

Terahertz Near-field Nanoscopy Based on Self-mixing Interferometry with Quantum Cascade Resonators

*Original*

Terahertz Near-field Nanoscopy Based on Self-mixing Interferometry with Quantum Cascade Resonators / Pogna, E. A. A.; Reichel, K.; Silvestri, C.; Biasco, S.; Viti, L.; Di Gaspare, A.; Beere, H. E.; Ritchie, D. A.; Columbo, L. L.; Brambilla, M.; Scamarcio, G.; Vitiello, M. S.. - ELETTRONICO. - (2021), pp. 1-1. ((Intervento presentato al convegno 2021 Conference on Lasers and Electro-Optics Europe and European Quantum Electronics Conference, CLEO/Europe-EQEC 2021 tenutosi a Munich, Germany nel 21-25 June 2021 [10.1109/CLEO/Europe-EQEC52157.2021.9542282]).

*Availability:*

This version is available at: 11583/2952582 since: 2022-01-26T14:18:39Z

*Publisher:*

Institute of Electrical and Electronics Engineers Inc.

*Published*

DOI:10.1109/CLEO/Europe-EQEC52157.2021.9542282

*Terms of use:*

openAccess

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

*Publisher copyright*

IEEE postprint/Author's Accepted Manuscript

©2021 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other uses, in any current or future media, including reprinting/republishing this material for advertising or promotional purposes, creating new collecting works, for resale or lists, or reuse of any copyrighted component of this work in other works.

(Article begins on next page)

# Terahertz Near-field Nanoscopy Based on Self-mixing Interferometry with Quantum Cascade Resonators

Eva A. A. Pogna<sup>1</sup>, Kimberly Reichel<sup>1</sup>, Carlo Silvestri<sup>2</sup>, Simone Biasco<sup>1</sup>, Leonardo Viti<sup>1</sup>, Alessandra di Gaspare<sup>1</sup>, Harvey E. Beere<sup>3</sup>, David A. Ritchie<sup>3</sup>, Lorenzo L. Columbo<sup>2</sup>, Massimo Brambilla<sup>4</sup>, Gaetano Scamarcio<sup>4</sup> and Miriam S. Vitiello<sup>1</sup>

<sup>1</sup>NEST, CNR-Istituto Nanoscienze and Scuola Normale Superiore, Piazza San Silvestro 12, 56127, Pisa, IT

<sup>2</sup>Dipartimento di Elettronica e Telecomunicazioni, Politecnico di Torino, C. Duca degli Abruzzi 24, 10129 Torino, IT

<sup>3</sup>Cavendish Laboratory, University of Cambridge, Cambridge CB3 0HE, UK

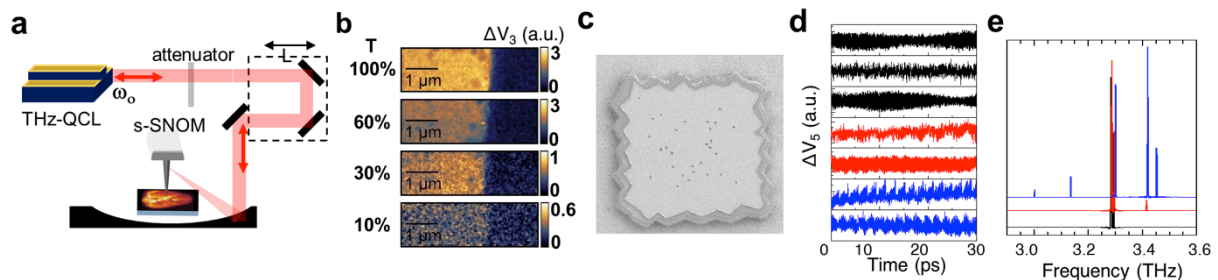
<sup>4</sup>Dipartimento Interateneo di Fisica, Università degli Studi e Politecnico di Bari, via Amendola 173, I70126 Bari, Italy

Corresponding Author e-mail address: [eva.pogna@nano.cnr.it](mailto:eva.pogna@nano.cnr.it)

Near-field imaging techniques at terahertz frequencies (0.5-10 THz), conventionally rely on bulky laser sources and detectors. Here, we devise a compact configuration for scattering near-field nanoscopy based on quantum cascade lasers (QCL) that can simultaneously act as powerful THz source and phase-sensitive detector, exploiting optical feedback interferometry [1], (see Fig 1a). Self-detection is based on the reinjection of the field scattered by the AFM tip into the laser cavity causing coherent interference. The near-field scattering is measured through the induced changes in the contact voltage of the QCL. By changing the path length with a movable mirror, self-mixing interference fringes are acquired and allow to retrieve both the amplitude and phase of the scattered field giving access to the complex-valued dielectric response of the sample [2]. Interestingly for imaging applications, this detection approach is fundamentally limited only by electron transport in the QCL allowing for fast image acquisition.

Here, we analyse amplitude and phase-sensitivity as a function of the driving current and feedback attenuation (Fig. 1b) using a single-mode Fabry Perot THz-QCL coupled to a s-SNOM, demonstrating fast (ps), sensitive (SNR>15) and high resolution (50 nm) nanoscopy of nanostructures and 2D nanomaterials.

Furthermore, we providing the first demonstration of self-mixing detection and s-SNOM with electrically-pumped, surface emitting random THz-QCL [3] exploiting a disordered arrangement of scatterers, lithographically patterned on the top laser surface, that act as light out-couplers [4], Fig.1c. The specific distribution of scatterers can cause either single-mode or multimode laser emission over a broad frequency bandwidth. These innovative sources offer easy surface-emission optical coupling, low-divergence (< 10°), large optical power output (>1 mW) in continuous-wave with low power consumption (< 3 W), electrical frequency tunability and/or multicolor emission, see Fig. 1d-e, and low spatial coherence which can be exploited for speckle free nanoimaging and quantum sensing across the far-infrared.



**Fig. 1** THz near-field nanoscopy based on Self-mixing interferometry with THz-QCL to detect backscattered light from the AFM tip of a s-SNOM; b) Map of third order near-field signal  $\Delta V_3$  at the interface of an Au marker (higher signal regions) on Si substrate (lower signal region) as a function of the optical feedback attenuation controlled with an attenuator of transmission T; c) Scanning electron microscope image of a random QCL resonator having an area of 0.06 mm<sup>2</sup>; d) Self-mixing fringes on near-field fifth order signal  $\Delta V_5$  acquired with random THz QCL in (c) at different driving current increasing from up to bottom, corresponding to tunable multimode spectra in (e);

## References

- [1] M. C. Giordano et al. "Phase-resolved terahertz self-detection near-field microscopy", *Opt. Exp.* 26, 18423-18435 (2018).
- [2] E. A. A. Pogna, M. Asgari, V. Zannier, L. Sorba, L. Viti, M. S. Vitiello, "Unveiling the detection dynamics of semiconductor nanowire photodetectors by terahertz near-field nanoscopy" *Light Sci. Appl.* 9, 1-12 (2020).
- [3] K. S. Reichel, E. A. A. Pogna, S. Biasco, L. Viti, A. di Gaspare, H. E. Beere, D. A. Ritchie, M. S. Vitiello, "Self-mixing interferometry in a quantum cascade random laser at terahertz frequencies" *Nanophotonics* (2021) in press.
- [4] S. Biasco, H. E. Beere, D. A. Ritchie, L. Li, A. G. Davies, E. H. Linfield, M. S. Vitiello, "Frequency-tunable continuous-wave random lasers at terahertz frequencies" *Light Sci. Appl.* 8, 43 (2019).