STM studies of the surface state of three-dimensional topological insulators

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A topological insulator (TI) has a full energy gap in the bulk, and contains gapless surface states that cannot be destroyed by any non-magnetic impurities. Because of time reversal symmetry, the surface states cannot be back-scattered by non-magnetic impurities. When a thin magnetic layer is applied on the surface, a full insulating gap is opened, and an electric charge close to the surface is predicted to induce an image magnetic monopole. When a thin superconducting layer is applied on top of the surface, elementary excitations are predicted to be Majorana fermions. This brief account of TI systems suggest that they may provide a novel platform for device physics, including low-impedance interconnects, unique switching devices, or provide basic building blocks for topological quantum computing systems. However, to date most applications of these materials are hampered by bulk and surface defects. Thus, it is of utmost importance to understand the electronic properties of the surface of TIs in the presence of impurities and defects. Scanning tunneling spectroscopy (STM) is particularly suitable for such studies.

STM studies on high-quality 3D topological insulators (TI) Bi_2Te_3 and Bi_2Se_3 crystals exhibit perfect correspondence to ARPES data, hence enabling identification of different regimes measured in the local density of states (LDOS). Oscillations of LDOS near a step are analyzed. Within the main part of the surface band, oscillations are strongly damped, supporting the hypothesis of topological protection. At higher energies, as the surface band becomes concave, oscillations appear which disperse with a particular wave-vector that is shown to result from an unconventional hexagonal warping term [1].

Further analysis of the data, beyond the oscillations, reveal a one-dimensional bound state that runs parallel to the step-edge and is bound to it at some characteristic distance. This bound state is clearly observed in the bulk gap region, while it becomes entangled with the oscillations of the warped surface band at high energy, and with the valence band states near the Dirac point. We obtain excellent fits to theoretical predictions that properly incorporate the three-dimensional nature of the problem to the surface state. Fitting the data at different energies, we can recalculate the LDOS, originating from the Dirac band without the contribution of the bulk bands or incoherent tunneling effects [2].

Finally, we look at the effect a local impurity on the surface of the TI has on the local density of states. We find that the LDOS around the Dirac point of the electronic spectrum at the surface is significantly disrupted near the impurity, exhibiting a low-energy resonance state. However, we find that for most common impurities, this is not sufficient to locally destroy the Dirac point [3].

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