Snapshots of Dirac Fermions near the Dirac Point in Topological Insulators

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Abstract: We utilized a ultrafast optical pump mid-infrared probe to explore the dynamics of Dirac fermions near the Dirac point in topological insulator. The femtosecond snapshots of the relaxation process were revealed by the ultrafast optics.
OCIS codes: (300.6530) Spectroscopy, ultrafast; (320.7130) Ultrafast processes in condensed matter, including semiconductors

1. Introduction

The discovery of 3D topological insulators (TIs) [1] initiated a new era of condensed matter physics [2, 3]. Recent TrARPES studies have shown the surface carrier population in TIs can be induced by photoexcitation [4, 5] and can separately obtain the temperature and chemical potential relaxation of both the surface and the bulk [6]. Nevertheless, the ultrafast behavior of Dirac fermions near the Dirac point and their detailed energy-dependent coupling with phonons remain elusive for lack of probes with the appropriate energy range (100 meV) specific to the Dirac cone. We further take the advantage of the appropriate probe photon energies in the optical pump mid-infrared probe (OPMP) spectroscopy to explore the nonequilibrium dynamics of TIs. The mid-infrared photon energy range (87–153 meV < bandgap energy of 300 meV in Bi_2Se_3) naturally selects the transitions limited within the Dirac cone, and the femtosecond-time and millielectronvolt-energy resolution allows us to distinguish the individual dynamics of both the surface and the bulk.

Fig. 1 provides a synopsis of the OPMP spectra for all samples investigated. To elucidate the origins of both the positive and negative signals, a model is shown in Fig. 2 for the optical pumping (1.55 eV) and mid-infrared probing processes in the schematic energy band structure of the TIs based on the ARPES image in Fig. 1b. Because the used probe photon energy (87–153 meV) of the mid-infrared (mid-IR) is much smaller than the band gap of 300 meV in Bi_2Se_3 (as shown in the ARPES images of Fig. 1b), the interband transitions between the valence band (VB) and the conduction band (CB) of the bulk are not allowed to occur. Thus, the free carrier absorption in the CB (mid-IR probe (1) in Fig. 2) and Dirac cone surface state (mid-IR probe (2) in Fig. 2) will dominate the probe processes, which are responsible for the positive and negative peaks in $\Delta R/R$, respectively.

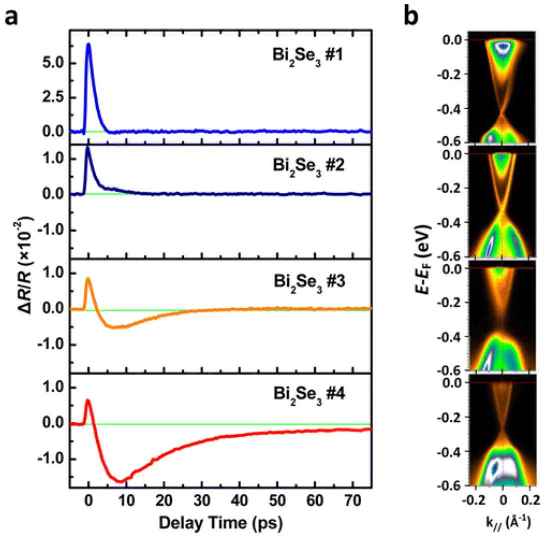

Fig. 1. Carrier concentration (n) dependence of the transient change in reflectivity ΔR/R in Bi_2Se_3 single crystals. (a) ΔR/R of samples #1, #2, #3, and #4 with a pumping fluence of 34 μJ/cm^2 and probing photon energy of 141 meV. (b) ARPES band dispersion images on samples of (a).[7]

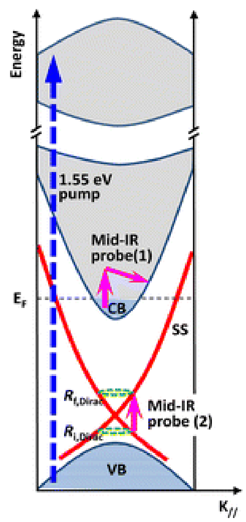

Fig. 2. Schematic energy band structure of TIs according to the ARPES images in Fig. 1b and the optical pump mid-IR probe processes. CB: conduction band. VB: valence band. SS: surface state. $R_{i,Dirac}$ and $R_{f,Dirac}$: the circumferences of initial and final states in Dirac cone for mid-IR probing.

2. References

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