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NEWS & VIEWS

Topological insulator: Both two- and three-dimensional

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Topological insulators are a special type of insulators which have become one of the research focuses of condensed matter physics in recent years. Electrons inside a topological insulator cannot conduct electrical current, just as in a usual insulator, e.g., diamond. But at the boundaries of a topological insulator to vacuum or a usual insulator, there always exist conducting channels in which electrons behave as in a good metal. Furthermore, the very existence of the conducting channels, so-called surface or edge states, is determined by the topological properties of the bulk energy band, and therefore is robust against the contamination at the surfaces/edges. The surface/edge states of topological insulators have some unique properties. For example, they are Dirac fermions, similar to the electrons in graphene, but do not have spin-degeneracy. These properties make topological insulators not only an interesting topic in fundamental condensed matter physics but also a class of important materials for applications in spin-based electronics and error-tolerant quantum computation [1–3].

There are two classes of topological insulators: two-dimensional and three-dimensional ones. The former ones are insulating thin films of topologically protected one-dimensional edge states [4, 5] (see Fig. 1 left). Quantum spin Hall (QSH) effect can be observed in two-dimensional topological insulators, so they are also referred to as QSH insulators. So far, only HgTe/CdTe quantum wells have been confirmed to be two-dimensional topological insulators [6]. Three-dimensional topological insulators are insulating bulk crystals with topologically protected two-dimensional surface states [7] (see Fig. 1 middle). Several materials, e.g., Bi_xSb_{1-x} alloys [8] and Bi_2Te_3 family materials [9, 10] have been confirmed to be three-dimensional topological insulators through direct observations of the Dirac surface states by angle-resolved photoemission spectroscopy (ARPES).

Recently, Hirahara *et al.* [11] realized an interesting material which is a combination between a three-dimensional insulator and a two-dimensional one. This special material is Bi_2Te_3, a three-dimensional insulator, covered by a Bi film of only two atomic layers.

Bulk Bi is metallic, or more exactly, semi-metallic due to its rather low density of states at Fermi level compared with usual metals. Bismuth has received long term research interests from researchers of condensed matter physics for the possible metal–insulator transition at low-dimension [12, 13]. In 2006, Murakami predicted that a Bi film in (111) crystalline orientation with the thickness of only one bilayer (the unit cell of Bi in this orientation) is not only an insulator but a two-dimensional topological insulator [14]. A later theoretic work claimed that even a little thicker Bi(111) films are still two-dimensional topological insulators [15].

Unfortunately, such thin Bi(111) films are difficult to obtain. With molecular beam epitaxy (MBE) technique, single crystal Bi(111) films above 4QL can be prepared on Si(111) [16]. But below 4QL, Bi film is transformed into a different phase, which makes thinner Bi(111) impossible. In this work, Hirahara *et al.* found that on the surface of Bi_2Te_3 single bilayer Bi(111) film can be made successfully with MBE. It is the first time that the candidate two-dimensional topological insulator, has been realized experimentally.

But a question is if the non-trivial substrate Bi_2Te_3 will influence the properties of the single bilayer Bi film. Although the surface of Bi_2Te_3 is covered by a Bi film, the two-dimensional Dirac surface state must still exist due to topological protection. With the in-situ ARPES and ab-initio calculations, Hirahara *et al.* investigated the surface band structure of the composite system. They found that the observed band structure is basically a simple overlap of the bands of single bilayer Bi(111) and the Dirac surface state of Bi_2Te_3. Since the band structure of the single bilayer Bi(111) film is little changed by the Dirac surface states of Bi_2Te_3, the film should still be a two-dimensional topological insulator with the topologically protected edge state. In other words,

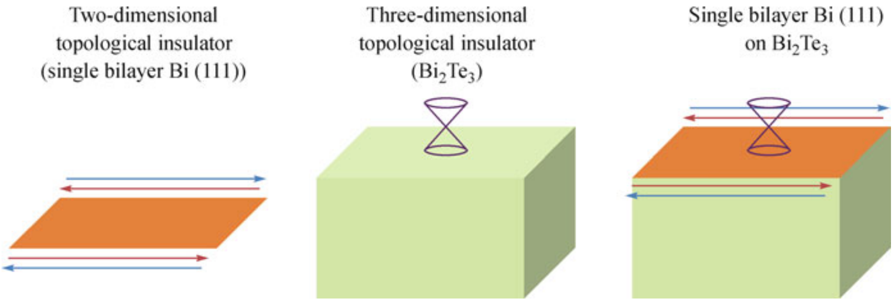

Fig. 1 Schematic diagrams of the Dirac edge/surface states of a two-dimensional topological insulator (single layer Bi(111)) (*left*), a three-dimensional topological insulator (Bi_2Te_3) (*middle*), and single bilayer Bi(111) grown on Bi_2Te_3 (*right*).

two-dimensional Dirac surface state and one-dimensional Dirac edge states coexist around the Bi top layer (see Fig. 1 right).

However, the present work has not given a direct evidence for the non-trivial character of single bilayer Bi(111). Future work with scanning tunneling spectroscopy may reveal the edge states of single bilayer Bi (111) islands. A more reliable evidence will be the observation of QSH effect. To remove the contribution from the Dirac surface states of Bi_2Te_3 to transport experiments, very thin (saying, 1 nm) Bi_2Te_3 films can be used as the substrates in which the Dirac surface states are gapped by finite-size effect. If realized, single bilayer Bi (111) will be confirmed to be another and simpler two-dimensional topological insulator material besides HgTe/CdTe quantum wells.

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