Magneto-optical study of topological phases in PbSnSe alloys and heterostructures

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Topological matter has recently been a wide source of interest in condensed-matter physics. Due to relativistic effects, an inversion in the band parity can occur for topological materials. In particular, the topological crystalline insulator $Pb_{1-x}Sn_xSe$ can host an inverted band structure highly tunable with external knobs like composition, temperature, or strain. In this inverted configuration, gapless Dirac cones, known as the topological surface states, emerge at the surface of the material. Controlling these topological surface states remains a big challenge as it would go along with many very important applications in ultrafast electronic devices, spintronics or quantum computing based on Majorana states.

In this presentation, we will demonstrate the $Pb_{1-x}Sn_xSe$ three-dimensional (3D) band structure and its dependence with chemical composition, temperature and strain by using magneto-optical experiments. These experiments rely on molecular beam epitaxially grown (111)-oriented $Pb_{1-x}Sn_xSe$ with very high mobilities (>10,000 $cm^2/V.s$) and low carrier densities ($n \sim 10^{17}$ cm^{-3}). The precise control on the growth parameters combined with infrared magneto-optical experiments allows an exhaustive mapping of the 3D PbSnSe topological band structure.

In a second part, in order to further study the topological surface states, we will present magneto-optical measurements in PbSnSe/PbEuSe uncoupled and coupled quantum wells – multi quantum well and superlattice heterostructures – to evidence the optical activity of the topological surface states. The observation and characterization of these states show their high tunability with temperature and confinement. In particular, a Quantum Spin Hall (QSH) phase is experimentally found in the superlattice structure. The magneto-optical characterization of PbSnSe-based topological heterostructures paves the way to evidence exotic transport phenomena like the QSH or quantum anomalous Hall effects.