Epitaxial Topological Insulator Heterostructures

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Topological insulators (TIs) of the Bi(Sb)-chalcogenide class of materials exhibit a complex lattice structure, consisting of $Bi(Sb)_2Te_3$ quintuple layers adjoined to each other by weak van der Waals forces. As a result, a layered crystal structure is formed that determines the physical properties as well as epitaxial growth. Moreover, the "openness" of the lattice structures provides a variety different lattice sites for incorporation of doping elements used to tune electronic or magnetic properties of the materials. In this presentation, the properties of growth by molecular beam epitaxy as well as the peculiar structural and electronic properties are described.

Particular focus will be on the magnetic doping used to induce magnetism in TI materials [1]. Ferromagnetism leads to the opening of a magnetic band gap in the topological surface state of TIs that enables the realization of the quantum anomalous Hall effect due to formation of dissipation less edge channels without external magnetic fields. However, doping of the Bi-chalcogenide TIs with transition metal elements such as manganese leads to a pronounced structural modification of the material due to the formation of natural self-assembled heterostructures that consist of quintuple layers alternating with septuple layers such as with $MnBi_2Te_4$ in a large variety of different stacking sequences [2]. Detailed structure analyses reveal that the magnetic doping atoms are indeed concentrated within the septuple layers with different degrees of disorder. This strongly enhances the magnetic exchange interactions which increases the magnetic Curie temperatures as well as the magnetic band gap of the Dirac electrons [2,3], which is a key parameter for achieving the anomalous quantum Hall effect at higher temperatures. Apart from these "natural" heterostructures, MBE allows to directly grow artificial TI heterostructures comprising of different TI and normal insulator layers. We present here the striking example of TI/NI heterostructures based on the IV-VI lead-tin chalcogenides, in which the quantization of Dirac states can be effectively tuned and controlled as shown by theory and experiments [4]. This opens up the means for band gap engineering as in traditional semiconductor heterostructures.

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