frontiers | Frontiers in Physics

TYPE Editorial
PUBLISHED 13 September 2022
DOI 10.3389/fphy.2022.1006756

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Editorial: Emerging non-volatile memories and beyond: From fundamental physics to applications

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OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Interdisciplinary Physics, a section of the journal Frontiers in Physics

RECEIVED 29 July 2022
ACCEPTED 22 August 2022
PUBLISHED 13 September 2022

CITATION
Piccinini E (2022), Editorial: Emerging non-volatile memories and beyond: From fundamental physics to applications.
Front. Phys. 10:1006756.
doi: 10.3389/fphy.2022.1006756

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KEYWORDS
phase change memories, resistive memories, neural networks, SPICE simulation, memristor

Editorial on the Research Topic
Editorial: Emerging Non-Volatile Memories and Beyond: From Fundamental Physics to Applications

At the beginning of the 21st century, many scientists and engineers from the most important semiconductor industries began to question whether, and to which extent, the NAND memory technology could be further scaled or not. Due to the widespread exploitation of NAND memories in electronic devices, this debate became soon a hot topic. While the mainstream NAND technology relies on charge trapping and floating gates, broadly speaking the alternative technologies rely instead on the possibility to alter the state of a material as the means to store the information, the device physics and physical structure being unique to each technology. All these technologies (phase change memories [1], resistive RAMs [2], spin-transfer-torque RAMs [3], ferroelectric memories [4], and others) were collectively addressed to as Emerging Non-Volatile Memories.

At the International Electron Devices Meeting IEDM 2012, the attendants to the panel session *Will Future Non-Volatile-Memory Contenders Disrupt NAND?* were asked to vote which technology in their opinion would have taken the lead in the next decade. The majority of the votes were cast to the NAND technology, that was indicated as the successor of itself; and among the emerging technologies, phase change memories were on top of the list closely followed by resistive RAMs. As a matter of fact, the manufacturing understanding of the alternative technologies was largely immature, the fabrication costs were substantially higher, and the long-term behavior was not well evaluated and established as that of the NAND technology. The predominance of phase change memories as a possible replacement for NAND derived from the deeper investigation of such a technology, that was started by the pioneering and visionary work of Ovshinskiy in the 1960s. In the late 2000s only phase change memories had in fact been commercially exploited by Numonyx aiming at a replacement for NOR memories in mobile phones, this shedding good light for their inclusion in further products. The commercial exploitation of phase change memories has recently been summarized by Fantini [5].

With the only significant exception of Intel and Micron's 3D XPoint memory, we cannot list nowadays any commercial solution or mass product where the so called emerging non-volatile memories have been incorporated at large scale, and the entire semiconductor industry is still dominated by NAND memories. Three questions raise spontaneously: is there really room for emerging non-volatile memories at production stage, or will they be emerging forever? Which are nowadays their limiting factors that hinder their potential? And, finally, are there alternative applications to exploit them as advanced devices, besides the pure memory functionality?

In this *Research Topic* devoted to *Emerging Non-Volatile Memories and Beyond: From Fundamental Physics to Applications*, 3 original research articles and a review paper take into consideration these questions, focusing on phase change memories and resistive RAMs.

The first contribution by Elisa Petroni et al. investigate Ge-rich Ge-Sb-Te alloys for phase change memories to be employed in automotive applications. Stricter requirements on data retention than conventional non-volatile memories are called for to fulfill the soldering compliance, and these specs can be met only be appropriate material engineering. During memory operations, elemental segregation leading to a local compositional variability occurs, as a result of a complex thermodynamics and electro-diffusive driving forces.

In this paper, the authors define a metrics for classifying the local composition on a statistical basis, use it to get rid of outliers of the main distribution, to compare trials to each other, and to quantify compositional properties and link them to the memory performance, thus better enabling alloy engineering.

The second paper of this issue, by Rossella Brunetti et al. also investigate chalcogenide alloys focusing on the dynamics of threshold switching. As a matter of facts, chalcogenide alloys of slightly different composition than those used in phase change memories, are exploited as two-terminal selectors in cross-point architectures. These selectors suffer from a delay time that occurs from the moment when the biasing voltage reaches the threshold voltage and the moment when the OFF-ON switch effectively occurs, as witnessed by a steep rise of the current. Such a delay is crucial to define the speed of the selector. Brunetti ad coworkers propose a model and investigate possible sources of this delay, splitting it into an intrinsic component given by the time required to generate a sufficiently large population of hot carriers, which represents the theoretical lower limit, and into an amplifying factor due to unavoidable parasitics, wirings and circuitry, that often dominates and quantifies the measured delay.

Going beyond the memory functionality, phase change memories and resistive RAMs have shown a high potential for in-memory and neuromorphic computing, thanks to their multi-level, quasi-analog programming capability that enables in-place data processing [6]. In the third paper of this issue, Fernando L et al. investigate the behavior of large cross-point arrays of RRAMs through a full time-dependent, compact model to be included into SPICE simulations. The authors are thus able to extend previous similar models by better clarifying the program operation of the synaptic weights in terms of time and precision, leveraging the major technological knobs.

The fourth and last contribution is a review paper by Ye et al. The article revises how memristors can be manufactured using binary oxides, 2D materials, solid-state electrolytes, and ferroelectric materials; then, memristors are classified as electronic, photonic, or optoelectronic, according to their working principle. Finally, neural networks of different kinds, such as artificial neural networks, deep neural networks, spiking neural networks, and photonic-based neural networks are analyzed and compared in terms of performances, limits, potential best application, and outlook in the near future.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

Conflict of interest

EP is an employee of Applied Materials Italia.

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