All-chalcogenide Phase-change Metasurfaces

Behrad Gholipour[1], Artemios Karvounis[1], Kevin F. MacDonald[1]*, and Nikolay I. Zheludev[1, 2]

[1] Optoelectronics Research Centre and Centre for Photonic Metamaterials, University of Southampton, Southampton, SO17 1BJ, UK

[2] Centre for Disruptive Photonic Technologies, Nanyang Technological University, Singapore 637371, Singapore

Chalcogenide phase-change media offer a uniquely functional platform for photonic meta-devices without noble metals, providing for optically- and electrically-driven non-volatile switching, tuning and reconfiguration of nanostructures, including conversion between plasmonic and non-plasmonic states. We present recent advances in the development of all-chalcogenide metasurface solutions for a new generation of flat-optics, sensor, all-optical switching and memory devices.

A variety of 'active' plasmonic and metamaterial functionalities have been achieved in recent years through the hybridization of noble metal nanostructures with phase-change materials including chalcogenides, vanadium dioxide, gallium and liquid crystals. We now demonstrate experimentally that chalcogenides alone can serve as a platform for the realization of optically-switchable all-dielectric near-IR metamaterials and switchably-plasmonic UV-VIS metasurfaces.

Our work employs nanoscale thin films of the chalcogenide alloy germanium antimony telluride (Ge:Sb:Te or GST), which (as in rewritable optical disk and electronic phase-change RAM technologies) can be converted in non-volatile fashion between amorphous and crystalline states. The films are deposited on transparent substrates and structured by focused ion beam milling with non-diffracting, sub-wavelength grating metasurface patterns.

At near-IR wavelengths, unstructured amorphous GST is a broadly transparent dielectric with a (compositionally-dependent) refractive index of order 2.6. Nano-grating metasurface structures introduce pronounced reflection and transmission resonances, with quality factors >20, at spectral positions proportional to the nano-grating period. Conversion to the crystalline phase is initiated by laser illumination at 532 nm (intensity and duration being tuned to momentarily bring the GST to a temperature between its glass-transition point ~160°C and its melting point ~600°C). The resultant increase in both the real and imaginary parts of the chalcogenide refractive index red-shifts and broadens the metasurface resonances, bringing about substantial changes in metasurface transmission and reflection, with resonant contrast ratios as high as 5:1.

Dramatically different behaviour is observed In the UV-VIS spectral range (between around 200 and 615 nm), where crystalline GST is metallic. Here, the amorphous-to-crystalline transition produces a change in the sign of the real part of the chalcogenide's relative permittivity, from positive to negative: The amorphous phase is largely transparent with levels of transmission, reflection and absorption that are not strongly perturbed by the presence of sub-wavelength grating structure; but in stark contrast the crystalline phase supports surface plasmon resonance modes, which manifest themselves as vibrant (grating period-dependent) colours in reflection imaging.