

Phase change materials: from emerging memories to switchable optics and active metasurfaces

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Phase change materials (PCMs) are a class of materials, primarily composed of chalcogenide glasses, that attract significant attention due to their unique properties. PCMs can be reversibly and rapidly (in a few ns) switched between a high-resistivity amorphous state (generally low-reflectivity) and a low-resistivity crystalline state (generally high-reflectivity) through thermal annealing^{1,2}. This characteristic has been exploited in nonvolatile optical memories such as CD-RW, DVD-RW, and Blu-ray discs, taking advantage of the substantial reflectivity difference between the two states. Besides, PCM properties are exploited in Phase Change Random Access Memory (PCRAM) applications. PCRAM is the most mature and promising technology among emerging memory concepts due to its scaling potential, overcoming the limitations of conventional flash-based approaches³.

The two most studied and prototypical materials for PCRAM applications are GeTe and Ge₂Sb₂Te₅ alloys. However, many compositions within the Ge-Sb-Te ternary phase diagram (GST) have been studied, including Ge-rich GST alloys for automotive applications. Such alloys, whether doped with other elements like N, C, or As, exhibit key material properties (crystallization temperatures, mode and kinetics, electrical and optical contrast) that are composition-dependent and drive the final devices properties (reliability, scalability, cyclability, power consumption). Material studies are thus essential for technological development and can be advanced by combining several *in situ* experiments, such as x-ray diffraction, x-ray reflectivity and sheet resistance measurement, to simultaneously monitor both structural and electrical properties upon crystallization^{4,5}.

A more recent application for PCMs concerns nanophotonics, where managing the propagation of light and its properties with greater control and efficiency has become a major challenge. This can be achieved with large arrays of sub-wavelength metallic or dielectric nanostructures known as metasurfaces. Typically, these are static, “fixed-by-design”, meaning their design determines their optical properties. The next major milestone in the development of metasurfaces is to incorporate tuning capability into their design by implementation of PCMs such as Ge_xSb_yTe_z or Sb₂S₃ alloys. Since PCM alloys can be reversibly switched between their amorphous and crystalline states with a unique contrast in both optical and electronic properties, they are ideal candidates to pair with dielectrics metasurfaces. This aims to develop tunable photonic devices⁶ (e.g. waveguides, phase shifters...) with the ability to change the displayed information in real time. However, the integration of PCM in photonic devices often relies on typical top-down microfabrication technologies (e.g. standard lithography, lift-off, etching) that are high-cost, cumbersome, difficult to implement on chalcogenides, and lead to small active surface areas.

In this talk, I will first introduce what a phase change material is, how it can be reversibly switched, which compound can be used for volatile or non-volatile applications, and the link between material properties and device performances. The second part of the talk will be dedicated to examples of combined *in situ* PCM studies. Finally, the last part of the talk will focus on the current progresses, main achievements and perspectives of exploring the use of the soft Nano Imprint Lithography (soft-NIL) methods^{7,8} to elaborate PCM active metasurfaces with various features, dimensions and pitches, aiming to break classical fabrication methods to achieve low-cost and wide panels of active surface dimensions and substrates.

¹ M. Wuttig and N. Yamada, Nat. Mater., 2007, 6, 824–32.

² M. Wuttig et al., Adv. Mater., 2018, 30, 1803777.

³ P. Noé et al., Semicond. Sci. Technol., 2018, 33, 13002.

⁴ M. Putero et al., APL Mater., 2013, 1, 062101.

⁵ J. Remondina et al., Sci. Rep., 2024, 14, 14677.

⁶ P. Hosseini et al., Nature, 2014, 511, 206.

⁷ S. Checcucci et al., Adv. Opt. Mater., 2019, 7, 1801406.

⁸ M. Modaresialam et al., Chem. Mater., 2021, 33, 5464.