Magnetotransport Properties Caused by the Magnetic Doping in Topological Insulators

Well crystallized Cu-doped (Pb,Sn)Se nanocrystalline were prepared by hydrothermal synthesis. More Cu doping content caused the refined grains. Weak ferromagnetism was found due to the Cu doping. The atomic moments per Cu was decreased with increased Cu content. By fitting the temperature-dependent resistivity curve, the energy barrier for electron jumping is also found to decrease. Higher magnetic field delocalizes the electrons, which results into lower energy barrier. At low temperature, the gradually changed field-dependent resistivity showed that the trivial state was even maintained at low temperature in these two samples without any transition into nontrivial state.

The samples with nominal composition of $Cu_x(Pb_{0.77}Sn_{0.23})_{1-x}Se$ (x = 0.05, 0.1) was prepared by hydrothermal synthesis by using appropriate $Pb(CH3COO)_2 \cdot 3H_2O$, $SnCl_2 \cdot 2H_2O$, $CuSO_4 \cdot 5H_2O$, Se powder as Pb, Sn, Cu and Se sources respectively. The hydrothermal synthesizes were carried out at 180°C for 10 hours. The resultant powders were dried by de-ioned water and ethanol

From the XRD results (Fig. 1), The PbSe-type cubic structure is achieved in both two samples. While, additional peaks from Se impurity phases are observed. The increased width of diffraction peaks indicates that increased Cu content leads to refined grains. By cooling down to 4 K under 0.1 T, the magnetizations are firstly increased slowly in the temperature between 300K and 50 K. when the temperature is decreased further, the magnetization increases drastically without showing any tendency of saturation. The magnetic hysteresis loops of two samples are compared in Fig. 1c. With increased external field, the magnetizations of two samples are increased but not saturated even at 5 T. The "S" shape loop suggests the weak ferromagnetism, which is supposed to be caused by Cu. Defining the magnetization at 5 T as the saturation magnetization (M_s), higher Cu content leads into larger M_s. The atomic moments calculated by Ms are $0.02\mu_B$/Cu for x=0.05 and $0.013\mu_B$/Cu for x = 0.1. Increased Cu content leads into decreased atomic moment per Cu atom. More Cu content leads into closer interatomic distance and stronger coupling, which causes the decreased atomic moment.

Due to the weak ferromagnetism introduced by Cu, the splitted electron energy bands would lead into different transport properties. The resistivities (R) of $Cu_x(Pb_{0.77}Sn_{0.23})_{1-x}Se$ (x = 0.05, 0.1) are measured between 4 K and 300K under zero field and 9 T. the typical semiconducting-like temperature dependences are observed.

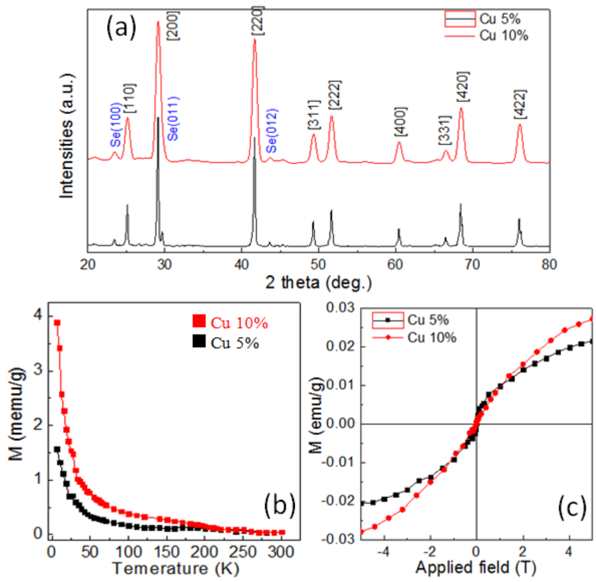

Fig.1 (a) Typical X-ray diffraction patterns of $Cu_x(Pb_{0.77}Sn_{0.23})_{1-x}Te$ (x = 0.05, 0.1). (b) The thermal magnetizations measured under 0.1 T in a cooling process. (c) The magnetic hysteresis loops measured at 4 K.

By applying 9 T, the dependences are not changed. By exponential fitting the R-T curves, the energy barrier is calculated to be 1.69 K_BT for zero field and increased to 3.21 k_BT for 9 T in $Cu_{0.05}(Pb_{0.77}Sn_{0.23})_{0.95}Se$. The increased energy barrier indicates that the electron is inclined to be localized. Only increasing Cu content, the energy barrier is decreased to 0.89 k_BT under zero field and 3.04 k_BT under 9 T. The change of the energy barrier with increased Cu doping is also due to the stronger exchange coupling. Higher Cu concentration leads into closer interatomic distance, which facilitates the tunneling of electrons between Cu atoms.

Fig. 2c and Fig. 2d show the magneto-conductance changes as the function of applied field. At 2K, an upward cusp is observed in ΔG-T curve. With increasing temperature, the cusp become curved and gradually changed into "W" shape. As comparison, with higher Cu content, the similar upward cusp is observed for ΔG-T curve at 2 K. With elevated temperature, the sharp corn becomes broadened. By comparing with R-T curve in Ref. 1, the trivial state is confirmed in the case of x=0.05. With increasing Cu content, the disappeared W-shape R-H curves and the appeared broadened R-H curve near zero field suggest the possible non-trivial state. while further confirmation is necessary by using APPERS to examine the temperature-dependent electron band changes.

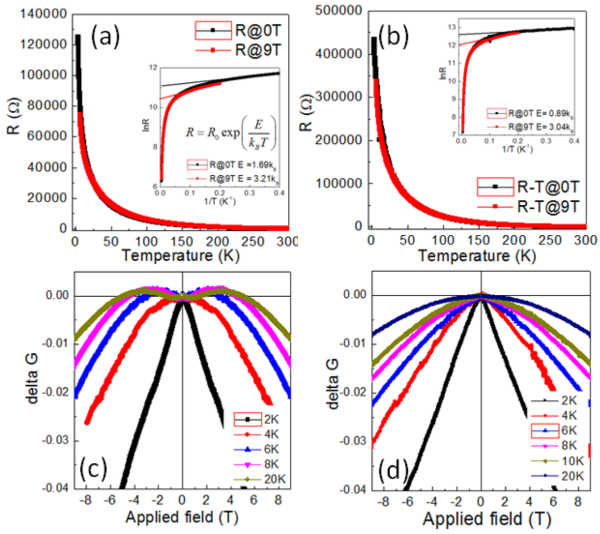

Fig.2 The temperature-dependent resistivity of $Cu_x(Pb_{0.77}Sn_{0.23})_{1-x}Te$ (x = 0.05(a), 0.1(b)) under zero field (black) and 9 T(red). The conductance change as the function of applied field for $Cu_x(Pb_{0.77}Sn_{0.23})_{1-x}Te$ (x = 0.05(c), 0.1(d)) at various temperature.

References

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