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Attempt to Control the Anisotropy of Topological Surface States

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Topological insulators have spin-polarized conduction states on their surfaces (= topological surface states), where the spin direction of electrons is locked by their momentum resulting the helical spin-texture. The unique helical spin-texture is considered to prohibit complete backscattering by non-magnetic impurities. Thus, the surface of topological insulators is expected to be promising platform for spintronics devices. However, other backscattering passes except for the complete backscattering are not prohibited [Fig.1(a)]. One solution to suppress the backscattering is forming an anisotropic Fermi surface, ideally a one-dimensional Fermi surface[Figs. 1(b) and 1(c)].

In previous research, it has been reported that Ag films on Si(111)-(4×1)-In, which has an array of In chains, exhibit a quasi-one-dimensional band structure [1]. This result is attributed to the confinement of electrons in the quasi-one-dimensional Ag films caused by the step and terrace structure, and a similar effect can be expected even on vicinal surface. The vicinal silicon surface has atomically regular step arrays and electron motion in the film grown on the surface might be restricted only one direction parallel to the step. From this analogy, we considered that it might be possible to obtain the anisotropic spin-polarized band structure by growing Bi_2Te_3 films on silicon vicinal surface. However, there is no report of the fabrication of Bi_2Te_3 film on silicon vicinal surface so far. Therefore, the purposes of this research are to fabricate Bi_2Te_3 film on silicon vicinal surface, measure the band structure, and evaluate the band anisotropy.

In our study, we grew Bi_2Te_3 ultrathin films on Si(111) and Si(557) by molecular beam epitaxy, which were used as flat and vicinal surface substrate, respectively. Si(557) is a surface tilted by 9.5° from Si(111), and its terraces have the same plane as Si(111). We checked the quality of surface structure by low energy electron diffraction (LEED) and auger electron spectroscopy (AES). Figure 2 shows LEED patterns and the spectra of AES of Bi_2Te_3 film on each substrate. As in Fig. 2, we can see clear spots in LEED and peak of Bi and Te in AES indicating that we could succeed to grow Bi_2Te_3 film on vicinal silicon surface.

To observe the band structure of the fabricated films, angle-resolved photoemission spectroscopy (ARPES) measurements were done at BL-7 in HiSOR. Figure 3(a) shows the wide energy range ARPES images on Si(111) (top) and Si(557) (bottom). Clear bulk bands are observed on Si(111). On Si(557) substrate faint but similar bands that are shifted by 9.5° from the results of Si(111) are observed. Figure 3(b) shows the magnified band structure near the Fermi energy of each sample. A clear V-shaped topological surface state is visualized on Si(111). The observed feature is very similar to the previously reported band structure of Bi_2Te_3/Si(111) films with one quintuple layer (QL) thickness [2]. Thus, the thickness of our film is estimated to be ~1 QL. On Si(557) substrate, similar V-shaped surface state crossing the Fermi energy can be seen, but it was hard to estimate the Fermi momenta (k_F) of surface bands due to the weak intensity. Although we attempted to evaluate the anisotropy of the surface bands by Fermi surface in Fig. 3(c), unfortunately, it was also difficult.

In conclusion, we succeeded to grow Bi_2Te_3 film on silicon vicinal surface and to measure the band structure. However it was difficult to evaluate the band isotropy because of the poor intensity of topological surface states on Bi_2Te_3/Si(557). Further experiment with the better sample quality is expected in the future.

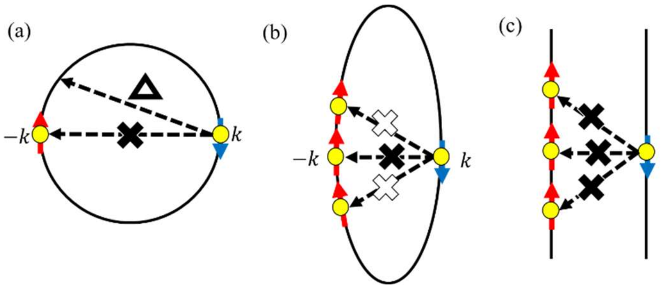

FIGURE 1. Schematic illustrations of isotropic (a), anisotropic (b), and ideally anisotropic (one-dimensional) Fermi surfaces (c) of topological insulator.

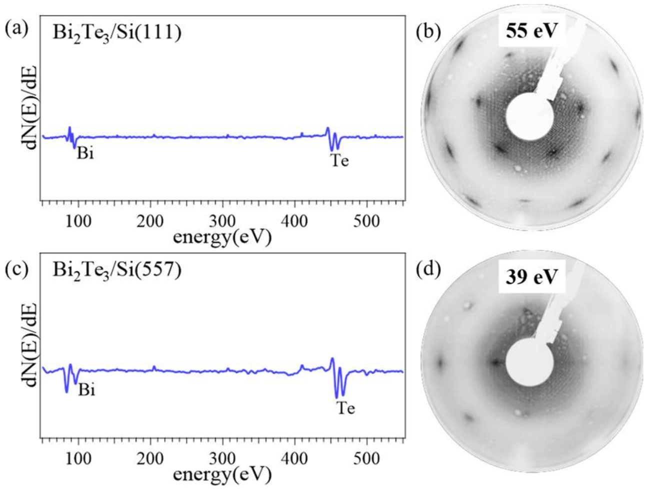

FIGURE 2. (a) AES spectrum of Bi_2Te_3/Si(111) (b)LEED pattern of Bi_2Te_3/Si(111) taken at 55 eV. (c) AES spectrum of Bi_2Te_3/Si(557) (d) LEED pattern of Bi_2Te_3/Si(557) taken at 39 eV.

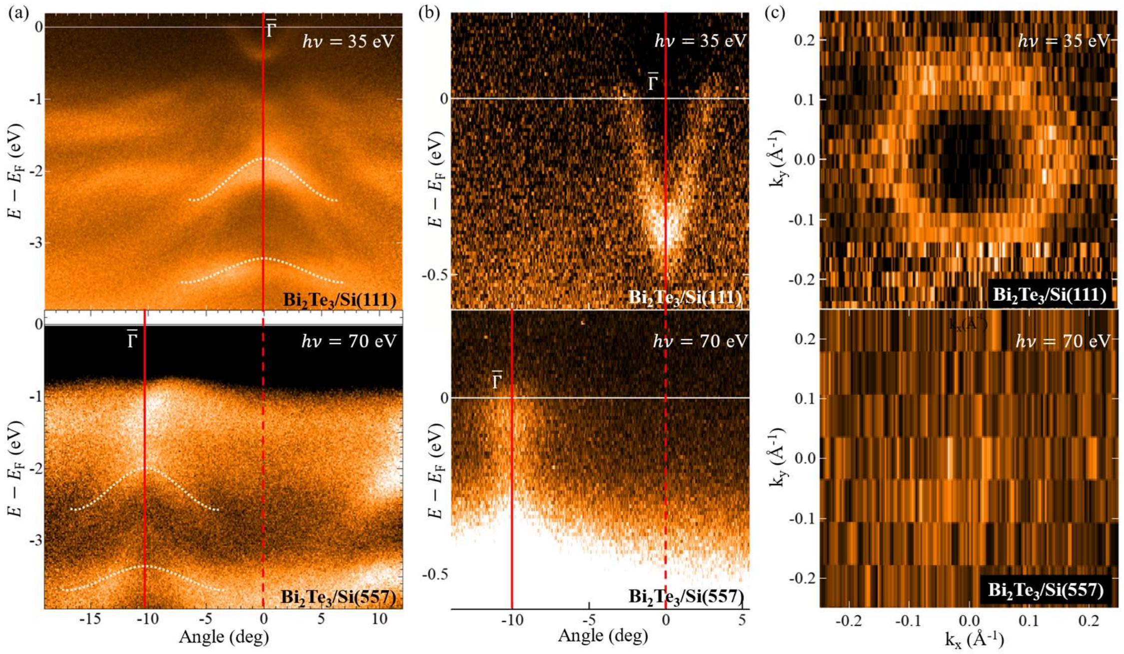

FIGURE 3. (a) Wide range ARPES images of Bi_2Te_3/Si(111) and Bi_2Te_3/Si(557) acquired at $h\nu = 35$ and 70 eV. (b) Magnified ARPES images around the Fermi energy of (a). (c) Fermi surface of Bi_2Te_3/Si(111) and Bi_2Te_3/Si(557)

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