. The sensing mechanism relies on the fluorescence intensity ratio between CdTe quantum dots (656 nm) and carbon dots (455 nm). Carbon dots were synthesized via a hydrothermal method using citric acid and ethylenediamine, while CdTe quantum dots were prepared following a slightly modified reported procedure [2]. The polymerization was performed using MEM as the template, hydroxyethyl methacrylate/methacrylic acid as functional monomers, ethylene glycol dimethacrylate as crosslinker, and AIBN as initiator.

The DE-MIP nanoparticles were coated onto filter paper (1 × 2 cm) via a simple soaking process to fabricate the test strips. The resulting platform exhibited high selectivity toward MEM with minimal interference. Fluorescence color changes proportional to MEM concentration enabled direct visual and semi-quantitative detection within 5 minutes using only 10 µL of sample. Performance evaluation in phosphate-buffered saline and artificial human serum demonstrated reliable detection with a linear range of 0.008–0.125 µg/mL and a limit of detection (LOD) of 0.0019 µg/mL.

This facile paper-based sensing strategy provides a rapid, low-volume, and on-site applicable platform for MEM monitoring, offering significant potential for clinical and wearable theranostic applications.

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Plasmonic AuNP-Derived Thin Films for Monitoring Cardiac Cells and their Biomarkers

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Introduction and objective of the research: Organ-on-Chip (OoC) devices are increasingly used to investigate cellular processes and model diseases,[1] integrating microfluidics, microelectrodes, and sensing elements to culture and monitor living cells.[2] In cardiac models, human-induced pluripotent stem cell-derived cardiomyocytes (hIPSC-CMs) require long maturation times and reliable platforms for continuous monitoring. Microelectrode architecture is central to device performance; however, conventional fabrication via photolithography and physical vapor deposition (PVD) is costly and time-consuming.[3] This work proposes a simple, rapid, and greener fabrication strategy based on spray-coated gold nanoparticles (AuNPs) to produce nanostructured plasmonic microelectrodes suitable for electrophysiological interfacing and label-free metabolic sensing via Surface Enhanced Raman Scattering (SERS).

Methodology: Thin metallic films were fabricated by spray coating AuNPs synthesized by laser ablation in solution (LASiS) onto glass substrates (Figure 1).[4] Inkjet-printed, water-soluble polysaccharide shadow masks enabled micrometric patterning without PVD.[5]This approach supports large-area deposition with reduced material consumption while preserving nanoparticle properties. The resulting nanostructured films (few hundred nanometers thick) were assessed for SERS activity. Adenine, ATP and hypoxanthine were analyzed via SERS mapping, and calibration curves were constructed within biologically relevant ranges. Multivariate chemometric models improved quantification in complex mixtures. In parallel, cardiomyocytes were cultured directly on patterned electrodes and monitored by electrochemical impedance spectroscopy (EIS) using a potentiostat to compare responses in the presence and absence of cells.

Key findings and results: Spray-coated AuNP films exhibited high-resolution micropatterning (tens of µm), good electrical conductivity, and strong SERS enhancement. Metabolites were detected at micromolar concentrations, potentially enabling assessment of cardiomyocyte metabolic state.[6] Cells displayed a characteristic EIS fingerprint, absent in controls. However, limited adhesion on glass substrates highlighted the need for improved supporting materials.

Conclusions: The proposed strategy offers a cost-effective, scalable alternative to PVD, delivering multifunctional plasmonic platforms that integrate impedance monitoring and label-free metabolic sensing for advanced OoC cardiac models.

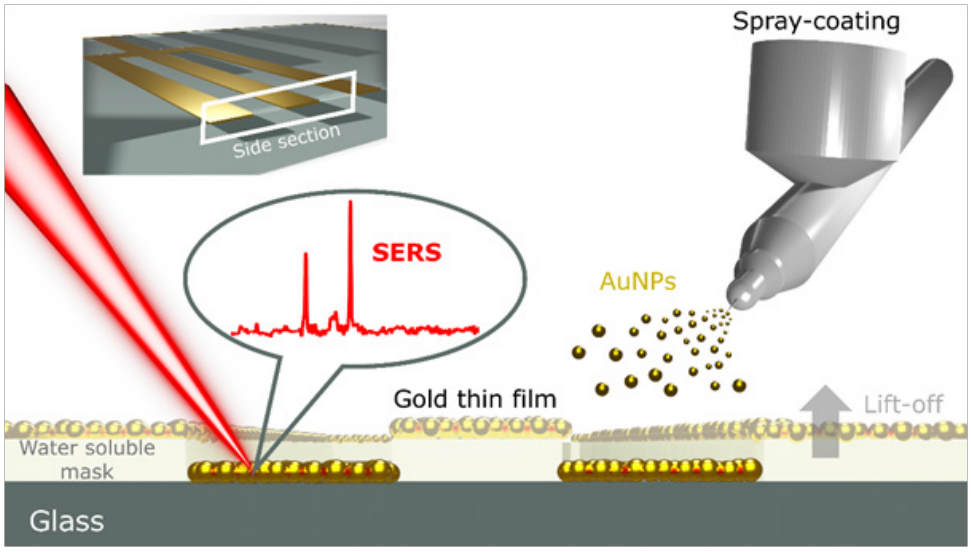

Figure 1: Schematics of the plasmonic microelectrode and the required fabrication steps.

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miR-155 Detection by Field Effect Transistor Biosensor (bioFET) Using Short- and Full-Length PNA Probe Design

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MicroRNAs (miRNAs) are promising biomarkers for early diagnostics, yet standard detection methods are often hampered by high costs and time-consuming procedures[1]. FieldEffect Transistor biosensors (bioFETs) offer a compelling alternative[2]. These devices can provide analytical performance comparable to conventional methods while offering additional practical advantages such as label-free operation and point-of-care (PoC) suitability. BioFETs rely on a transducer (i.e., working electrode) where a biorecognition element (i.e., probe) is immobilized to capture the target and translate this binding event into electrical signals [3]. Crucially, the probe determines both selectivity and sensitivity, ensuring that only target recognition induce a measurable analytical signal. Among various probes, Peptide Nucleic Acids (PNAs) are particularly promising[4,5]. PNAs are nucleic acid analogues characterized by a neutral peptide-like backbone that eliminates electrostatic repulsion, ensuring remarkable affinity for complementary miRNA targets. Beyond probe chemistry, bioFET sensitivity is strictly governed by the proximity of miRNAs charges to the transducer surface; therefore, shortening the PNA probe sequence could offer a valuable strategy to amplify signal generation. Such design is expected to create unhybridized target overhangs that position miRNA charges closer to the sensor surface [6].To exploit this rationale, we implemented a short-length (S-PNA) design (10-mer) for miRNA 155 (miR-155) detection, comparing its performance against a traditional full-length (FL-PNA) configuration (22-mer) (Figure 1).

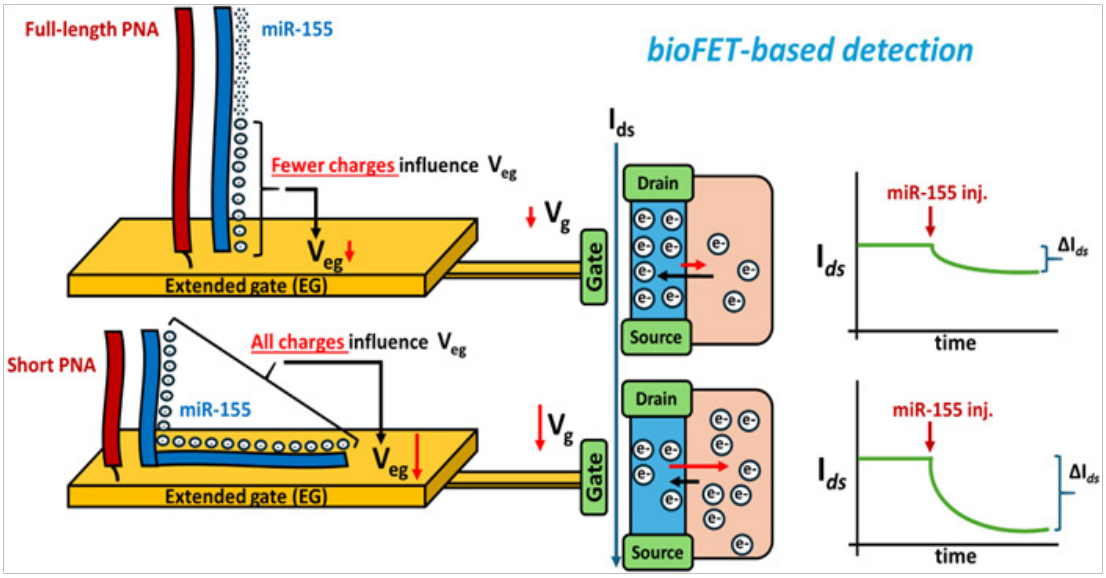

Figure 1: The short PNA design vs. full-length design for bioFET detection of miRNA 155.

Concurrently, Surface Plasmon Resonance (SPR) was employed to optimize the probe immobilization. The application of the S-PNA design to bioFETs, alongside optimized probe functionalization, yielded a Limit of Detection (LoD) of 0.2 fM. This performance represents a 1000-fold improvement over the traditional FL-PNA configuration. The device maintained high specificity against non-complementary and double-mismatched variants. Overall, these findings establish a robust framework for enhancing bioFET performance for ultra-sensitive miRNA detection.

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Degradable Nanocomposites for the Construction of Sustainable Point-of-Care Electronic Biosensors

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Electronic biosensors are promising platforms for point-of-care diagnostics and temporary monitoring in healthcare due to their excellent sensitivity, versatility, rapid response, small footprints, and straightforward digital readout.[1,2] Traditional point-of-care electronic biosensors have short operational lifecycles and rely on persistent materials for device construction (e.g., silicon, glass, polyimide, and noble metals), significantly contributing to electronic and medical waste accumulation. This issue is exacerbated by direct exposure of sensing interfaces to physiological fluids, favoring the use of disposable components due to difficult regeneration. Therefore, the development of sustainable biomaterials for electronic biosensor construction is necessary to achieve broader adoption while minimizing environmental impact through safe biodegradation or recycling. Degradable nanocomposites are particularly attractive for sensor design because of the possibility to tune surface properties and tailor degradation behavior for the required functionality and operational lifetime.

This talk presents two degradable nanocomposite biomaterials that facilitate the design of sustainable electronic biosensors. First, we developed phytoglycogen nanoparticle-based multilayered hydrogel coating as an interface for degradation-induced impedimetric detection of α-amylase. By leveraging the layer-by-layer deposition of phytoglycogen-cysteine and heparin-maleimide, we achieved a stable and reproducible response to enzymatic biodegradation, allowing for measurements in a broad clinically relevant range of α-amylase concentrations (101–105 U/L). Attachment of the sensitive coating to composite molybdenum/polycaprolactone electrodes patterned on a flexible polycaprolactone substrate enabled the construction of a robust and fully degradable impedimetric biosensor. Second, we developed rigid degradable substrates with low surface roughness (<1 µm) by synthesizing composites of polycaprolactone, polylactide, and $CaCO_3$ nanoparticle fillers. These substrates are compatible with printing and sputter deposition of electrodes, enabling the formation of disposable electrode arrays. We demonstrate their ability to support multiplexed electronic biosensing relevant for potentiometric and amperometric platforms. Our nanocomposites and fabrication strategies hold promise for reliable and tunable design of diverse sustainable bioelectronic platforms.

Keywords: degradable sensor components, hydrogel nanoparticle coatings, ceramic nanoparticle fillers, in vitro diagnostics, sustainable bioelectronics

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From SERS Sensors to a Complete Solution for Color Analysis: Visualization-Augmented Deconvolutional SERS (VAD-SERS)

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We report the development of a technique for complex color analysis that combines reversed-phase liquid chromatography with in-line detection via Surface-Enhanced Raman Scattering (SERS).The SERS detection is enabled on an alumina (aluminum oxide) solid support. Alumina beads (4 mm diameter) are sequentially treated with cetyltrimethylammonium bromide (CTAB) and a water-repelling agent to form a surface with inter-twined hydrophilic and hydrophobic segments. This facilitates subsequent adsorption and enrichment of silver nanoparticles (AgNPs) and the analyte molecules into the hydrophilic niches while maintaining bulk surface hydrophobicity. These alumina beads are excellent SERS sensors, as demonstrated by the efficient detection of common food colorants[1]. The dual-property surface is recreated on 10-µm alumina powders to provide a stationary phase for reversed-phase liquid chromatography. The stationary phase in a glass column is used to analyze complex colors.We dub this technique VAD-SERS,as it enables the resolution of color components and subsequent SERS-based structure identification in a single device.

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Flexible Organic Photonic Device for Sensor Application

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During there centpandemic,many biosensors were developed forvirtualclinics, aconcept that patients do not need to visit hospitals personally to receive diagnosis and treatment. For instance, they can measurephysiologicalparameterssuchasPhotoplethysmogram(PPG)athomeanduploadthosedata tocloudsforanalysis.Ifsuchabiosensorcandetect NIR(near-infrared)light,itcanalsocapturevein images for biometric authentication. The vein pattern is underneath the skin surface, so it is more difficulttocounterfeitthanthefingerprint.Moreover,theabilitytomeasurephysiologicalparameters can tell a real person's vein image from a fake and lifeless one easily. High-speed image capture is also desirable because it facilitates the use of advanced post-processing methods to filter the PPG signalofeachpixelinabiosensorarrayandreconstructtheunder-skinbloodperfusionimages.Inthis study,wehavedevelopedsheet-typeimagesensorwithlow-noiseorganicphotodiode.Thedeveloped sheet-typeimagesensorisfabricatedbydenselyintegratingahigh-efficiencyreadoutcircuitusingan activematrixofalow-temperaturepolysiliconthinfilmtransistorandanorganicphotodiodethatuses ahighlyefficientorganicsemiconductorasaphotosensitivelayer.Theweaklightdetectabilityallowed the capture of artery information from deep tissue during vein imaging and enabled the removal of additional light source to utilize only near-infrared in the indoor ambient as light source. In addition, thehigh-speedcapabilityallowsustovisualizethebloodperfusionimagebycombingtimeseriesdata and singular value decomposition (SVD) method.

Porphyrin-Inspired Carbon Dots for Electrochemical Sensing of Allopurinol

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The development of sensitive, selective, and cost-effective electrochemical sensors for pharmaceutical monitoring has become increasingly important due to the widespread use of therapeutic agents and the need for rapid analytical methodologies. Allopurinol, a xanthine oxidase inhibitor extensively prescribed for the treatment of hyperuricemia and gout, requires reliable analytical detection because inappropriate dosage and prolonged administration may lead to adverse physiological effects. Conventional analytical techniques such as high-performance liquid chromatography, spectrophotometry, and capillary electrophoresis provide excellent accuracy; however, they often involve expensive instrumentation, extensive sample preparation, and limited portability. In this context, nanostructured carbon-based materials offer promising opportunities for the development of next-generation electrochemical sensing platforms.

In the present work, porphyrin-inspired carbon dots (PCDs) were synthesized through a facile and environmentally microwave mediatedrouteusing chlorophyllin as molecular precursors. The resulting nanomaterials shows the unique electronic characteristics of porphyrinic architectures together with the advantageous physical and chemical features of polymeric of carbon dots

This study introduces a versatile strategy for integrating porphyrin-inspired molecular design principles into carbon-dot nanotechnology to create advanced electrochemical sensing materials. The proposed platform provides a rapid, sensitive, and scalable approach for allopurinol monitoring and opens new opportunities for the development of heteroatom-engineered carbon nanomaterials for pharmaceutical analysis, biomedical diagnostics, and environmental sensing applications. The findings highlight the growing potential of functional carbon dots as sustainable nanomaterials for high-performance electrochemical devices.

Hybrid Hydrogels Based on 2D MoS_2/PEGDA/PANI for Application in Peripheral Heart Rate Sensors

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The integration of two-dimensional (2D) nanomaterials, such as molybdenum disulfide (MoS_2) nanosheets, into hydrogel matrices offers significant potential for the development of biocompatible piezoresistive sensors[1]. Hydrothermal synthesis provides a scalable and environmentally favorable route for producing large quantities of 1T-MoS_2 nanosheets[2]. The metallic 1T phase of MoS_2 exhibits high electrical conductivity and large specific surface area, which promote efficient charge transport and enhanced interfacial interactions in composite systems. These properties significantly improve the electromechanical sensitivity of hybrid materials, making them particularly attractive for piezoresistive sensing applications.

In this work, we report a biocompatible piezoresistive sensor based on 1T-MoS_2 nanosheets embedded within a photo-crosslinked polyethylene glycol diacrylate (PEGDA)hydrogel matrix. Electrical conductivity was further enhanced by the in-situ incorporation of polyaniline (PANI), which facilitated efficient charge transport within the composite network. To achieve precise structural control and reproducible performance, 3D printing using digital light synthesis (DLS) was employed as a powerful manufacturing platform, enabling the production of conductive hydrogel architectures with defined geometries and tunable mechanical properties in a cost-effective and scalable way [3]. The resulting hybrid material exhibits stable and reversible electromechanical behavior, demonstrating its suitability for sustainable, wearable, and real-time peripheral heart rate monitoring applications.

Keywords: Hybrid hydrogels, hydrothermal synthesis, MoS_2, 3D-DPL, heart rate sensors.

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