Specific Heat, Magnetic Susceptibility and Resistivity Of In-Doped $Sn_{0.8}Pb_{0.2}Te$

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Abstract

We report experimental results on In-doped $Sn_{0.8}Pb_{0.2}Te$ solid solutions which are semiconductors with superconducting properties. We carried out simultaneous magnetic susceptibility and resistivity (four-point) measurements down to 1.5 K, as well as specific heat below 4.2 K, on poly-crystalline samples. All measurements indicate same critical temperature region, above which the specific heat exhibits a T^3 behavior, with $\theta_D \sim 85$K consistent with that of the constituent elements. Application of a magnetic field ($\sim$ 1 kG) suppresses the specific heat anomaly from the temperature range down to 2 K. The results suggest that this compound undergoes a bulk superconducting transition.

Key words: specific heat; superconductivity; semiconductors

1. Introduction

$A^{IV}B^{VI}$ compounds take the intermediate place between the classical semiconductors, such as Si, Ge, $A^{III}B^{V}$ and semi-metals such as Bi, Sb and their alloys. Because of considerable deviations of the content from stoichiometry [1], they are characterized by a large concentration of electrically active point defects, and, as a result, high concentration of charge carriers n, $p \sim 10^{18} - 10^{21} cm^{-3}$. These materials have high static dielectric constant ($\epsilon_0 \sim 100$) that increases as the temperature decreases. Because of the indicated peculiarities these materials do not possess shallow Coulomb-like impurity states. The only possible origin of impurity states is connected with a short-range potential. Due to a small energy gap, these states are often in the permitted zones of the energy spectrum (e.g., Tl in $PbTe$, In in $SnTe$ and $PbTe$) and may have quasi-stationary properties due to exchange of electrons between impurity and zone states.

The In-doped $Sn_xPb_{1-x}Te$ combines these properties with surprisingly high solubility and very high localization of electrons ($r \sim 5\mathring{A}$) at the impurity. For $x > 0.3$, the resonant states of In are located deep in the valence zone [2,3]. A step-like change in the resistivity was detected in the range of liquid ^4He; such jump is suggestive of a transition to a superconducting state [4]. However, due to poly-crystalline morphology of the samples, one cannot indisputably conclude the bulk character of superconductivity from resistivity alone. Thus, along with the resistivity, below 4.2 K, we measured magnetic susceptibility, $\chi(T)$, and heat capacity $c(T)$ at zero (Earth's) and non-zero fields. A sample of composition $x = .8$ and doped with 5% In was chosen because of the high critical temperature, $T = 2.83$ K (by resistivity), combined with low In contents.

2. Experimental Details

The samples used were fabricated by the powder-metallurgy method and was annealed at 650^{o}C for 100

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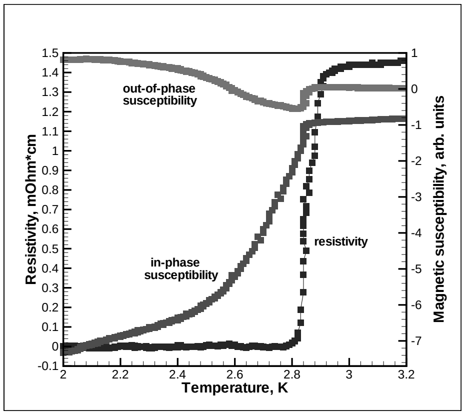

Fig. 1. Magnetic susceptibility and resistivity of $Sn_{0.8}Pb_{0.2}Te$ doped with 5% In vs. temperature around the superconducting transition.

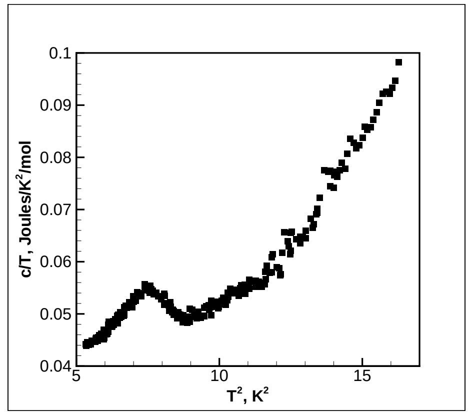

Fig. 2. Specific heat for $Sn_{0.8}Pb_{0.2}Te$ doped with 5% In, in $J/K-mole$ results, as $\frac{c}{T}$ vs. T^2, in the temperature range 2-4 K.

hours, which resulted in poly-crystals of average grain size of 200μm. The measurements of magnetic susceptibility and resistance on the sample were carried out simultaneously, whereas the measurement of the heat capacity was measured independently in a different set-up. For susceptibility we used home wound coils along with a lock-in-detector and a digitally controlled multi-function generator, with 208 Hz as excitation frequency to avoid an integer multiple of the power frequency. For resistivity, DC four-point resistance measurements were carried out using currents around 100μ A.

The heat capacity measurements were carried out using ac ($<$ 10 Hz) method [5], that is suitable for slow temperature sweep through phase transitions, and requiring a sample size $\sim 2\times3\times7$ mm^3 and about 1 g mass. The addenda consists of a gauge 40 constantan wire no longer than 3.5 in. as a heater and a ruthenium oxide bare resistor chip as the thermometer, with a total mass less than 10. mg.

3. Results and Discussion

Figure 1 shows the simultaneously measured ac magnetic susceptibility, $\chi(T)$, and resistivity, $\rho(T)$, around the transition to the superconducting state for $Sn_{0.8}Pb_{0.2}Te$ doped with 5% of In. The resistivity drops by 3 to 4 orders of magnitude in the transition region. The striking feature in Figure 1 is the slight difference of temperature at which each signal goes through its transition, the sample's temperature being one temperature. The two signals give a T_c of 2.79 K and 2.83 K for susceptibility and resistivity, respectively with the usual definitions.

Due to the constituent superconducting elements of the sample, the resistivity and susceptibility transitions cannot be conclusive of bulk superconductivity. Thus, we also report on the specific heat measurements. These are presented in Figure 2, as $\frac{c(T)}{T}$ vs. T^2, both for highlighting the anomaly between 2.75 and 2.90 K and to show that $c(T)$ has a T^3 dependence, due to lattice contribution, above the transition, with a $\theta_D\sim 85$ K that is comparable to that of major elements in this material. The T^3 dependence can be seen in the linear portion of $\frac{c(T)}{T}$ vs. T^2, in Figure 2.

Subtracting the lattice contribution from the total accentuates the specific heat jump at T_c and allows for an estimation of the electronic contribution to it. Using $\frac{\Delta c_e(T_c)}{\gamma T_C} = 1.43$ [6] yields $\gamma \sim 7.7mJ/K^2/mole$, which is higher then that obtained for Tl-doped $PbTe$ by Chernik *et. al.* [7], but this is consistent with the electron density of states at the Fermi level as deduced from measurements of H_{c_2}[4] and its temperature dependence for the two materials. It should be noted that $c(T)$ measurements in a magnetic field ($H_a\sim 1$ kG) showed no anomaly down to 2 K. Because of these facts, one can safely state that $Sn_{0.8}Pb_{0.2}Te$ doped with 5% In compound is a bulk superconductor below 2.75 K.

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