Structural and Electronic Properties of Topological Insulators and Nodal line Semimetals

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Chapter 8

Summery and future scope

8.1 Summery

Within the scope of this thesis, both the structural and electronic characteristics of topological insulators and semimetals have been dissected. In the case of topological insulators, we saw a stable surface state that didn't change even when subjected to thermal stimulation or doping. This was an interesting finding. This surface state is spin-polarized and protected by time-reversal symmetry. On the other hand, in the case of the Dirac semimetal, the time reversal and inversion symmetry guard the bulk band that contains the Dirac cone, preventing it from being destroyed. It turns into a nodal line semimetal if the Dirac point extends to a line in the Brillouin zone in the form of a line or loop. The novel compounds we studied yielded a number of findings that piqued our interest. We observed a metal-semiconductor phase transition for the case of a doped topological insulator. This transition originated from the bulk band, whereas the surface state, which is protected by time-reversal symmetry, remained intact even at room temperature. The distinct surface band observed up to room temperature from the T-dependent ARPES study. However, despite the fact that it is an insulating phase, the bulk band is extremely sensitive to doping. A shift from *p*-type to *n*-type in the bulk band can occur if there is a fluctuation in the dopant or if a defect is introduced while the crystal is growing.

From the results of the photon energy-dependent ARPES analysis in the nodal line semimetal, we have also seen a robust Dirac cone, which is protected by time reversal and crystalline symmetry. This observation was made in the bulk band of the nodal line semimetal. The discovered Dirac cone has a nature of *type II* and is safeguarded by *C4* symmetry. The nodal line semimetal demonstrates a number of fascinating properties as well, including the phase transition from semiconductor to metal when a magnetic field is applied to it, along with a very high magnetoresistance that is accompanied by carrier compensation. In addition, we visualize the three-dimensional topology of the Fermi surface from the quantum oscillation study and derive several essential parameters, such as effective mass and quantum mobility.

8.2 Future scope

The non-trivial band structures of topological materials have generated a significant amount of attention in the field of spintronics technology. In addition, magnetic sensors, magnetic switches, memory devices, and incredibly efficient low-power electronics can all make use of the topological semimetals' giant MR and extremely high mobility. Although the theoretical aspects of topological insulator materials have received enough recognition, the experimental problems still present a large number of difficulties, and attempts are still underway to solve them. The presence of unwanted bulk residual carriers as a result of inherent flaws is one of the most significant experimental challenges that researchers have when working on the synthesis of those materials in their bulk forms. The investigation of nanostructured topological surface states has the distinct advantage of mitigating the influence of unfavorable bulk electronic states in transport measurements to the greatest extent feasible. As a result, it makes it simpler for topological surface or edge states to make a contribution. Because of this, the dimensions of the material are extremely important in the surface-dominant transport regime in order to make the most of the beneficial features possessed by the surface electrons. Another advantage of nanostructured materials is that it is simple to modulate the Fermi level via field effect gating (FEG), which is a process that is difficult to accomplish with bulk crystals due to their larger volumes. The surface-dominated electron transport that FEG guarantees are made possible in nano

TI by the significant surface-to-volume ratio of the material. Additionally, the exceptional morphology of TI nanomaterials allows for control over the topological surface states in decreased dimensions, such as nanoribbons, nanoplates, nanorods, nanowires, nanotubes, nano-rings, and quantum dots. This control can be applied to a wide variety of nanoscale structures.

Even though the term"topological insulators" was coined quite some time ago, the study of topological materials (such as topological crystalline insulators, WSMs, DSMs, NLSMs, and so on) has flourished in recent years, and recent theoretical works suggest that a sizeable portion of all the materials about which we have knowledge may have topological properties by their very nature. In recent years, research on the condensed matter has focused on topological materials, which have recently exploded into a multidimensional field and offer one of the most exciting and crucial study frontiers in contemporary modern times. Topological proximity effect with dissipation less conduction, field-effect transistors with fast-switching, a broadband photodetector for optoelectronic devices, ultrafast photodetector for innovative photodetection technologies, topological p-n junction diode for electronic devices, and qubits for robust quantum computers based on one-dimensional topological superconductors are essential for potential device applications. The TI surface state is suitable for manufacturing spin-orbit torque (SOT) via the spin Hall effect (SHE), and the effective control over SOT by the gate voltage represents energy-efficient gate-controlled non-volatile spintronic memory and logic devices. The SOT can be effectively controlled by the gate voltage. In addition, it has been demonstrated that TIs are very effective in converting spin to charge, which suggests that they may be put to use either as spin detectors or as efficient spin-to-charge converters. In conclusion, recent developments in the physics of topological insulators may be traced back to the early theoretical breakthroughs as well as the following experimental verification of those breakthroughs. The presence of exotic metallic surfaces atop these insulators may pave the way for the invention of novel spintronic and electronic devices as well as the discovery of newly discovered quantum states that are rich in unknown physics.