Chalcogenide metamaterial phase change all-optical switch of nanoscale thickness

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Abstract: Non-volatile, bi-directional, all-optical switching in a phase-change metamaterial delivers high-contrast transmission and reflection modulation at visible and infrared wavelengths in device structures only ~ λ /8 thick.

Keywords: Phase change, metamaterial, chalcogenide, all-optical, non-volatile, nanoscale

1. INTRODUCTION

The phase change technology behind the current rewritable optical disks and the latest generation of electronic memories has provided clear commercial and technological advances for the field of data storage, by virtue of the many key attributes chalcogenide materials offer (1). New generations of optoelectronic devices are being driven by the merging of optics and electronics, as photons and electrons begin to cooperate in a single material platform. As a part of this evolution, plasmonics and metamaterials bring with them the ability to focus and manipulate light on the nanoscale, far beyond the diffraction limit of conventional optics. With such strong credentials in the `parent' fields of photonics and electronics, it is more than reasonable to assume that chalcogenides have much to offer in the plasmonic domain as well (2). With these considerations in mind the use of chalcogenide glass media in active plasmonic switching devices are considered and proof of principle demonstrations of nanophotonic switching in the near and infrared domain based on reversible photo-induced changes in the optical properties of a chalcogenide thin film is presented.

Switching optical signals on the nanoscale is not a trivial problem: conventional modulators exploiting the Pockels or Kerr effects are based on interference over distances much longer than the wavelength, necessitating devices with dimensions of several cm in the propagation direction. Modulating a signal by controlling the absorption coefficient or refractive index of a medium also requires substantial propagation lengths over which amplitude/phase changes accumulate.

Here we demonstrate an approach to nanoscale all-optical modulation based on the fact that the resonant optical properties of a plasmonic metamaterial strongly dependent on the near-field dielectric environment: small changes in the in the refraction of an adjacent chalcogenide nano-layer (associated with optically-induced transitions between its amorphous and crystalline states) produce massive changes in the transmission and reflection characteristics of the hybrid structure.

2. MATERIALS

We report on the first demonstration of non-volatile all-optical switching in plasmonic metamaterials functionalized with the phase-change chalcogenide glass, namely germanium antimony telluride (GST). The switching results in high-contrast modulation of transmission and reflectivity in the visible-to-infrared range and is achieved through optical excitation in device structures only ~λ/8 thick (Fig. 1). These hybrid materials provide a robust and versatile platform for a new generation of optical switching and memory devices.

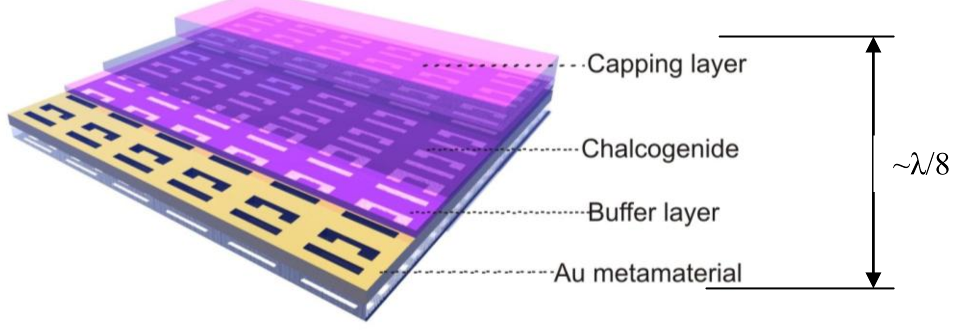

Fig. 1: Layer structure of chalcogenide hybrid metamaterial switch.

Our work is based on experimental device structures fabricated in our dedicated nanofabrication cleanroom facilities. These devices comprised of a calcium fluoride or fused quartz substrate; a 50 nm thick gold metamaterial film (patterned photolithographically or by focused ion beam milling with a square array of asymmetric split ring resonators covering an area of 50 x 50 um^2); a functional nm thin film of chalcogenide glass (GST sputtered under argon); and inert ZnS/SiO_2 buffer and capping layers either side of the chalcogenide film (to prevent metal diffusion into the glass and degradation in air at elevated phase transition temperatures).

3. METHODOLOGY AND RESULTS

Phase transitions were initiated uniformly across large (~2000 μm^2) areas of the GST film by single-pulse laser excitation, with pulse energy and duration (down to nanosecond pulses) optimized separately for the forward (amorphous-crystalline) and reverse (crystalline-amorphous) transition directions. This phase switching in the chalcogenide layer of the hybrid metamaterial produces marked changes in its transmission and reflection spectra (measured with a microspectrophotometer). The amorphous-to-crystalline transition in GST increases its refractive index and red-shifts the resonance frequency of the metamaterial, bringing about a substantial change in optical properties at wavelengths in the vicinity of the resonance, as illustrated in Fig. 2.

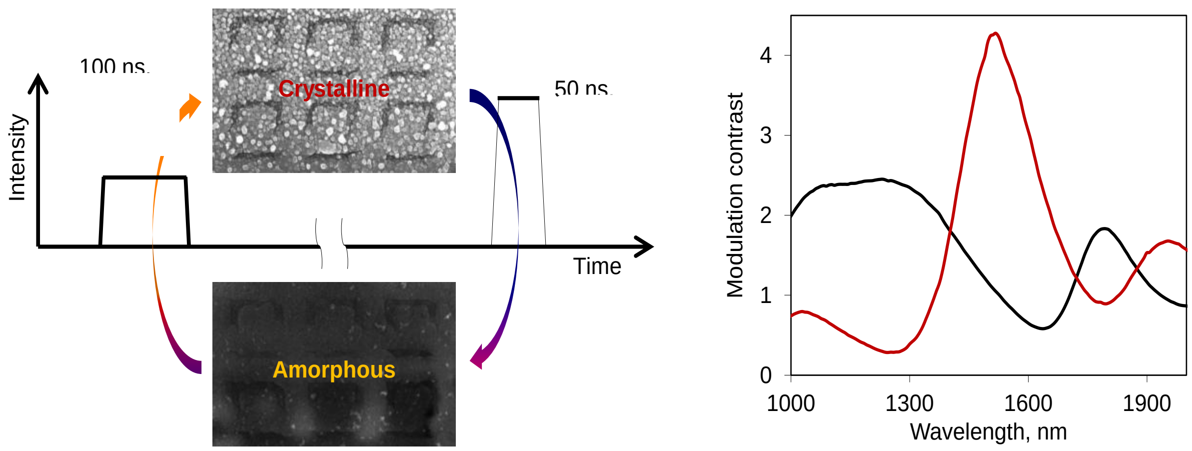

Fig. 2: All-optical near-IR chalcogenide metamaterial switching: Single pules laser excitations convert the GST layer, across the entire metamaterial array (unit cell size = 400 nm), between amorphous and crystalline state, thereby switching the reflectivity and transmission of the hybrid structure with high contrast at wavelengths close to the metamaterial resonance.

4. SUMMARY

Chalcogenide phase-change metamaterials can be switched electronically and thermally as well as optically to produce high-contrast intensity and phase modulation, and may be engineered through metamaterial design to function at any visible to mid-infrared wavelength within the chalcogenide's transparency range. As such they offer a platform for the development of a new generation of nanoscale optical switching, memory and spatial light modulation devices.

5. REFERENCES

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Biographies

Behrad Gholipour graduated from the School of Electronics and Computer Sciences at the University of Southampton with a BEng in Electronics and an MSc with Distinction in Nanoelectronics. He is currently a Research fellow within the Novel Glass group at the Optoelectronics Research Centre at the University of Southampton. His research involves the development of next generation optoelectronic devices using chalcogenide thin films and nanostructures for data storage, optical and electro-optical switches and next-generation computing applications. He is a recipient of a UK EPSRC ICT Pioneer Award for his research.