Project 4.22. Limitations for Protected Transport and Exotic Topological States in Topological Semiconductors

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Background:
Breaking away from the popular trend focusing on effective models for topological matter we will develop theory for real-life topological semiconductors (TSs). There is a demand for better modeling of these materials to understand the observed lack of topological protection of transport in 2D quantum spin Hall (QSH) insulators. Moreover, multilayer TSs exhibit number of other intriguing topological phenomena. For instance, surface atomic steps in Sn(Pb)Se(Te) systems, separating regions of even and odd number of layers, were found to host topological in-gap states. Recently, also a zero-bias conductance peak was observed in Sn(Pb)Se(Te) system containing steps. Such peaks are considered to be one of the signatures of the intensively searched Majorana zero modes, holding a promise for topological quantum computation. However, detailed analysis of topology of states localized at a single step suggests that they can be due to the magnetic domain walls. Since a surface step has similar symmetries as a nanowire, it is a good question to ask whether similar states can be found there as well. This is an important question because SnTe nanowires are considered as a platform for realizing Majorana zero modes, alternative to the celebrated InSb nanowires where the signatures of such zero modes have been reported. Finally, TSs offer a unique possibility for realizing non-Hermitian topological phases, being topologically nontrivial eigenstates of open system Hamiltonian, where the energy is dissipated or gained. This can be achieved by putting a single- or few-layer TS in a photonic resonator. Photons in such a microcavity strongly interact with a TS and an exciton-polariton condensate is formed. It is then an intriguing question to ask what will be the topology of the exciton-polariton state for a single cavity or an array of cavities.

Aim:
In this project we will address four critical questions related to topological semiconductors:
(A) Lack of topological protection in HgTe/CdTe-type quantum wells. We will model transport in disordered topological multilayers and our aim is to show that the additional edge modes can be responsible for the lack of topological protection.
(B) Study of symmetry-protected topological invariants and symmetry-broken states for multilayer semiconductors, involving surface atomic steps and nanowires.
(C) Control of topological invariants, design of systems that exhibit QSH effect at a macroscopic scale. We will search for such a design of a quantum well that the additional edge modes are either absent or moved out of the gap.
(D) Non-hermitian topological systems, multilayer semiconductors in microcavities and beyond. Going beyond means implementing non-Hermitian Hamiltonians with non-trivial topology using chains of superconducting or optomechanical circuits.

Collaboration with the experimental groups at MagTop/IFPAN.

Requirements:

- sufficient proficiency in English
- some experience in programming (Mathematica/MatLab/Python or similar)

- background in the theory of condensed matter systems
- background in linear algebra

Net stipend paid from the project: ca. 4300 PLN.