Ultrafast Surface State Dynamics of Topological Insulators Metamaterials at Optical Frequencies

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Abstract: We report time-resolved pump-probe and ARPES measurements of topological insulator crystals and nanoslit metamaterials of $Bi_xSb_{1-x}Te_ySe_{1-y}$ (BSTS) at optical frequencies, which reveal the ultrafast dynamics of topological surface states at room temperature.

Thanks to the presence of topologically protected surface states, topological insulator (TI) crystals are extremely attractive materials for nanophotonic devices that combine electronic, sprintronic and plasmonic properties at optical frequencies. Here we attempt isolating the contribution of metallic surface states probing their ultrafast dynamics using femtosecond pump-probe spectroscopy and time- and angle-resolved photoelectron spectroscopy (TR-ARPES) of unstructured and nanostructured crystals of the chalcogenide TI BSTS (Fig. 1a).

We fabricated various kinds of nanostructures such as simple nanoslit arrays (inset Fig. 1a) and more complicated, three-dimensional chiral structures, by focused ion-beam milling on the exfoliated TI films. Tuning the geometric parameters of the nanoslits results in strong, polarization dependent resonances throughout the UV to mid-IR optical range [1], which holds promise for the realization of surface state coupled spin-plasmons.

TR-ARPES measurements of unstructured crystals reveal the existence of well-defined topological surface state band crossings which survive high photon energy pump excitation (λ=688 nm) even at room temperature (Fig 1b). Time-resolved surface state dynamics shows ultrafast population of high energy bulk and surface state bands, followed by sub-ps carrier thermalization into the surface states down to the Fermi level, consistent with ultrafast differential reflection measurements of unstructured films.

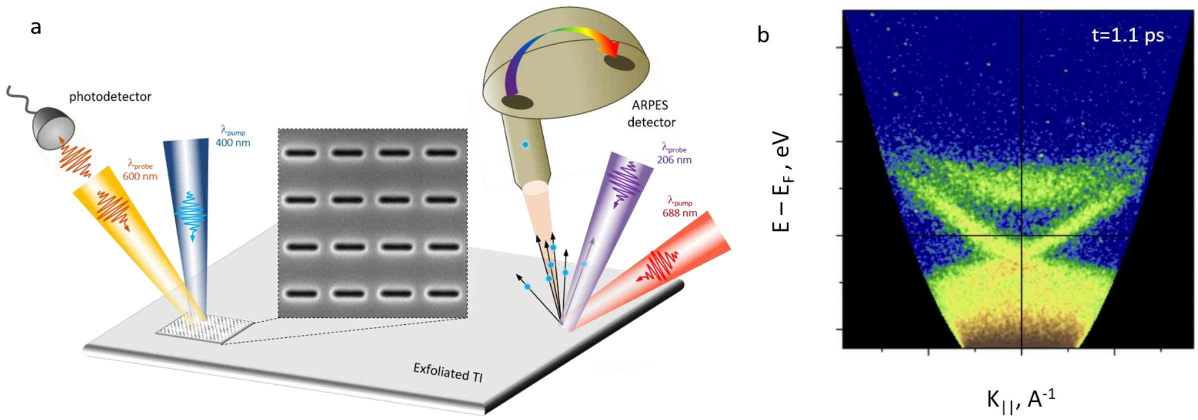

Figure 1: a) Schematics of pump-probe experiment on metamaterials (left) and time-resolved ARPES (right) on BSTS topological insulator crystals, (inset shows a secondary electrons image of slit metamaterials with slit length of 140 nm, carved by Focused Ion Beam (FIB) milling); b) snapshot map of unstructured BSTS bandstructure around the bandgap, showing the surface state bands, obtained by TR-ARPES at room temperature at t=1.1 ps pump-probe delay.

The resonant absorption of metamaterials tuned at the probe wavelength (λ~600 nm) modulates the intensity of differential reflection of nanostructured topological insulator crystals at ultrashort time scales, enabling polarization dependent control of the ultrafast response.

References

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