Plasmonics of topological insulators

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Abstract: We discuss the plasmonic properties of chalcogenide topological insulators arising from interband transitions and Drude-like response of metallic surface states in the UV to mid-IR, which provide a new platform for electronics and photonics integration.

Topological insulator (TI) crystals are bulk insulators with robust conducting surface states protected by time-reversal symmetry due to strong spin-orbit coupling (SOC). These TI materials have been widely investigated for spintronic applications and quantum computation, and are now considered emerging optical materials for plasmonics. Localized plasmons have been observed in TIs from THz to UV-visible frequencies. Moreover, multiple plasmon modes were recently reported in TI nanocrystals and flakes. Ellipsometric data indicated the presence of high optical conductivities, possibly linked to the existence of topologically protected surface states.

To determine the contribution of topological surface states to the optical response, and their suitability for nanoplasmonics, we conducted first-principles density functional theory analysis of the dielectric functions of few quaternary $(Bi,Sb)_2(Te,Se)_3$ chalcogenide TIs. DFT calculations match well the ellipsometric data, as shown in top and middle row of Fig 1. (a) to (c) and indicate that bulk plasmonic properties, dominated by interband transitions, are observed from 2 to 3 eV and extend to higher frequencies, while topologically protected surface states capable of supporting Drude surface plasmons contribute over a very broad wavelength range, with characteristic plasma frequency from 4.1 to 7.8 eV, far beyond where the bulk switches from metal to dielectric.

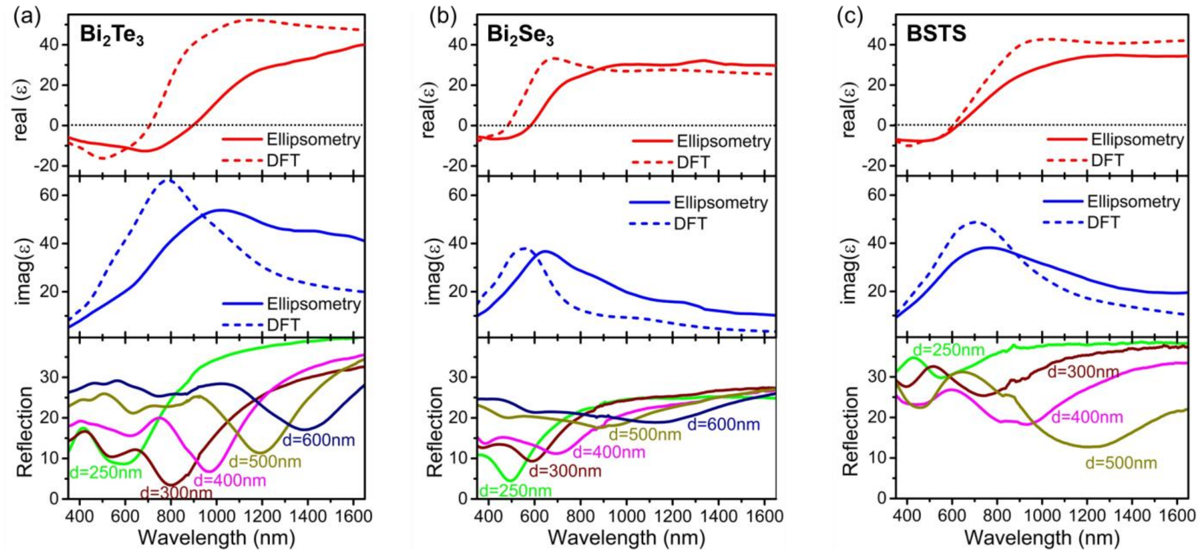

Fig. 1: Optical properties of 3 different TI compounds, (a) Bi_2Te_3, (b) Bi_2Se_3 and (c) BSTS. Top and centre rows show respectively real and imaginary part of optical permittivity from both ellipsometry measurements and DFT calculations. Bottom row shows broadband tuning of plasmonic resonance in nanostructured topological insulators for different nanoslit length 'd'.

These properties make TIs an extraordinary material platform for broadband nanoplasmonic devices that can be modulated optically, through injection of electrons, or by applied magnetic fields. We design and fabricate metamaterials slit arrays by Focused Ion Beam milling of the TI, which show plasmonic and dielectric resonant response across a wide optical range from the visible to near-infrared. We discuss the origin of these resonances in the context of both surface states and bulk optical response of the TIs.

Our results elucidate origin and composition dependence of bulk plasma wavelength in the UV-visible to mid-infrared parts of the spectrum, and confirm that the oscillation of topologically protected surface charge carriers has appreciable contribution to the plasmonic response of topological insulators.