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Abstract

PhD dissertation: Molecular beam epitaxial (MBE) growth and angle-resolved photoelectron spectroscopy (ARPES) studies of $Pb_{1-x}Sn_xSe$ and α-Sn topological materials.

This PhD dissertation focuses on the $Pb_{1-x}Sn_xSe$ and α-Sn (grey tin) thin film topological materials, which belong to the topological crystalline insulators (TCI) and the Luttinger semimetal classes of materials, respectively. The unique property of the topological materials is the presence of the topologically protected gapless surface states, and their behaviour under external perturbation is of great interest. In particular, understanding the band structure at the interface of TCI and magnetic material (MM) holds the potential to realise exotic electronic properties and pave the way for novel spin-orbitronic devices. The topological phases of α-Sn can be tuned by strain or magnetic field, opening the way for possible applications in topological electronics.

In the research for this dissertation, the molecular beam epitaxy (MBE) method was used to produce high-quality thin films of $Pb_{1-x}Sn_xSe$ TCI as well as compressively strained α-Sn in the Dirac semimetal (DSM) phase, grown on hybrid insulating CdTe/GaAs (001) substrates. Structural characterisation of the epilayers was carried out by Reflection High-Energy Electron Diffraction (RHEED), X-ray diffraction (XRD), scanning electron microscopy (SEM) and atomic force microscopy (AFM).

The electronic structure and spin polarization of the surface states of $Pb_{1-x}Sn_xSe$ were investigated using angle-resolved photoelectron spectroscopy (ARPES) and spin-resolved ARPES (SR-ARPES). These studies not only tested the predictions of the band gap opening resulting from the magnetic impurities on the surface of the TCI but also revealed the existence of Rashba-split surface states (RSS) induced by the deposition of a submolayer amount of transition metal (TM) on the surface of the TCI. The results obtained demonstrate the tunability of the Rashba coefficient within the range from 0 to 3.5 eV·Å, along with the absence of a surface states band gap opening of magnetic origin, after TM deposition on the surface of TCI. SR-ARPES investigations conducted at higher photon energies revealed helical spin polarization in both the TCI and normal insulator (NI) phases of $Pb_{1-x}Sn_xSe$, with in-plane spin polarization reaching up to 30%. Remarkably, the TCI-NI transition was observed, triggered by surface compositional changes as a result of TM deposition, rather than surface magnetism from magnetic impurities.

The electronic structure of compressively strained α-Sn was also examined by ARPES. The studies performed revealed the presence of topological Dyakonov-Khaetski states and proved the presence of a DSM phase in compressively strained α-Sn, grown on hybrid insulating CdTe/GaAs (001) substrates.

This work also provided a basis for further optical and transport investigations of topological materials through important contribution to development of the MBE growth technology of such materials and by supplying appropriate structures. Additionally, it proved that α-Sn grown on insulating hybrid substrates is an attractive material for the exploration of relativistic physics, including chiral anomaly.

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