Substrate and Thickness Dependence of Anisotropic Topological Surface States of Bi_2Te_3 Thin Films

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Topological insulators (TIs) have spin-polarized metallic surface states called topological surface states (TSS). As in Fig. 1(a), in TSS, the spin direction of electrons is locked by their momentum resulting in 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 possible approach to overcome this problem is to modify the surface band structure into an anisotropic form [Fig.1 (b)]. An anisotropic surface band can deform the spin texture into a configuration that further suppresses backscattering, potentially extending the average spin relaxation length. Furthermore, if an ideal one-dimensional anisotropic band structure could be realized, all backscattering processes would be completely prohibited [Fig. 1(c)].

It is reported that Bi_2Te_3, representative TI, can be grown as thin films on Si(111) surface and its band dispersion exhibits a clear thickness dependence [1]. In addition, studies on the Au(788) surface, which exhibits a regular one-dimensional step array of the Au(111) plane, have demonstrated the discretized one-dimensional band dispersion induced by quantum confinement effects [2]. Therefore, by depositing Bi_2Te_3 on the substrate possessing one-dimensional step array of Si(111) plane, it is expected that anisotropic one-dimensional TSS induced by confinement effect as same as Au(788) is observed. In this study, Bi_2Te_3 was deposited on a Si(557) substrate featuring a Si(111) step array with a terrace width of approximately 1.8 nm. We aimed to realize a one-dimensional Bi_2Te_3 crystal structure and to investigate the resulting modulation of its topological surface states.

Sample preparation and measurements were performed at beamline BL-9B of HiSOR. Bi_2Te_3 thin films were grown on both Si(111) and Si(557) substrates. To investigate thickness dependence, we attempted to fabricate wedge-shaped Bi_2Te_3 films. After the growth, the surface band structure was measured by angle-resolved photoemission spectroscopy (ARPES).

Fig. 2(a) and (b) show the Fermi surface of 6-QL Bi_2Te_3 films grown on Si(111) and Si(557) substrates, respectively. For the film on Si(111), an isotropic hexagonal Fermi surface with warping was clearly observed. On the Si(557) substrate, although an anisotropic Fermi surface was expected, no clear anisotropy was also detected.

It has been reported that the wave function of the topological surface states in Bi_2Te_3 extends more than approximately 1 nm from the crystal surface [3]. Since the step height of a typical Si(557) substrate is about 0.32 nm, which is smaller than the spatial extent of the Bi_2Te_3 surface-state wave function, the confinement effect might have been insufficient, resulting in an apparently isotropic band structure. To enhance the confinement potential between steps, we intentionally induced a step bunching on the Si(557) substrate, which is expected to increase the substrate-derived step potential and strengthen the confinement effect. Step bunching was successfully obtained by annealing the Si(557) substrate at 850 °C for 1.5 hours after flash annealing.

Fig. 2(c) shows the Fermi surface of the 6-QL Bi_2Te_3 film grown on the bunched Si(557) substrate. Unlike the case of the non-bunched Si(557) substrate, a clear anisotropy is observed. These results demonstrate that anisotropic topological surface states were successfully realized on the bunched Si(557) substrate. In addition, we investigated the thickness dependence of the anisotropy using wedge-shaped Bi_2Te_3 films. As a result, stronger anisotropy is observed in the 1-QL film than in the 6-QL film, suggesting stronger confinement of the TSS in the thinner film.

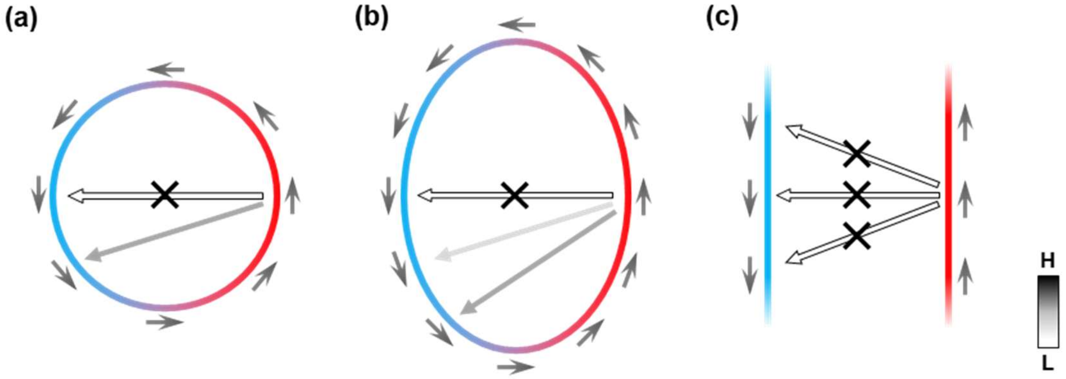

FIGURE 1. Schematic spin-texture of (a) isotropic, (b) anisotropic, and (c) one-dimensional Fermi surfaces (c) of topological insulators.

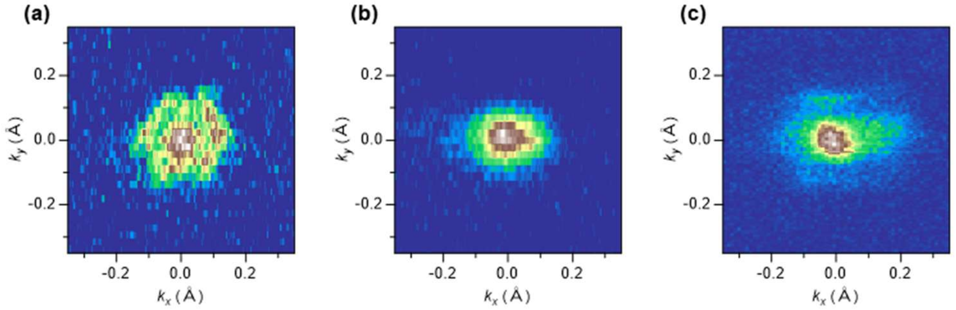

FIGURE 2. The Fermi surface of 6-QL Bi_2Te_3 film grown on (a)Si(111), (b)Si(557) and (c)bunched Si(557).

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