Magnetic topological insulators.

Topological phases create a novel category of phases with quantum order that goes beyond the well-known Landau symmetry breaking theory that successfully describes transition of classical phases connected with different states of matter or magnetic order. The first, discovered in 1980, topological phase was the quantum Hall state linked immanently with two dimensional electron gas at high magnetic field, with topological nature manifested in form of a series of quantized Hall conductance plateaus that corresponded to a topological invariant – the "Chern number". With the quantum Hall state discovery, it has been realized that materials that have bulk energy gap (in this case between Landau levels) may have gapless edge modes which can provide robustness charge transport. Next topological phase - fractional quantum Hall state, discovered a little later, in 1982, has brought a new physics with novel, fractionally charged quasi particles obeying anyon statistics. All these together triggered search for new topological phases. It however took over twenty years before topological insulators, the other quantum phase, came to the scene. Topological insulators were first predicted theoretically in materials with high spin-orbit interactions so their energy gap is inverted. A topological insulator has a bulk energy gap, but in contrast to normal insulator, possesses also gapless states at its surface that are protected by time reversal symmetry. These surface states have linear dispersion, characteristic for relativistic Dirac fermions. In 2009 second-generation topological insulators were identified by theoretical calculations as well as angle-resolved photoemission spectroscopy (ARPES) experiments. This group included Bi_2Se_3, Bi_2Te_3 and Sb_2Te_3. Doping topological insulators with transition metal ions is another interesting field for investigations. It is expected to lead to novel physical phenomena. Magnetic impurities are expected to modify topological surface states, through breaking time reversal symmetry, causing in particular band gap opening at the Dirac point and modifying spin texture. It has been also indicated theoretically, that Dirac electronic states can mediate the RKKY interaction among localized magnetic moments that can result in long-range ferromagnetic order. Quantum anomalous Hall effect has been recently observed for the first time, in ferromagnetic $(BiSb)_2Te_3$, completing the quantum Hall trio (quantum Hall 1980, quantum spin Hall 2007, and quantum anomalous Hall effects 2013). Magnetically doped topological insulators with ferromagnetic order are important as realizations of novel topological phases. These materials are important both for theoretical understanding of the formation of different topological phases, and have direct implications for proposed devices using magnetic interfaces with topological insulators, such as magneto-electric junctions, to integrate into multifunctional topological transistors. The key for utilization of topological insulators is low bulk conductivity in order to expose electric transport through the surface. Binary topological insulators suffer large bulk conductivity due to dominating lattice defects, Se vacancies and Bi antisites in Bi_2Se_3 and Bi_2Te_3, respectively. It is possible to reduce to some extent the concentration of native defects by applying specific growth conditions; non-stoichiometric melt compositions and doping with compensating donors or acceptors, respectively. The ternary topological insulator Bi_2Te_2Se (or BTS) offers already much better electric parameters, as formation of the native lattice defects is naturally suppressed by its structure. Going further, quaternary compounds with antimony, $Bi_{2-x}Sb_xTe_{3-y}Se_y$ (or BSTS), has been recently proposed to optimize the bulk-insulating behavior, with $x = 0.5$ and $y = 1.3$ giving the lowest bulk carrier density.

In this project we plan to study quaternary topological insulators doped with transition metal ions. The aim of the project is to develop a method for obtaining topological insulators with ferromagnetic order with the greatest possible bulk resistivity and good structural properties, without presence of other phases in form of precipitates, and to determine physical phenomena underlying magnetic ordering in topological insulators. We will focus first on the nature of observed magnetic properties, we will aim to determine how magnetic dopants incorporate into the body of a topological insulator, under what conditions they can form ferromagnetic phase, we will endeavor to distinguish surface and bulk magnetic contributions, to determine what is the mechanism of magnetic ordering. Once good quality ferromagnetic samples are obtained, they will be subject of studies how the magnetic doping (breaking the time-reversal symmetry) influences topological surface states (protected by this symmetry) and electric transport.