CHAPTER 8

Summary and future perspectives

Chapter 8

8.1 Summary

The present dissertation addresses interesting magnetotransport properties, ARPES studies and theoretical investigation of some TIs and WSMs. The high quality single crystal samples of TIs and WSMs were synthesized by adhering modified Bridgman technique and chemical vapor transport technique (CVT), respectively. The single crystalline nature of all grown samples was confirmed by XRD and Laue diffraction. Further, the extensive transport measurements, magnetic measurements, ARPES measurements and pressure dependent transport measurements have been performed. $Sb_{1.9}Cu_{0.1}Te_3$, $BiSbTe_3$, $Bi_{1.9}Dy_{0.1}Te_3$, $Bi_{1.9}Dy_{0.1}Se_3$ TIs materials and NbP, $Nb_{0.5}Ta_{0.5}P$, TaP WSMs materials have been chosen for present thesis work.

It is observed that Cu doping in pure Sb_2Te_3 TI induces antiferromagnetic ordering. Quantum oscillations have also been noticed in magnetoresistance (MR) and magnetization data as a function of magnetic field. Shubnikov-de haas oscillations (SdH) measurements support the non-trivial Berry phase π, which confirms the dominancy of Dirac fermions in transport. The observed non-linearity in Hall data has been assigned to the presence of AHE and THE in the material due to existence of magnetic ordering and spin texture. The observed antiferromagnetism in the compound has been assigned to the Cu^{2+} spin state, which was confirmed from XPS analysis. The presence of antiferromagnetic ordering is also supported by theoretical calculations. All the investigated results are mentioned in chapter 3.

The effect of external pressure on the resistance of $BiSbTe_3$ TI with variation of temperature has been investigated. The presence of Bi, Sb, and Te is confirmed by X-photoelectron spectroscopy. A sharp drop in resistance was observed by applying 8 GPa

external pressure, which was assigned to the manifestation of superconductivity in $BiSbTe_3$ TI with the critical temperature (T_c) of ~2.5 K. With increasing pressure, the T_c increased further and reached to its maximum value ~3.3 K at 14 GPa. It has been confirmed from theoretical analysis that the surface states are remains unaltered under pressure and the occurrence of superconductivity is associated to the bulk states. Besides this, from the ARPES study, it has been observed that the Fermi level exactly coincides with the Dirac point near the bulk valance band, which could be the ideal condition for technological exploitations.

The impact of Dy doping on Bi_2Te_3 TI has been inquired by measuring magnetic and transport properties. Robust surface states without any appreciable energy gap at Dirac point have been revealed from ARPES measurements. Furthermore, we have observed large MR in $Bi_{1.9}Dy_{0.1}Te_3$ TI, it is as large as ~1500% at 2 K and 7 T field, which is the highest reported so far for any A_2B_3 type system in TIs family. The robust surface states have been ascribed to such a large value of MR, which is elaborated in chapter 5. Moreover, the presence of an antiferromagnetic ordering has been confirmed from the magnetic analysis together with DFT calculation. The AHE has been established from the non-linear Hall data, which is attributed to the presence of antiferromagnetic ordering in bulk by Dy doping in Bi_2Te_3 TI. Therefore, different exotic behaviors have been observed for surface and bulk states, indicating the capability of these TIs in technological practices.

The study of the impression of Dy doping on Bi_2Se_3 TI has also been made. It has been demonstrated that Dy doping induces AFM ordering in Bi_2Se_3. A surface bandgap of ~52 meV at 6.5 K and ~38 meV at 18 K has been elucidated by ARPES analysis. A clear transition from PM to AFM ~9 K has been seen. Another transition near to 5 K is also observed, which has been assigned to a transition from AFM to FM. Furthermore, the Kondo effect and WL to WAL crossover have also been established. The theoretical calculations based upon DFT along with the μ-SR measurements have promoted the establishment of magnetic properties in $Bi_{1.9}Dy_{0.1}Se_3$ TI.

Very promising observations have been found for all WSM single crystal samples. From the resistivity versus temperature plot, a semi-metallic nature has been observed for all the samples in the full range of temperature. Pure-electron-correlation-dominated scattering mechanism has been established from power-law fitting in low-temperature range (< 115 K), while in high-temperature range (115 K-300 K) dominance of electron-phonon scattering is observed. Role of scattering on MR has been understood by Kohler's scaling on MR data and the SdH oscillations have also been detected from MR measurement. Fermi wave vector, Fermi velocity, effective cyclotron mass and carrier concentration were evaluated from observed SdH oscillation. The quasi-particle nature of the charge carriers has also been confirmed from Landau level fan diagram by extracting the osanger phase for all three compounds. The linearly dispersive bands about chemical potential and band-crossing points in bulk band structure in the vicinity of Fermi level have been predicted from the DFT calculation for all three WSM systems.

8.2 Future Perspectives

The discovery of TIs and WSMs has emerged as a subject of immense attraction in current era. These materials have Dirac and Weyl quasi-particle excitations, exhibit extraordinary properties from the viewpoint of both fundamental and technological enthusiasm. The focus of the present work was to observe some interesting results and to explore some new quantum phases of materials by manipulating some internal and external parameters of well-recognized TIs and WSMs for the benefit of fundamental research and technological applications. Few given goals may be achieved in the future.

- X-ray magnetic circular dichroism (XMCD) / X-ray magnetic linear dichroism (XMLD) could be performed for magnetic TIs to know the exact origin of magnetic ordering in the systems.
- Thickness dependent transport study can be performed after growing the TIs and WSMs thin films.
- Magnetotransport properties could be tuned upon doping of magnetic and nonmagnetic elements in WSMs.
- Study of quantum phenomena could be done in future for some new type-I and Type-II WSM materials under extreme conditions such as high pressure and magnetic field.