学位論文要旨

Spin filtered surface state scattering and electronic states of three-dimensional topological insulator Bi_2Te_2Se

（三次元トポロジカル絶縁体 Bi_2Te_2Se 表面のスピン選択的電子散乱と電子構造）

氏　名　　Munisai Nuermaimaiti

As the new insulating phase, topological insulator (TI) has attracted great attention in condensed-matter physics due to its striking physical properties and potential technological applications. Like an ordinary insulators, TIs have a bulk energy gap separating the filled valence bands and the empty conduction bands, but have protected conducting states on their edge or surface. Three-dimensional topological insulators (3D TIs) represent a recently discovered state of matter, whose hallmark is the surface state in the absolute bulk energy gap, which has a spin non-degenerate Dirac-cone energy dispersion and helical spin texture. The topological surface state (TSS) is protected by time-reversal symmetry and is robust against nonmagnetic perturbations. These unique electronic structure and spin texture of TSS provide a venue not only to explore novel quantum phenomena in fundamental physics but also to show potential applications in spintronics and quantum computing [1–3].

Angle-resolved photoemission spectroscopy (ARPES) and its spin resolved version (SARPES) are widely used to identify and characterize surface states of the 3D TIs. As useful surface-sensitive techniques, these methods can directly visualize the Dirac-cone like surface state and its spin textures. Some of their peculiar properties have been revealed by one of the most powerful surface probes, scanning tunneling microscopy/spectroscopy (STM/STS), which providing direct information on the electronic structure of topological surface states and their scattering properties. Standing waves caused by scattering off from line defects or point like impurities on the surface of 3D TIs is an effective way to present the topological nature of the surface states. The interference between incoming and outgoing waves at momenta leads to a Friedel oscillation in the local density of state (LDOS). One can unveil the spin structure of surface states through the presence or absence of standing waves both for occupied and unoccupied states. Fourier transformed images of the observed standing waves give bias-dependent scattering vectors in momentum space. Meanwhile, the surface energy band structure was determined by employing $k.p$ theory and first principle calculations with comparison the experimental data.

Recently, interband optical excitation of topological surface states by pulsed laser radiation has attracted a great attention in generating longer-lived spin-polarized carriers at the surface [4]. In order to understand the photo excited spin and charge dynamics, knowledge of unoccupied topological surface state far above the Dirac point and the unoccupied bulk continuum is crucial. Note that photoelectron spectroscopy, with which most of the studies on topological insulators have been performed, cannot access unoccupied states or provide direct information on the in-plane electron scattering. Thus, there has been a dearth of measurements on the unoccupied electronic states of 3D TIs, and the present study is motivated by the necessity of getting the information about the unoccupied spectrum.

In this thesis, we focus on 3D TI Bi_2Te_2Se, which is very promising for spintronic applications owing to its highly spin polarized TSS and high bulk resistivity. The topological nature of surface state and electronic structure of Bi_2Te_2Se has been studied by using STM/STS and ARPES measurement in a wide energy region in combined with theoretical results. We have unraveled for the first time unoccupied topological surface state of Bi_2Te_2Se with a clear scattering pattern. The imaged quasiparticle interference pattern on the cleaved surface of Bi_2Te_2Se originates from the strongly warped constant energy contours of the TSS with substantial out-of-plane spin polarizations which has been further clarified by the $k.p$ model Hamiltonian and First principle calculations. The clear linear dispersion relation exhibits the linear behavior up to 1000 mV related to the Fermi energy, which gives the important information for transport and electronic properties. The TSS is thus found to survive up to energies far above the Dirac point. This is a novel message deduced from new data not available at the time of the previous work. This finding provides a deeper understanding of optically excited spin and charge dynamics at the surface of TIs and paves a way to designing opto-spintronic devices.

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