Plasmonics of Topological Insulators at Optical Frequencies

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We show that topological insulator crystals are an excellent plasmonic platform in the UV to near-IR part of the spectrum, thanks to the interplay of interband transitions and Drude-like response of metallic surface states. This opens up exciting opportunities for the integration of plasmonic, electronic and spintronic devices.

Topological insulator (TI) crystals are bulk insulators with robust conducting surface states protected by time-reversal symmetry due to strong spin-orbit coupling (SOC). TI materials have been widely investigated for spintronic applications and quantum computation, and are now considered as emerging optical materials for plasmonics. Localized plasmons have been observed in TIs from THz to UV-visible frequencies, and linked to the existence of topologically protected surface states with high optical conductivity.

To unravel the contribution of topological surface states to the optical response of TIs, we conducted first-principles density functional theory analysis of the dielectric functions of several quaternary $(Bi,Sb)_2(Te,Se)_3$ chalcogenide TIs (Fig. 1a), and compared them with ellipsometric measurements. We find that bulk plasmonic properties, dominated by interband transitions, are observed from ~1.5 to 2.5 eV and extend to higher frequencies, while topologically protected surface states, that are capable of supporting both interband transitions and Drude surface plasmons, contribute over a very broad energy range, up to the UV.

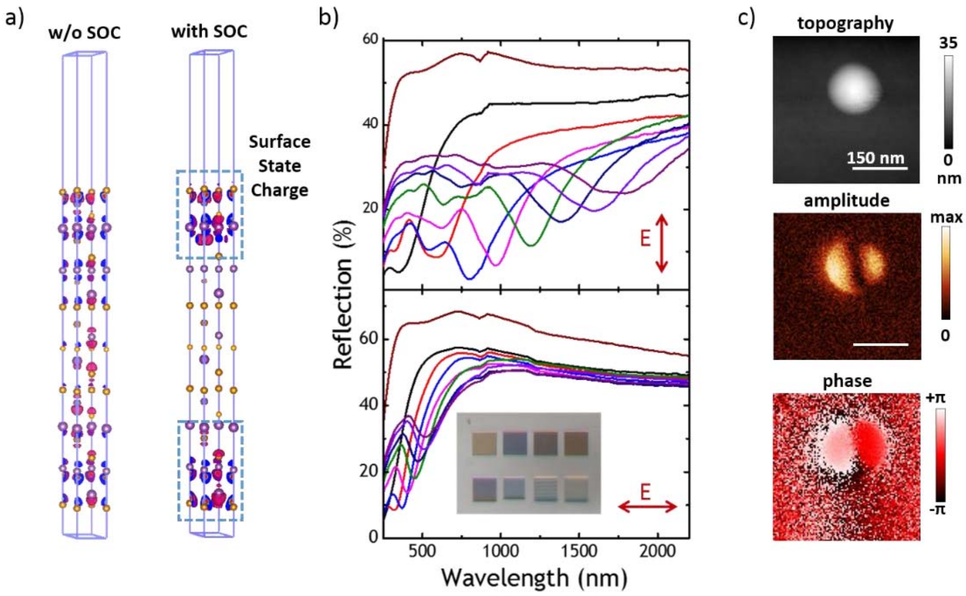

Fig. 1 Topological insulator plasmonic materials and structures. (a) Surface charge carrier distribution in BSTS compounds obtained by first-principles calculations. b) Broadband tuning of plasmonic resonance in nanoslit arrays with different geometrical parameters, milled on the surface of Bi_2Te_3 crystal. c) Apertureless near-field microscope image of a BSTS nanodisc, showing a localised dipole resonant mode at visible frequency (λ = 633 nm).

As a proof of principle, we designed and fabricated metamaterials slit arrays by Focused Ion Beam milling of TI crystals, which show plasmonic and dielectric resonant response from the visible to near-infrared (Fig. 1b). Dipole and higher order resonant modes are also observed in near-field scanning microscope images of TI nanostructures (Fig. 1c). We discuss the origin of these resonances considering both, surface states and bulk optical response of the TIs.

These results elucidate origin and composition dependence of plasmonic properties of TIs at optical frequencies, proving them an extraordinary material platform for broadband nanoplasmonic devices that could be modulated optically, through injection of electrons or spins, or by applied magnetic fields.

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