Hollow-core waveguides with *n*<1 chalcogenide cladding

Jinxiang Li[1], Behrad Gholipour[1, 2], Davide Piccinotti[1], Kevin F. MacDonald[1] and Nikolay I. Zheludev[1, 3]

1. Optoelectronics Research Centre and Centre for Photonic Metamaterials, University of Southampton, UK

2. School of Chemistry, University of Southampton, UK

3. Centre for Disruptive Photonic Technologies & The Photonics Institute, School of Physical and Mathematical Sciences, Nanyang Technological University, Singapore

Abstract: We utilize compositionally controlled low refractive index (n<1) chalcogenide semiconductors in hollow-core waveguides operating across ultraviolet frequencies. Such materials enable π-phase shifts over nanometric propagation lengths in slab and fibre configurations.

Hollow-core waveguides operating at ultraviolet (UV) frequencies can benefit numerous applications in environmental and biochemical sensing, as they enable simultaneous confinement of light and the substance to be probed (analyte) in the core of the waveguide, offering increased light-matter interaction compared to conventional solid-core waveguides. This confinement relies on the use of a cladding material with a refractive index below that of air/vacuum. It is impossible to obtain total-internal reflection (TIR)-based hollow-core waveguides using high-index (n>1) materials in the cladding section of a waveguide. An alternative therefore is to employ low-index materials with sub-unitary refractive indices. Here we show that a range of chalcogenide semiconductors exhibit a refractive index less than 1 across a band of wavelengths extending from around 220 to 400 nm, depending on alloy composition, making them suitable as cladding materials for such waveguides.

In numerical simulations (Fig. 1), we investigate fibre and slab hollow-core waveguide geometries based upon antimony telluride ($Sb_{4.1}Te_{0.9}$), which has a refractive index $n = 0.7$ at $\lambda = 289$ nm (Fig 1a). The electric field modes with the lowest propagation loss are found to be the TE_{01} mode in the cylindrical fibre geometry and TE_0 mode in the rectangular slab configuration (Fig 1c).

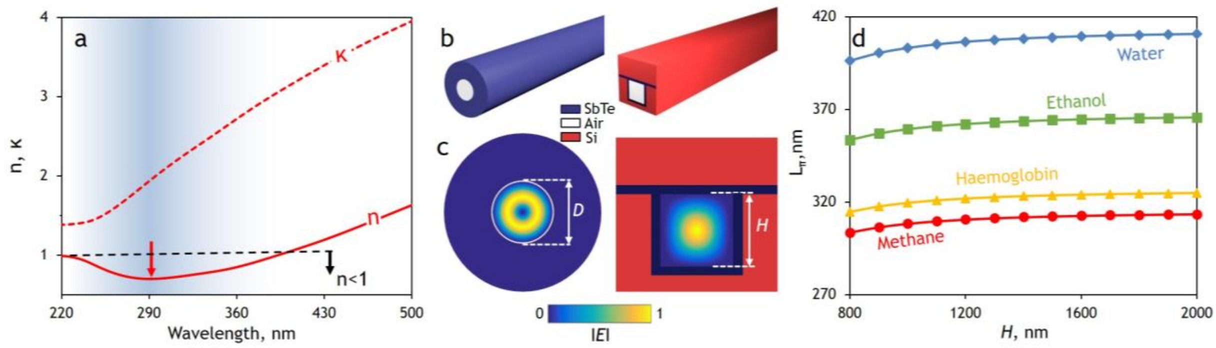

Fig. 1 (a) Spectral dispersion of the real [n] and imaginary [κ] parts of the complex refractive index for as-deposited amorphous $Sb_{4.1}Te_{0.9}$ [from ellipsometric measurements]. (b) Schematics of numerically simulated fibre (left) and slab waveguide (right) geometries and (c) corresponding mode electric field distributions at a wavelength of 289.65 nm where n_{SbTe} takes its minimum value of 0.7. (d) Propagation length L_π required to achieve a π optical phase shift as a function of slab waveguide core height H for a selection of different analytes in the core [as labelled].

For sensing applications, hollow-core waveguide based sensors are widely implemented in a Mach-Zehnder interferometer configuration, with the refractive index of a liquid or gaseous analyte being quantified via measurements of the optical phase shift resulting from its presence in the core of one arm. Here, we evaluate the phase shift $\Delta\phi$ arising from the introduction of an analyte to a hollow-core SbTe slab waveguide as $\Delta\phi = 2\pi\Delta n_{eff}L/\lambda$, where L is the propagation length, Δn_{eff} is the difference between the effective indices of analyte- and air-filled waveguides. We consider a selection of analytes relevant to biomedical, water safety and gas sensing applications. Fig 1d shows the propagation length L_π over which the presence of these materials results in a π optical phase shift (for the slab waveguide configuration). In all cases considered, L_π lies in the range from approximately 300 to 400 nm, and is found to be minimally dependent upon core size. For comparison, an equivalent solid-core silicon waveguide sensor, operating at a wavelength of 1000 nm, would have L_π lengths ranging from 0.34 to 8.3 mm (i.e. three to four orders of magnitude larger) for the same analytes. Chalcogenide low-index hollow-core waveguides may thus enable the realisation of highly-integrated sensing devices with a fraction of the footprint, and thereby weight, of current technologies.