Phase-Change and Ovonic Materials (Third Edition)

Pierre Noé,* Bart J. Kooi, and Matthias Wuttig

As the French say, “never two without three”, so we continue the E\PCOS tradition by bringing you this third edition of the special issue on phase-change and ovonic materials that will be published each year as part of the European Symposium on Phase-Change and Ovonic Science (E\PCOS). After a 1 year hiatus, it has to be said that again this year, despite the fact that the Covid crisis was still at its peak in our daily lives at the time of the conference last September, the 2021 edition of E\PCOS has been a huge success. This is mainly due to the invaluable work of the local organizers in Oxford who were able to provide attendees with an exceptional virtual experience while maintaining the spirit of the conference. For once in this editorial, Harish, Luci and the Oxford team are sincerely thanked on behalf of the entire E\PCOS community.

As in the past, this special issue once again aims to summarize recent and innovative scientific and technological achievements in phase-change materials, as well as their possible new applications. In addition to recent advances in this field, the aim is also to present emerging interests in neuromorphic computing, phase-change photonics, and plasmonics. Therefore, this special issue provides an overview of the state of the art, both experimental and theoretical, for experienced and young researchers interested in these topics. As usual, let us first recall, for the younger and newer members of our ever evolving community, that E\PCOS was born in Switzerland in 2001, with the aim of providing a platform to discuss and promote the fundamental science of phase-change materials (PCM). This goal also included setting up a platform to discuss and promote the fundamental science of phase-change materials (PCM). This goal also included providing a platform to discuss and promote the fundamental science of phase-change materials (PCM). This goal also included their applications in rewritable optical discs (e.g., first with CDs and later with the successfully developed DVD and Blu-ray Disc formats) and hence initially PCOS referred to phase-change optical storage (which was in 2005 diversified to phase-change and ovonic science). In fact, E\PCOS was born out of the first PCOS symposium held in Japan in 1990, thanks to Professor Masahiro Okuda, who has been the advisor of E\PCOS in its early years. In recent years, the field has diversified tremendously. Although the scientific and technological footprints of the field’s founding father, the late Stanford Ovshinsky, are still very much recognizable, the number of topics covered has continued to grow considerably with applications particularly in non-volatile electrical memories, optoelectronics, photonics and neuromorphic computing.

Although the global Covid-19 crisis in 2020 forced the E\PCOS program committee to cancel a meeting for the first time ever, the 2021 virtual edition of E\PCOS definitely promoted E\PCOS as the premier international conference on this exciting and still vibrant field. This 2021 virtual edition was a challenge for the E\PCOS community. However, it confirmed the strong connection between key players and actors in the field, both academic and industrial. By again covering a rich variety of topics beyond phase-change memories, this third special issue will mark again the history of E\PCOS.

This is first well illustrated through the paper of Zhou et al. on the use of AIST-based photonic memory cells as a promising platform for artificial neural networks and neuromorphic photonic computing hardware.1 A similar goal has also motivated the work presented by Kang et al.2 showing that van der Waals-layered [(GeTe)1nm/(Sb2Te3)1nm]4 and 8 superlattices, also commonly called iPCM devices, can act as synaptic devices featuring gradual and symmetric conductance update characteristics and can implement multilevel characteristics with quite stable operation. Thus, these results show the potential of iPCMs for applications in neuromorphic computing with high accuracy. By using a same approach than iPCM stacks employing PCM-based heterostructures, Terebenec et al.3 demonstrated that integration in memory devices of GeTe/C nanocomposites is a promising system to improve PC memory performance. Indeed, GeTe/C MLs memory devices exhibit significantly reduced programming energy compared with standard PCM devices probably due to an increase of thermal confinement within the memory cell resulting from the reduced thermal conductivity of polycrystalline GeTe/C MLs. This novel exciting system appeals for future fundamental studies in order to better understand the expected major impact of the multiple GeTe/C interfaces on phonons scattering and hence material macroscopic thermal conductivity not only for memory applications but also for thermoelectric converters and so on.

For experimental characterization of PCMs, Hans et al.4 investigated the effects of H treatment on the crystallization behavior on N-doped, Ge-rich Ge5Sb2Te2 phase-change materials...
in thin films and patterned thin films partly with additional metallization layers. Their aim was to elucidate the influence of hydrogen on the crystallization onsets of Ge and Ge$_2$Sb$_2$Te$_5$ in Ge-rich Ge–Sb–Te alloys for memory applications using synchrotron X-ray diffraction (XRD) in situ during heat treatment. Their main observation was that the effect of hydrogen or deuterium treatment, respectively, leads to a lowering of the $T_c$ of both Ge and Ge$_2$Sb$_2$Te$_5$ with negligible or no effect in the preprocessed and patterned samples.

From a more theoretical and fundamental point-of-view, Baratella et al.\cite{5} calculated by means of Born–Oppenheimer density functional theory (DFT) molecular dynamics (MD) simulations the transport and electro-thermal coefficients of liquid Ge$_2$Sb$_2$Te$_5$ at a few temperatures above the melting temperature. These transport coefficients are of paramount importance for electro-thermal modeling of PCM devices. Using also calculations, Sun et al.\cite{6} investigated the structural and optical properties of As$_2$Te$_3$ in both crystalline and amorphous phases using ab initio simulations. Homopolar bonds and five-fold primitive rings present in the amorphous with respect to its crystalline counterparts enhances the glassy phase stability against rapid crystallization. Moreover, the large reflectivity contrast between amorphous and crystalline As$_2$Te$_3$ phases is in good agreement with what could be expected from the “Metavalent Bonding” (MVB) map (for details see Ref. [6]). The optical difference between rhombohedral and monoclinic As$_2$Te$_3$ would be explained here by the reduction in coordination number and the reinforced Peierls distortion, which weakens the MVB in the monoclinic phase. Peierls distortion drive the metal-semiconductor transition in PCM as described by Jean-Pierre Gaspard in his paper\cite{7} in which a minimal model of covalent bonding is involved to explain the remarkable properties of PCMs with a particular emphasis on the vibrational properties. Exploring the devices physics could open further opportunities for memory applications as illustrated in the paper from Saxena et al.\cite{8} that reviews the current understanding of threshold switching (TS) properties in various chalcogenide materials, ionic threshold switching (OTS) and ionic memory switching (OMS). In this review, they extensively detail the current knowledge on the nature of TS, voltage-dependent transient characteristics, and the role of TS in governing the programming speed based on research efforts over the last six decades. Understanding of the uncommon electronic transport properties of chalcogenide materials also motivated the study of Kim et al.\cite{9} on electrical conduction mechanism of β-MnTe thin film with wurtzite-type (WZ) structure since this chalcogenide compound shows nonvolatile memory properties with a significant change in resistance via a polymorphic transition between NiAs-type (NC) structure (low resistance) and WZ structure (high resistance). To this aim, they measured resistivity, Hall mobility, and Seebeck coefficient of WZ-MnTe films obtained by RF sputtering at various temperatures. The conduction mechanisms in the β-MnTe films, that exhibit p-type conduction, vary depending on the temperature range from variable-range hopping (VRH) conduction for temperature range [120–300 K] to Small Polaron Hopping (SPH) conduction above. In a similar context, Fukuda et al.\cite{10} investigated the relationship between structural phase transitions and photo-thermal effects induced by high-density laser excitation by means of coherent phonon spectroscopy of polymorphic MoTe$_2$ single crystals using a femtosecond-pulsed laser. Their main observation was that, even with the use of femtosecond pulsed light sources, Te segregation makes it difficult to achieve light-induced structural phase transitions between the 2H and 1T phases of MoTe$_2$, suggesting that the eliminating surface oxidation by using for instance high vacuum or selective photon energies may be efficient ways to suppress Te segregation and realize the light-induced structural phase transitions.

Among all the challenges to be faced by PCM memory technology, one major one deals with patterning of chalcogenide materials. Zhao et al.\cite{11} shows the realization of high-resolution relief patterns on Ge$_2$Sb$_2$Te$_5$ (GS) films by laser direct writing and wet-etching. This study shows that GS could be a promising heat mode resist for the fabrication of the photonic devices.

In conclusion, we hope you enjoy this new issue of 2021 presenting the latest research on phase-change and ovonic materials. We also hope that this issue will help to keep us connected in anticipation of the next EPCOS meeting that is scheduled to be face-to-face during a regular meeting at Oxford University in September 2022. We look forward to a lively and exciting upcoming conference to celebrate 21 years of EPCOS together. We inaugurated in 2021 the beginning of a new decade for EPCOS and the last edition in 2021 demonstrated that, despite a confusing global context, phase-change materials and their research are still thriving.

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Guest editors

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Keywords

chalcogenide, European Symposium on Phase-Change and Ovonic Science (E\PCOS), ovonic, phase-change materials