MSc project proposal: Ferromagnetic domain walls and plasmonic exchange interaction in QAH edge states

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Summary

Electron transport in magnetically doped topological insulators (*1*) is governed by a single ballistic edge state propagating in a direction set by the magnetization direction of the ferromagnetic dopants. The magnetization direction of a thin-film sample of V-doped $(Bi_xSb_{1-x})_2Te_3$ (V-BST) can be switched below the materials Curie temperature by applying large magnetic fields (H_c $\pm 1\,\mathrm{T}$) (*2*, *3*). The quantum anomalous Hall edge states manifest themselves as a quantized Hall resistance of magnitude $\pm R_K = \pm h/e^2 \approx 25.9k\Omega$, as well depending on the materials magnetization direction. In order to investigate the dynamics of plasmonic charge excitations within the ballistic edge channels of the quantum anomalous Hall insulator we use a microwave excitation setup. Next to the charge dynamics of a single edge plasmon we want to investigate coupling mechanisms in between edge plasmons co-propagating next to each other. In order to investigate coupling mechanisms of two co-propagating edge plasmons it is necessary to define magnetic domains of different magnetization direction.

Your task will be to investigate experimental techniques for the local switching of the ferromagnetic order within thin-film samples of V-BST for the creation of magnetic domain walls. Therefore, you will use the cleanroom facilities of the Ando group to structure mesoscopic devices of V-BST. The V-BST thin films are grown by means of molecular beam epitaxy, also kindly provided by the Alexey Taskin of the Ando group. You will use optical lithography in combination with a plasma sputter tool in order to deposit patches of ferromagnetic materials on top of the structured V-BST thin films. By varying the materials thickness, the coercive field of these patches varies, such that the magnetization direction of these patches can individually be tuned. The ferromagnetic coupling in between the V-BST thin films and the ferromagnetic patches can be simulated by e.g. using mumax^3 (https://mumax.github.io/). Another possibility to investigate is the switching of the magnetization direction of the magnetically doped TI directly by applying large current pulses (*4*). Within our group you will be supervised by one of our PhD students or PostDocs.

Keywords: **Topological Insulator, Quantum Anomalous Hall Insulator, Ferromagnetism, Spin-Transfer-Torque, Spin-Orbit Torque, Mesoscopic Physics**

Research background

Topological insulators have, compared to trivial insulators, an inverted band structure due to a strong spin-orbit interaction of charges within p-orbitals energetically closest to the Fermi energy (*5*). Well-known examples are the heavy-element binary compounds Bi_2Te_3 (BT), Bi_2Se_3 (BS), Sb_2Te_3 (ST) as well as ternary $(Bi_xSb_{1-x})_2Te_3$ (BST) and quaternary $(Bi_xSb_{1-x})_2(Te_ySe_{1-y})_3$ (BSTS) alloys of these chalcogenide V-VI compounds. The topologically non-trivial band ordering evokes gapless surface states at the interface towards a topologically trivial insulator as bands of the same parity need to connect. This gives rise to metallic surface states with linear Dirac dispersion at

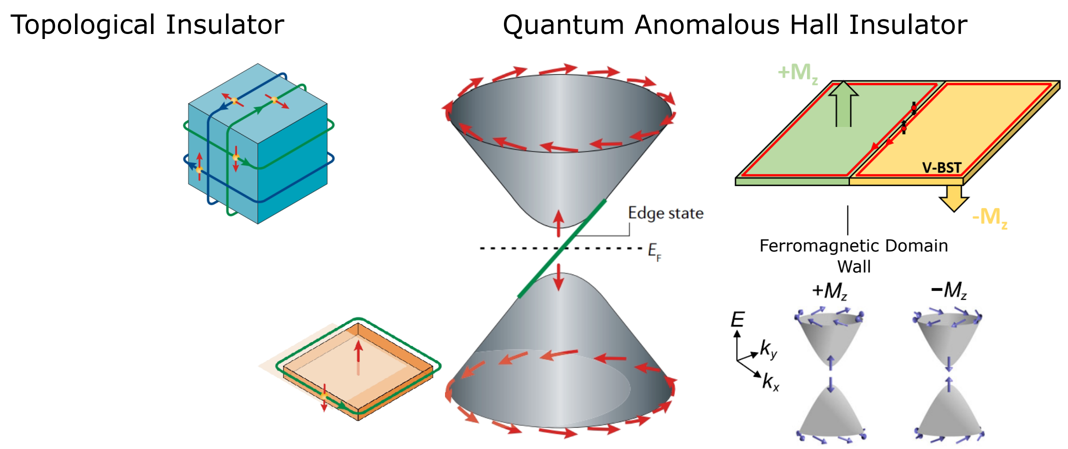

Figure 1: Schematic representation of the surface and bulk state dispersion in topological insulators (TI, left) and the surface and edge state dispersion in quantum anomalous Hall insulators (QAHI, right), adapted from (*7*). The surface state dispersion of the TI is represented by the Dirac cone shown in grey, highlighting the helical spin dispersion of surface charges. Due to a magnetic exchange interaction in magnetically doped TIs an energetic gap in the surface state spectrum around small momenta at the Dirac point established. Within the magnetic gap chiral QAH edge states arise (green). By joining two regions of the magnetically doped TI V-BST of two different magnetization directions, a magnetic domain wall can be realised at which two edge modes of different chirality co-propagate.

the interface of a TI towards a trivial insulator. Due to the strong spin orbit interaction on atomic level, the spin of charges in TI thin-films is also found to be dependent on the charges momentum within the crystal. In three dimensions the band dispersion of the surface states resembles a Dirac cone as schematically depicted on the left side of Fig. 1.

Just recently the **quantum anomalous Hall state** (quantum Hall state with intrinsic magnetic moment) has been experimentally verified in magnetically doped topological insulator materials. These materials include Cr- and V-doped $(Bi,Sb)_2Te_3$ (BST). When magnetised below the Curie temperature (20-30 K) the magnetization of the magnetic dopants within Cr-/V-BST perpendicular to the surface will open an exchange gap around small momenta at the Dirac point of the topologial insulator surface states. Within the exchange gap chiral anomalous Hall edge states give rise to a quantized Hall resistance of h/e^2. The surface state dispersion including the magnetic exchange gap are schematically depicted in Fig 1 (right side).
Spin-transfer-torque describes the magnetization possibility of a ferromagnetic layer using a spin-polarized electrical current. In topological insulators the strong spin-orbit coupling of heavy elements leads to spin polarization of electronic charges based on their momentum. Therefore, an applied current bias within a topological insulator is able to change the magnetization direction in nearby ferromagnetic layers (*6*).

References

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