Plasmonic response of chalcogenides and switchable all-dielectric metamaterials

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Abstract: Crystalline germanium antimony telluride shows a profound plasmonic response in the optical-UV spectral range that disappears in the chalcogenides's amorphous state. We harness this effect to realize tuneable and plasmonic/all-dielectric phase-change memory metasurfaces.

A variety of active plasmonic and metamaterial functionalities have been realized via the hybridization of noble metal nanostructures with phase-change media including chalcogenides, vanadium dioxide, gallium and liquid crystals. We now demonstrate experimentally that chalcogenides alone can serve as a compositionally tuneable platform for the engineering of non-volatile optically-/electronically-switchable all-dielectric NIR metamaterials and switchably-plasmonic UV-VIS metasurfaces benefitting from protected topological surface states.

We employ nanoscale thin films of Ge- and Bi-based chalcogenide alloys. We first show that the NIR all-dielectric metasurface reflection/transmission resonances of nano-gratings in high-index alloys such as Ge:Sb:Te (GST) can be spectrally shifted in non-volatile fashion via optically or electronically-induced amorphous-crystalline phase switching (which changes the magnitude of both the real and imaginary parts of refractive index), delivering high-contrast changes in reflectivity and transmission at wavelengths selected by design – up to 7 dB contrast over a device thickness of $<\lambda/5$ (Fig. 1a).

Markedly different behaviour is observed in the UV-VIS spectral range (Fig. 1b), where crystalline GST can be a plasmonic topological insulator. Here, the amorphous-crystalline transition produces a change in the sign of the real part of the chalcogenide's relative permittivity ε: While the amorphous ($\varepsilon_1>0$) phase is largely transparent with levels of UV-VIS transmission, reflection and absorption that are not greatly perturbed by nano-grating structures with periodicity in the 300-400 nm range, the crystalline ($\varepsilon_1<0$ at $200 < \lambda < 615$ nm) phase supports surface plasmon resonances, which manifest themselves as vibrant (grating period-dependent) colours.

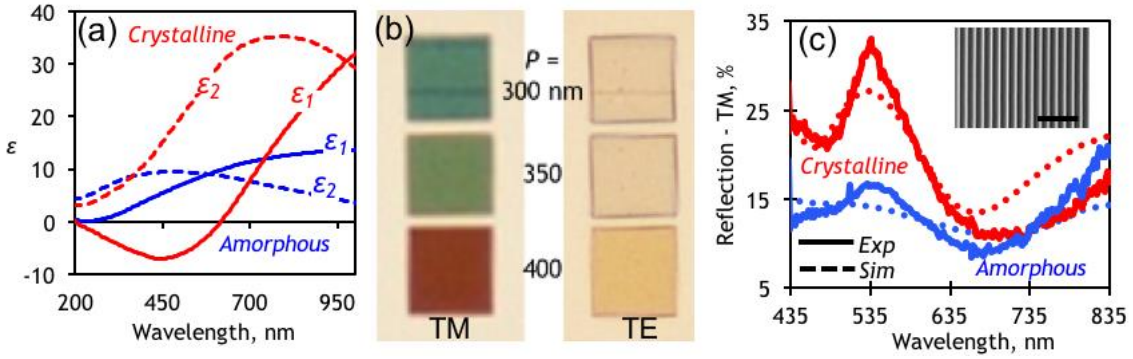

Fig. 1 (a) Spectral dispersion of the real and imaginary parts of the relative permittivity of a 500 nm GST film in its amorphous and crystalline phases [from ellipsometric measurements]. (b) Reflection optical microscopy images of crystalline phase GST nano-gratings of varying period [as labelled; 20 μm × 20 μm square domains surrounded by unstructured crystalline GST], for TM and TE polarized incident light. (c) Experiemntally measured [solid lines] and numerically simulated [dotted lines] spectral dispersion of normal incidence TM-polarized reflectivity for a 300 nm period GST grating in the amorphous and crystalline phases [as labelled], a section of which is shown in the inset scanning electron microscope image.

We also explore the compositional tuning of optical properties in Bi:Te and Bi:Sb:Te phase-change topological insulator thin films and metasurfaces, using high-throughput physical vapour deposition and screening techniques. The precisely controlled growth of compositionally graded films provides for the mapping (and subsequently selection) of material properties such as relative permittivity, resistivity and phase transition energy over the vast compositional space offered by binary and ternary chalcogenides (Fig. 1c).