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Anisotropic Topological Surface States Induced by One-Dimensional Structure and Their Thickness Dependence

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Topological insulators have spin-polarized metallic surface states called topological surface states (TSS). As in the Fig. 1(a), in the TSS, 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. This property is expected to realize long spin coherent length and applied for spintronics devices. However, other backscattering passes except for the complete backscattering are not prohibited completely [Fig.1(a)]. One solution to overcome this problem is to form an anisotropic TSS, ideally a one-dimensional TSS [Figs. 1(b) and 1(c)] in which the direction of spin becomes closer to anti-parallel at the opposite k-point.

In the previous research, it has been reported that a quasi-one-dimensional band structure can be realized in the Ag films on Si(111)-(4 × 1)-In surface in which Ag film has regular step and terrace structure [1]. Thus, we expected that a similar effect might occur in the topological insulator film on vicinal surface with atomically regular step arrays. To investigate this hypothesis, we tried to fabricate Bi_2Te_3 film on silicon vicinal surface and measure its electronic structure.

Bi_2Te_3 ultrathin films were grown by molecular beam epitaxy on Si(111) and Si(557), which were used as a flat and a vicinal surface substrate, respectively. Si(557) is a surface tilted by 9.5° from Si(111), and has a Si(111) plane with a terrace width of 1.8 nm. The qualities of these films are evaluated by low energy electron diffraction (LEED) and auger electron spectroscopy (AES). Figure 2 shows LEED pattern and AES spectrum of the Bi_2Te_3 film on each substrate. As in Fig. 2(b) and (d), we can see clear spots in LEED and peak of Bi and Te in AES indicating that we succeeded in growing the Bi_2Te_3 film on both surfaces.

To observe the band structure of the fabricated films, angle-resolved photoemission spectroscopy (ARPES) measurements were performed at BL-9B in HiSOR using He Iα (21.2 eV) light. Figure 3(a), (b) shows the Fermi surface (top) and band structure (bottom) of 5 quintuple layer (QL) Bi_2Te_3 film on Si(557) surface. In these results, we can see the anisotropic TSS and Dirac point at around – 0.4 eV, which indicates that TSS is expanded to the direction perpendicular to the step by the effect of electron confinement. Figure 3(c), (d) and Figure 3(e), (f) show the results of 1~2 QL sample and less than 1 QL sample, respectively. In Figure 3(c), (d), we can see the anisotropic Fermi surface, but in Figure 3(e), (f), the anisotropy of Fermi surface and band structure is much weaker compared to 1~2 QL sample. Additionally, comparing the elongation of the Fermi surface, Fig. (c) (1~2 QL sample) shows the strongest anisotropy. This means the band anisotropy induced by evaporating on vicinal surface depends on the film thickness and quality of

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substrate.

In conclusion, we succeeded in growing the Bi_2Te_3 film on vicinal silicon surface and observing the anisotropic topological surface states. In addition, we could also investigate the properties of the thin film on the vicinal surface. From these results, we found that it is possible to fabricate the one-dimensional topological insulator. Additionally, to effectively utilize the spin-texture of the anisotropic TSS, controlling the film thickness and ensuring the quality of substrate are important. These results will contribute to realizing the long spin coherent length and the future spintronics applications.

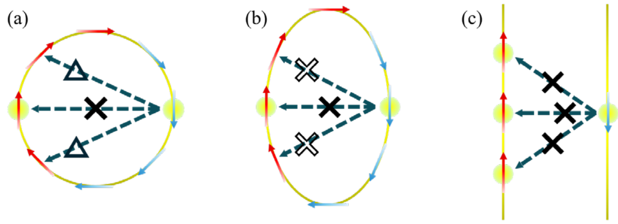

FIGURE 1. Schematic spin-texture of (a) isotropic, (b) anisotropic, and (c) one-dimensional Fermi surfaces (c) of topological insulators.

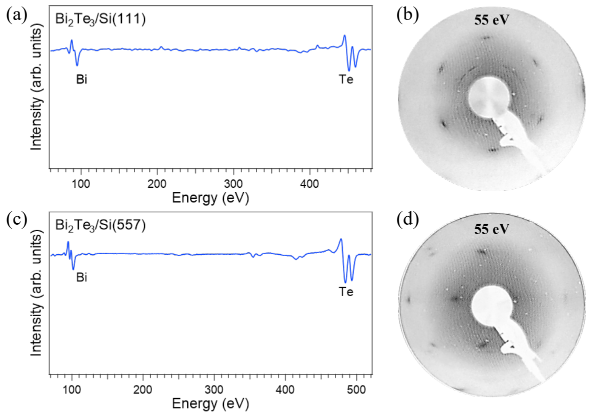

FIGURE 2. (a) AES spectrum of Bi_2Te_3/Si(111) (b)LEED pattern of Bi_2Te_3/Si(111) taken at 55 eV. (c),(d) the same as (a), (b) but of Bi_2Te_3/Si(557)

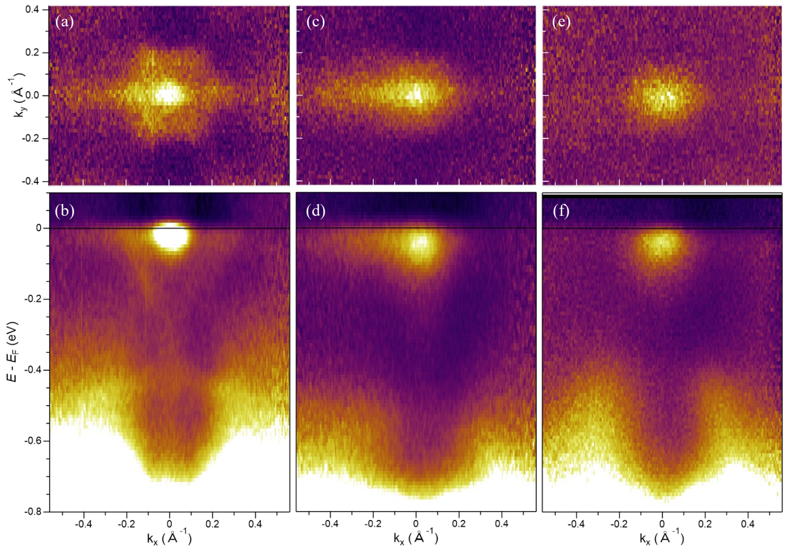

FIGURE 3. (a) Fermi surface and (b) band structure of 5 QL Bi_2Te_3/Si(557). (c), (d) the same as (a), (b) but of 1~2 QL Bi_2Te_3/Si(557). (e), (f) the same as (a), (b) but of less than 1 QL Bi_2Te_3/Si(557). All the data were measured by He Iα (21.2 eV) light.

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