Femtosecond Multi-level Phase Switching in Chalcogenide Thin Films for All-optical Data and Image Processing

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We report on the non-volatile switching of amorphous chalcogenide glass thin films to the crystalline phase through a through a number of reproducible, discrete, optically distinguishable intermediate states, and on the re-amorphization of these films using femtosecond laser pulses. Potential applications lie in high-base (>binary) all-optical signal modulation, high-density data storage, image processing and non-Von Neuman computing.

Chalcogenide phase-change media such as Ge2Sb2Te5 (GST) are commercially established as a platform for both optical and electronic data storage (re-writable CDs, DVDs and Blu-Ray discs; Phase-change RAM). These technologies harness non-volatile amorphous-crystalline (binary) transitions in the chalcogenide induced by nanosecond optical or electronic excitations, which have also recently been applied to the realization of metamaterial electro- and all-optical transmission/reflection modulators for near- to mid-IR wavelengths providing switching high-contrast in device structures only a fraction of a wavelength thick. However chalcogenides offer a much richer pallet of transitional behaviours that can be exploited to enhance all of these functionalities and to open up new computational and image processing paradigms: they retain a 'memory' of sub-threshold excitations, such that transitions ordinarily initiated by single excitation pulses can be reproducibly stimulated by sequences of arbitrarily timed shorter/lower energy pulses cumulatively delivering the required energy.

Here we demonstrate multi-level switching of GST films down to 30 nm thick using femtosecond optical pulses. Domains ranging in size from 100 down to 1 µm2 are progressively converted through at least eight distinct partially crystalline states using 85 fs pulses. Intermediate states are distinguished and their progressively changing optical properties characterised using white light reflectivity, transmission/reflection microspectrophotometry and spectroscopic ellipsometry measurements.

Applications potential is demonstrated to high-density data storage - encoding/read-out of multiple bits per (semi-)crystalline mark with micron-level pixellation, the performance of optical arithmetic operations, and progressive tuning of chalcogenide hybrid metamaterial resonances.