Surface Dirac fermion dynamics and spin polarizations of three-dimensional topological insulators

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Three-dimensional topological insulators (3D TIs) with a gapless topological surface state (TSS) in a bulk energy gap induced by a strong spin-orbit coupling have attracted much attention as key materials to revolutionize current electronic devices. A spin helical texture of a TSS, where the electron spin is locked to its momentum, is a manifestation of a 3D TI. Among the established 3D TIs, Bi_2Se_3 has most extensively been studied because of its relatively large energy gap and the simplest TSS. However, the topological surface state is energetically obscured by bulk continuum near and below the Dirac point, which is disadvantageous for spintoronic applications. Furthermore, magnetically doped topological insulators, possessing an energy gap created at the Dirac point through time-reversal-symmetry breaking, are predicted to exhibit exotic phenomena including the quantized anomalous Hall (QAH) effect. Although several candidates of magnetically doped TIs were demonstrated to show long-range magnetic order, the realization of the QAH effect is so far restricted to V- and Cr-doped $(Sb,Bi)_2Te_3$ systems at extremely low temperature [1, 2]; however, the microscopic origin of its ferromagnetism is poorly understood. Besides, investigation of fermion dynamics near the Dirac point is crucial for the future development of spintronic devices incorporating topological insulators.

Spin- and angle- resolved photoemission spectroscopy (SARPES) enables us to experimentally confirm their topological characteristics and it has actually been playing major roles in finding some real 3D TIs. SARPES experiments have been performed for several topological insulators at the ESPRESSO end station (BL-9B) at Hiroshima Synchrotron Radiation Center (HSRC) [3]. The VLEED-type spin detector utilized in the ESPRESSO machine achieves a 100 times higher efficiency compared to that of conventional Mott-type spin detectors [2]. Highly spin-polarized features are found for Bi_2Te_2Se and $GeBi_2Te_4$. A buried TSS under the topmost layer found in $PbBi_4Te_7$ [3, 4] and $PbBi_4Te_4S_3$ will also be presented.

Second part of my talk will be focused on the *p*-type non-magnetic and magnetic topological insulators, where the TSSs are mostly unoccupied and cannot be totally accessed by ARPES. Instead, angle-resolved photoemission spectroscopy implemented by a pump-and-probe method (TrARPES) has been used to study both occupied and unoccupied states. Using this technique with energy, momentum and time resolutions, electron dynamics can also be elucidated. First, the surface Dirac fermion dynamics in the topological insulator Sb_2Te_3 and the related *p*-type TIs have been explored. Sb_2Te_3 has a Dirac node completely located above the Fermi energy. The excited electrons in the upper Dirac cone stay longer than those below the Dirac node to form an inverted population. This is attributed to a reduced density of states near the Dirac node [5]. Second, I present an element-resolved study for V and Cr-doped $(Sb,Bi)_2Te_3$ using X-ray magnetic circular dichroism to unambiguously show that the long-range magnetic order is mediated by the *p*-hole carriers of the host lattice, and the interaction between the Sb (Te) *p* and V(Cr) *d* states is crucial [6]. Our results are important for material engineering in realizing the QAH effect at higher temperatures. TrARPES experiment has also been applied to these magnetic topological insulators. The surface Dirac cones are clearly observed for all the studied samples. Time evolution of the pumped Dirac electrons of these magnetic TIs will also be discussed.

References

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