Electronic materials, Energy materials

Control of the surface electronic structure of topological Kondo insulators

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Abstract

Topological insulators (TIs) behave as insulators in bulk but have metallic properties on their surfaces, which originate from the edge state due to the different topology between the inside and outside of materials. Since the surface state is protected by the topology, it has been believed that the control of the topological surface state (TSS) is impossible by other methods. In this study, an anisotropic structure with a symmetry different from that of the bulk was fabricated on the surface of samarium hexaboride (SmB_6), a topological insulator, in only a few atomic layers near the crystal surface. The Fermi surface observed by angle-resolved photoelectron spectroscopy suggests that the surface electronic state of TIs not only originates from the topology of the bulk electronic structure but also reflects the state of the surface structure. This suggests the breakdown of the bulk-related in-plane rotation symmetry in the TSSs of SmB_6.

Background & Results

In the last decade, topological materials, which are classified according to the symmetry of their electronic state inside the crystal (bulk), have been the focus of intense research. Among these, TIs, which were discovered at an early stage, have extremely promising properties as materials for next-generation devices: their bulk is an insulator, but their surface is a metal with high electrical conductivity with spin polarization that depends on the direction of electron motion.

The TSS has been determined by the topological classification of the bulk electronic state. So, it is thought to be difficult to control the TSS according to purpose.

In this study, a new surface superstructure was fabricated by polishing the slightly tilted (vicinal) surface of the topological Kondo insulator, SmB_6, from a square crystal plane with high symmetry [(001) orientation] (Fig. 1).

To observe the TSS of the vicinal surface, the electronic state was observed by angle-resolved photoemission spectroscopy. As shown in Fig. 2, a topological surface state with a bright Fermi surface in only a diagonal direction was observed. This result suggests that a different topological surface state has been created by fabricating a slightly tilted surface structure.

The results show that the TSS does not reflect the bulk state in a 'robust' manner, as previously thought, but is strongly influenced by the surface atomic structure, including the superstructure, and is 'flexible'.

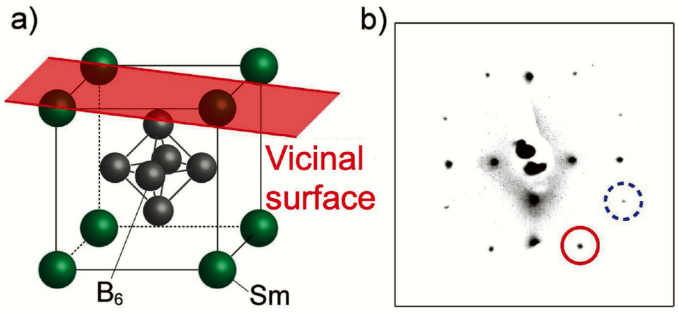

Fig. 1 a) Crystal structure of samarium hexaboride (SmB_6) and the vicinal surface. b) The electron diffraction pattern of the vicinal surface. The intensity difference intensity between spots marked by solid and dashed lines reflects the anisotropy.

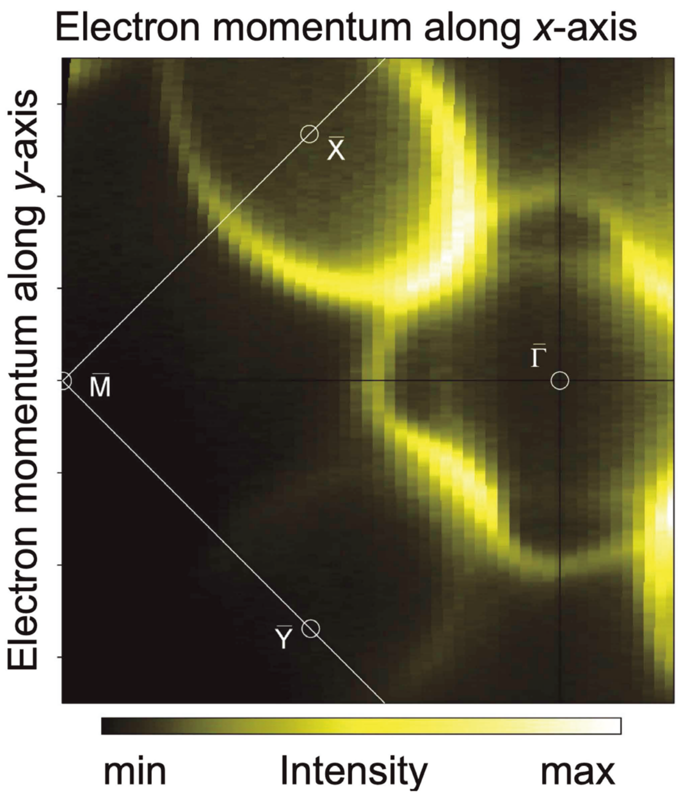

Fig. 2 The Fermi surface of the surface electronic state obtained with an angleresolved photoelectron spectroscopy. The intensity is extended in a diagonal direction, which does not reflect to the four-fold symmetry of bulk crystal structure but to the two-fold symmetry of the surface structure.

Significance of the research and Future perspective

It has been assumed that the surface electronic state of TI is determined solely by the topological nature of the bulk electronic state, but it has been shown that it also reflects the state of the surface structure. As the newly discovered method to control TSS, engineering of surface atomic structure is expected to be applied to next-generation devices with low power consumption and high speed, and quantum computers.

Patent

Treatise

Ohtsubo, Yoshiyuki; Kimura, Shin-ichi et al. Breakdown of bulk-projected isotropy in surface electronic states of topological Kondo insulator SmB_6(001). Nature Communications. 2022, 13, 5600. doi: 10.1038/s41467-022-33347-0

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