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Angle-resolved photoemission study of topological insulator $Bi_{2-x}Sb_xTe_{3-y}Se_y$

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1 Introduction

The three-dimensional topological insulator is a novel quantum state of matter where the insulating bulk hosts gapless topological surface states (SS) characterized by the Dirac-cone energy dispersion [1]. The realization of topological-insulator devices to utilize the peculiar surface-transport properties requires a highly insulating bulk property and the tunability of Dirac carriers. To achieve the latter, it is desirable to control the energy position of the Dirac cone in the band gap, because the chemical potential of bulk insulators is difficult to tune [2]. Here we show that the tetradymite solid-solution $Bi_{2-x}Sb_xTe_{3-y}Se_y$ is the first topological-insulator system that simultaneously satisfies the above requirements, by directly measuring the electronic structure with angle-resolved photoemission spectroscopy [3]. Upon increasing the Sb content x with tuning the Se content y so as to maintain the bulk-insulating nature, we observed that the chemical potential is always located in the bulk gap and the surface Dirac point, which separates the hole- and electron-like regimes and is buried in the bulk band in Bi_2Te_2Se (x = 0; y = 1), starts to be isolated from the bulk band above $x \sim 0.25$. Furthermore, a sign change of the Dirac carriers was observed at $x \sim 0.9$. Such a tunable Dirac cone in the bulk-insulating platform opens a promising pathway to the development of novel topological-insulator devices.

2 Experiments

High-quality single crystals of $Bi_{2-x}Sb_xTe_{3-y}Se_y$ were grown by melting high purity elements with the stoichiometric ratio at 850□ in an evacuated quartz tube, followed by gradual cooling and annealing [2]. ARPES measurements were performed with a VG-Scienta SES2002 electron analyzer with a tunable synchrotron light at the beamline BL28A at Photon Factory (KEK). We used circularly polarized light of 36-116 eV. The energy and angular resolutions were set at 15-30 meV and 0.2°, respectively.

3 Results and Discussion

Figure 1 shows comparison of the Fermi surface and the near-E_F band structure for different compositions in the bulk insulating phase. The bulk insulating nature is confirmed by the present ARPES result (Fig. 1) showing that only the SS is seen at E_F for all the samples. Interestingly, the SS Fermi surface systematically shrinks upon increasing x (Fig. 1a) accompanied with an overall upward shift of the SS (Fig. 1b), demonstrating that the increase of x (and the simultaneous increase of y) provides more acceptors likely because of the slight change in the carrier compensation. We find that the Dirac band is systematically shifted in a rigid-band manner as a function of x, since the bands for different x values essentially overlap with each other when they are plotted with respect to the Dirac-point energy (E_{DP}) despite the total chemical potential (μ) shift of as large as 0.3 eV. Intriguingly, the SS band dispersion below E_F for x = 1.0 suggests that the Dirac point is located slightly above E_F, pointing to the sign change of Dirac carriers from n- to p-type at some x between 0.5 and 1.0. Another important indication in Fig. 1 is that the bulk VB does not show a rigid-band shift relative to the SS, as evident from the experimental result that the lower hole-like branch of the Dirac cone for x = 1.0 is more clearly visible than in x = 0. The present result provides an important step to establish the means to control of surface Dirac fermions in TIs and to explore a variety of exotic physical properties proposed for this exciting class of materials.

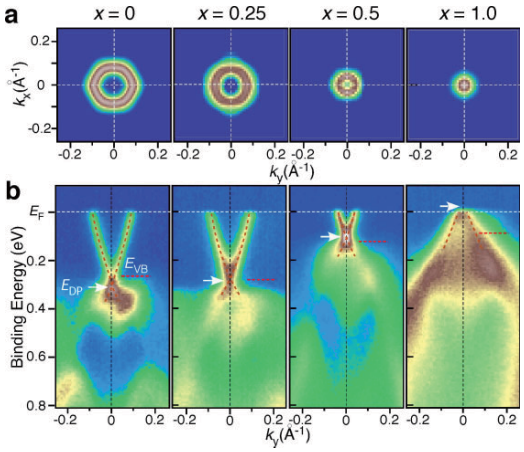

Fig. 1: (a) Fermi surface and (b) band structure of $Bi_{2-x}Sb_xTe_{3-y}Se_y$ for various compositions.

References

[1] M. Z. Hasan and C. L. Kane, Rev. Mod. Phys. **82** (2010) 3045.

[2] Z. Ren *et al.*, Phys. Rev. B **84** (2011) 165311.

[3] T. Arakane *et al.*, Nat. Commun. **3** (2012) 636.

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