Memristive Materials, Devices, and Systems (MEMRISYS 2023)

ADVANCED ELECTRONIC MATERIALS Open Access
www.advelectronicmat.de

Memristive Materials, Devices, and Systems (MEMRISYS 2023)

Carlo Ricciardi, Daniele Ielmini, Fernando Corinto, and Sabina Spiga*

The first edition of the International Conference on Memristive Materials, Devices, and Systems (MEMRISYS) was held in Athens in April 2017. The aim was to consolidate at a single international conference on Memristor Technologies in the research communities in circuit theory, materials science, electronic devices, and neuromorphic computing. The 6th edition was held in Torino, Italy: while most of the contributions were about MEMRISYS *core* topics such as resistive switching mechanisms and in-memory computing, increased interest was recorded towards new device schemes (like 3-terminal ones), edge applications, and unconventional computing paradigms (such as reservoir computing).

This Special Issue well reflects MEMRISYS 2023 conference with 13 invited contributions that can be mostly divided into four categories:

1) theoretical aspects of memristors
2) mechanisms of resistive switching
3) in-memory computing
4) disordered networks and physical reservoir computing

In article number 2400172, new theoretical aspects of memristors regarding the high-frequency limit of electro-thermal threshold switches, classified as volatile memristor devices, were studied by Ioannis Messaris and coauthors. By analyzing the experimental response of NbO_2-Mott nanodevices, a mathematical framework that can be extended to all electrothermal devices was proposed.

Three papers study resistive switching dynamics in very different devices: article number 2300818, 2400062, and 2400221. Integrative and stochastic switching effects in Ag/SiOx/Pt electrochemical memristive devices were discussed by Mrinmoy Dutta and coauthors in article number 2400221. The interplay between switching and relaxation times governing the identified switching phases and modes was evaluated, thanks to a complete electrical characterization as a function of pulse voltage, time width, and inter-pulse interval. In article number 2400062, Johannes Hellwig and coauthors proposed a relaxation model based on drift-diffusion dynamics for the low resistive state (LRS) drift of crystalline $Pt/SrTiO_3/Nb:SrTiO_3$ devices. Interestingly, the results of such a model are claimed to be applicable to all Valence Change Mechanism (VCM)-based devices where oxygen exchange between an oxide and a metal is the origin of resistive switching. In article number 2300818, Andrzej Sławek and coauthors reported a theoretical and experimental study on memristive properties of thin layers of dibenzotetraaza[14]annulene complexes of Ni(II), when sandwiched between Cu and ITO contacts. Thanks to electrical characterization, advanced spectroscopic studies, and density functional theory (DFT) simulations, a filamentary-type resistive switching based on redox reactions of stationary molecules within a molecular solid was proposed.

Two papers review recent specific aspects of in-memory computing: capacitance and conductance compensation methods in article number 2400452 and analog phase change memories in article number 2400599. In the first article, 2400452, Yubiao Luo and coauthors reviewed the compensation techniques for balancing the capacitances and conductances of memory arrays, thus improving the accuracy of analog in-memory computation of matrix and vector operations. In the second, 2400599, Andrea Redaelli and coauthors reviewed the most recent advances in the topic of phase change memory (PCM) from device physics and application viewpoints, focusing on PCM-based analog-in-memory computing circuits and systems.

Five papers concerned with disordered networks and physical reservoir computing: article number 2400360, 2400434, 2400443, 2400625, and 2400750. New electrical characterization approaches for analyzing spatiotemporal dynamics in multiterminal nanowire networks were reported by Davide Pilati and coauthors in article number 2400750. In particular, voltage maps using floating electrodes were employed to observe asynchronous and spatially localized network activities, as well as to evaluate how conductance state and local areas can have an impact when nonlinear transformation tasks are employed. A similar approach was reported by Takumi Kotooka and coauthors in article number 2400443, where a random network of thermally

C. Ricciardi
Department of Applied Science and Technology
Politecnico di Torino
Corso Duca degli Abruzzi 24, Torino 10129
E-mail: carlo.ricciardi@polito.it
D. Ielmini
Dipartimento di Elettronica, Informazione e Bioingegneria
Politecnico di Milano and IU.NET
Milan 20133, Italy
F. Corinto
Department of Electronics and Telecommunications
Politecnico di Torino
Corso Duca degli Abruzzi 24, Torino 10129, Italy
S. Spiga
Unit of Agrate Brianza
CNR – IMM
Agrate Brianza 20864, Italy

The ORCID identification number(s) for the author(s) of this article can be found under https://doi.org/10.1002/aelm.202400850

DOI: 10.1002/aelm.202400850

stable Ag_2Se nanowires was employed as a physical reservoir for waveform generation tasks and voice classification. Interestingly, the accuracy with the voice dataset called free-spoken digit data (FSDD) was demonstrated higher than 80% and comparable to a software reservoir computing counterpart based on an Echo State Network (ESN). A second contribution from the same group, article number 2400360, investigated short- and long-term memory in a random network based on Ag-Ag_2S nanoparticles, instead of nanowires. In addition to paired-pulse facilitation typical of short-term plasticity, such a disordered and sparse network can turn to long-term potentiation after stimulation of 100 pulses, showing state retention of 40 minutes. Stefano Radice and coauthors in article number 2400434, investigated the neuromorphic properties of nanostructured Pt films obtained by the self-assembling of Pt clusters from the gas phase. They reported that such films show resistive switching, correlated spiking activity, and negative differential resistance, thus being suitable for the realization of programmable analog circuits, such as a gain amplifier and a square wave generator controllable by a pulsed signal. The last contribution of this category is article number 2400625, a review paper where Takashi Tsuchiya and coauthors provided an extensive overview of physical reservoir computing using ion-gating transistors, a class of devices that exhibits a variety of electrical characteristics thanks to fine control of electrochemical mechanisms such as electrical double layers and redox reactions. Materials, machine learning tasks, and operating mechanisms were compared and deeply discussed.

Finally, two innovative contributions hardly classify in the previous categories: article number 2400432 on a three-terminal artificial neuron with tunable firing probability, and article number 2400638 on a RRAM device for neural data processing. In article number 2400432, Mila Lewerenz and coauthors fabricated and electrically characterized a nanoscale Ag-SiOx-Pt three-terminal (3T) memristor device, where the set voltage and, thus, the spiking probability of the neuron circuit were widely tuned by the gate electrode voltage. Simulations using a custom LT-spice model showed that such tunability can induce delayed firing due to the modulation of the threshold potential, thus an important characteristic for neuromorphic computing applications where a fine-tuned control of neuron firing is needed. In article number 2400638, Caterina Sbandati and coauthors proved that analogue multistate switching properties of RRAM devices such as Pt/TiOx/Pt and TiN/HfOx/TiN could be used to successfully encode in resistance displacements the above-threshold events of multiunit activity envelope (eMUA), i.e., the envelope of the entire spiking neuronal activity. The authors also showed that monolithic integration of this approach with a suitable front-end and back-end stage would reduce the total system power consumption below 1 μW.

Conflict of Interest

The authors declare no conflict of interest.

Carlo Ricciardi is a Full Professor of Physics at the Applied Science and Technology Department, Politecnico di Torino, Italy. He received his Ph.D. in Physics from Politecnico di Torino in 2004. He was a visiting scientist at the University of California, Berkeley in 2007 and a visiting professor at EPFL, Switzerland in 2017. His main research activities refer to bioinspired nanodevices as: i) Memristive nanodevices for unconventional computing and ii) Nano-mechanical devices for innovative biological and chemical sensing.

Daniele Ielmini is Full Professor at Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, Italy. He received his Ph.D. from Politecnico di Milano in 2000. He held visiting positions at Intel Corporation (2006), Stanford University (2006), and University of Illinois at Urbana-Champaign (2010). His research interests include phase change memory (PCM), resistive switching memory (RRAM), and in-memory computing circuits. He is an Associate Editor of IEEE Trans. Nanotechnology and Semiconductor Science and Technology.

Fernando Corinto is a Full Professor of Electrical Engineering with the Department of Electronics and Telecommunications, Politecnico di Torino. He received a Ph.D. and European Doctorate from Politecnico di Torino in 2005. He was Dresden Senior Fellow at the TUD in 2013 and 2017, August- Wilhelm Scheer visiting professor at TUM in 2016, and a member of the Institute for Advanced Study – at TUM. His research activities include nonlinear circuits and systems, complex nonlinear/nanoscale networks, and memristor nanotechnology.

Sabina Spiga is Research Director at the Institute for Microelectronics and Microsystems of the National Research Council (Italy). She received her Ph.D. in Material Science from Università di Milano in 2002. She is in charge of the development of memristive devices for neuromorphic systems and novel computing paradigms. She is a member of the IEEE EDS Neuromorphics Technical Committee, the MEMRISYS Steering Committee, of the editorial board of the J. Phys D: Applied Physics.