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Materials for the quantum anomalous Hall effect: From extrinsic to intrinsic magnetic topological insulators

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Ferromagnetic topological insulators have been used to demonstrate the quantum anomalous Hall (QAH) effect. In electronic devices, the QAH edge states may be used for lossless interconnects or for lossless edge channel spintronics. Moreover, in conjunction with superconductors, they could host chiral Majorana fermions which are among the contenders for the realization of topological qubits.

These are some examples that underline the importance of materials science of magnetic topological insulators. So far, stable 3+ impurities (Cr, V) in $(Bi, Sb)_2Te_3$ topological insulators have been the mainstream approach for these materials. However, there remain several challenges: Firstly, the temperature at which the QAH effect can be observed is only 1 K even though the principle limit is the Curie temperature which is one to two orders of magnitude higher. Secondly, the magnetic gap at the Dirac point of topological insulators, which is believed to host the chiral edge states, has never been observed directly. Thirdly, disorder leads in these randomly doped materials to considerable scattering in gap size and chemical potential.

Here, we use low temperature ARPES to reveal the magnetic gap of Mn-doped Bi_2Te_3 films which is present only below the Curie temperature of ~10 K. Interestingly, the size of the gap is 5 times larger than predicted by density functional theory. This enhancement is due to a remarkable structure modification induced by Mn doping. Instead of a disordered impurity system, it forms an alternating sequence of septuple and quintuple layer blocks, with Mn in the center of the septuple layers. We argue that a stable 2+ state as with Mn naturally favors these septuple layer units of $A_1B_2C_4$ stoichiometry.Mn-doped Bi_2Se_3, which has been extensively studied in the literature, forms a similar heterostructure, however, only a large, albeit nonmagnetic gap is formed. Moreover, the magnetic anisotropy is in plane for Mn-doped Bi_2Se_3 and out of plane for Mn-doped Bi_2Te_3. We learn that the higher spin-orbit interaction in the telluride acts in two ways: it prevents the nonmagnetic gap and it causes the perpendicular anisotropy which is the precondition for the magnetic gap and the QAH effect.