Pressure effects on topological crystalline insulator SnTe and derived superconductor Sn0.5In0.5Te

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Pressure effects on topological crystalline insulator SnTe and derived superconductor $Sn_{0.5}In_{0.5}Te$

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Abstract. We are reporting decrease in superconducting transition temperature accompanied by increased metallicity in indium doped SnTe superconductor. SnTe is a topological crystalline insulator and superconductivity is achieved by indium substitution in place of tin. With application of hydrostatic pressure we find negative dT_c/dP of ~ -0.6K/GPa upto 2.5 GPa. The overall phenomenon is ascribed to unconventional superconductivity. Decrease in resistivity is also seen in single crystal SnTe with application of pressure but no evidence of superconductivity is observed.

Keywords: $Sn_{0.5}In_{0.5}Te$, Topological Insulators, Hydrostatic pressure.
PACS: 62.50.-p, 74.62. Fj

INTRODUCTION

A topological insulator has a bulk band gap but due to the gapless edge states it is conducting on the surface [1,2]. The well-studied topological insulators are Bi_2Se_3, Bi_2Te_3, and Sb_2Te_3 [3,4,5]. Superconductivity by doping and intercalations is possible in these systems. This holds promise to detect Majorana fermions, and realisation of quantum computations [6]. Copper and Strontium intercalation in Bi_2Se_3 has been reported to induce superconducting transition temperature of 3.8 K and 2.9 K respectively [7,8]. Similarly, indium doping in place of tin in SnTe gives superconducting transition temperate of 4.8 K [9,10]. SnTe is a well-known topological crystalline insulator in which edge states are protected by crystalline symmetry rather than time reversal symmetry.

Most conventional superconductors show a decrease in superconducting T_c on application of external pressure. On the contrary, superconductivity is achieved in topological insulators under high pressure. For example, Bi_2Te_3 turns a superconductor at 3 GPa (T_c ~3K) without any structural phase transition [11] and goes upto maximum T_c of 8K at 15 GPa through various phase transitions [12]. Similarly Bi_2Se_3 shows a superconducting behaviour at 0.5K on applying 13.5 GPa pressure that goes upto 7K on application of 30 GPa external pressure. On the other hand, Cu Intercalated Bi_2Se_3 which is already a superconductor at 3.8 K has been reported to show decrease in T_c with external pressure. By extrapolating the graph total suppression of T_c has been seen around 6.3 GPa [13]. In this paper we elaborate on synthesis and the effect of external hydrostatic pressure on the transport properties of $Sn_{0.5}In_{0.5}Te$ [14].

SAMPLE PREPARATION

Single crystals of SnTe were grown by melting stoichiometric amounts of high purity elemental shots of Sn (99.9%), Te (99.99%) and In (99.9%) at 900 °C for 5 days in sealed evacuated quartz ampoules. Intermittent shaking of sample was done to achieve homogenous mixture. The sample was cooled slowly to 770 °C over 24 h followed by annealing at this temperature for 72 h. Quenching was done in ice cold water. Single crystals were cleaved and cut into rectangular pieces.

The pressure dependent resistivity measurements were performed in Physical Property Measurements System (*PPMS*-14T, *Quantum Design*) using HPC-33 Piston type pressure cell with Quantum design DC resistivity Option. Hydrostatic pressures were generated by a BeCu/NiCrAl clamped piston-cylinder cell. The sample was immersed in a fluid (Daphne Oil) with pressure transmitting medium of Fluorinert in a Teflon cell. Annealed Pt wires were

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affixed to gold sputtered contact surfaces on each sample with silver epoxy in a four-probe configuration

RESULTS AND DISCUSSION

X-ray diffraction patterns of powder $Sn_{0.5}In_{0.5}Te$ and parent compound SnTe were measured in Rigaku diffractometer (Figure 1). Powder XRD pattern is matched by ICDD data card no. 089-3974. The lattice parameter of $Sn_{0.5}In_{0.5}Te$ is found to be 6.265 Å and cell volume 245.65$Å^3$ with cubic structure in Fm-3m space group. Figure 2(a) shows a crystal structure while in figure 2(b) we have shown a SEM image of the surface of crystal at 20 µm resolution. Clean surface topography can be observed.

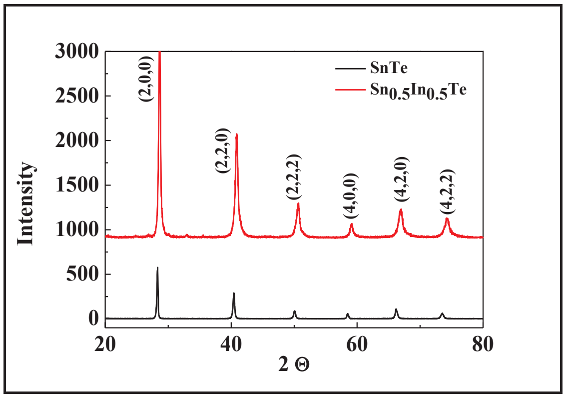

FIGURE 1. XRD analysis for the SnTe and $Sn_{0.5}In_{0.5}Te$.

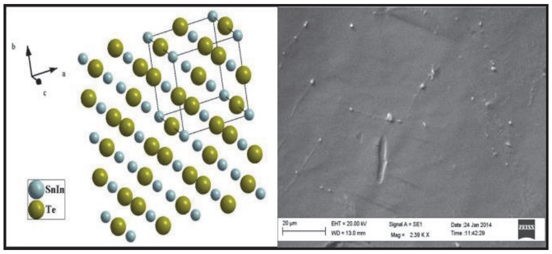

FIGURE 2. (a) Crystal structure of SnTe in cubic form. (b) SEM images of sample at 20 µm scale.

Next, we plot the electrical resistivity of parent compound SnTe as a function of temperature in Figure 3 at different applied pressure. The parent SnTe remains metallic over the measured temperature range. Evidently, it's normal state resistivity decreases with pressure. Also if we look at the extended part of higher pressure 1.5GPa and 2.5GPa data (inset) there is a resistivity upturn at around 100 K. But no indication of superconductivity has been seen down to 2K with the maximum available pressure of 2.5GPa.

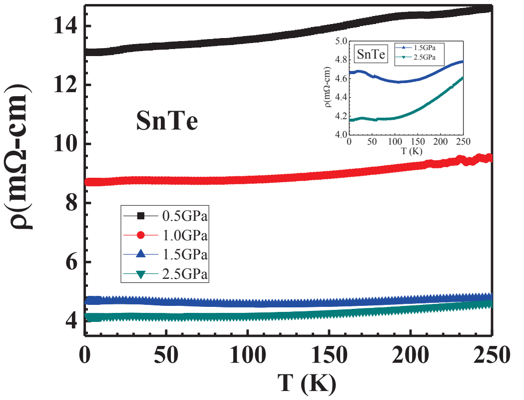

FIGURE 3. Resistivity of parent compound SnTe at 0.5, 1, 1.5, 2 and 2.5 GPa. No indication of superconductivity has been seen down to 2K.

In figure 4 we have plotted the resistivity curves of $Sn_{0.5}In_{0.5}Te$ at ambient pressure and at 0.5, 1, 1.5, 2, 2.5 GPa. A sudden decrease in resistivity has been seen on applying 0.5 GPa pressure. T_c onset has decreased from 4.5 to 2.8 K and T_c zero from 3.6 K to 2.3 K. A negative coefficient of pressure ($d\rho/dT \sim -0.6$ K /GPa) has been observed. Change in resistivity shows metallic behaviour with increase in pressure and sample becomes more metallic in normal state under pressure. A suppression in T_c can be under stood with the help of relation $T_c \sim \theta_D \exp(-1/N(E_F)$ where θ_D is the Debye temperature, V_0 is the electron- phonon coupling and density of state $N(E_F) \sim m^* n^{1/3}$ where effective mass is m^* and carrier concentration is represented by n. If carrier density increases that means decreasing resistivity can cause the decrease in T_c. But in this case resistivity is decreasing which means decrease in the T_c is governed by the decrease in the effective mass m*. In the inset we can see transition temperature is decreasing with the application of pressure.

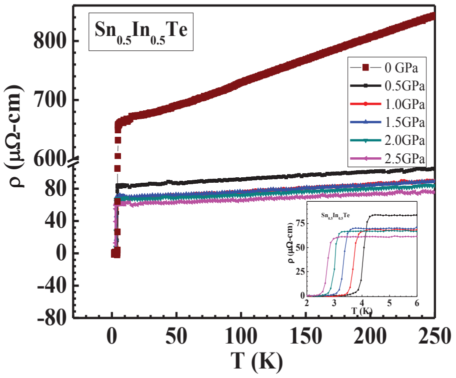

FIGURE 4. Resistivity as a function of temperature for $Sn_{0.5}In_{0.5}Te$ at various pressures. In the inset superconducting transitions are seen to be suppressed under pressure.

In figure 5 we have plotted the graph between applied pressure and superconducting transition temperature T_c. It shows a linear decrease in the T_c onset but the T_c zero is not linear particularly at lower pressure.

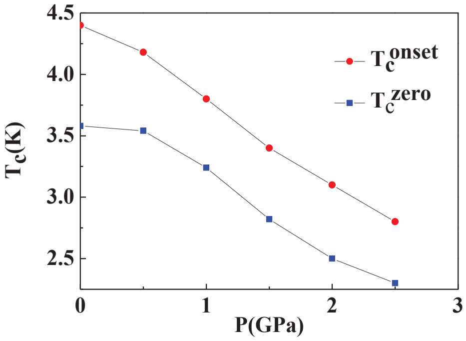

FIGURE 5. Dependence of superconducting transition temperature (onset and zero resistivity state) on pressure is plotted.

CONCLUSION

In conclusion, we have prepared single crystals of topological insulator SnTe and superconductor $Sn_{0.5}In_{0.5}Te$ that is derived from parent compound. XRD analysis confirms phase purity. SEM analysis shows a clean crystal surface. The resistivity of parent compound SnTe shows metallic behavior that decreases on applying pressure. In the optimal superconductor $Sn_{0.5}In_{0.5}Te$ a negative coefficient of pressure dT_c/dP of ~ -0.6K/GPa has been reported. The decrease in normal state resistivity accompanied by suppression of T_c under pressure is reflective of unconventional superconductivity.

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