JOURNAL OF MATERIALS SCIENCE 21 (1986) 3243–3247

Transport properties of vacuum deposited tin–tellurium alloy films

I.S. ATHWAL, MEENAKSHI THAMAN, R. K. BEDI
Solid State Research Laboratory, Department of Physics, Guru Nanak Dev University, Amritsar-143005, India

The transport properties of $Sn_{1-x}Te_x$ ($0 < x < 1$) alloy films (200 nm) deposited on a glass substrate at room temperature have been studied. It has been observed that films with composition around $x = 0.6$ show minimum resistivity, maximum carrier mobility and more order in their structure. The ordered films are found to have a higher value of temperature coefficient of resistivity than the disordered ones.

1. Introduction

Tin telluride and its alloys are considered to be potential materials for their applications as infrared detectors [1], as radiation receivers [2] and in thermoelectric devices [3]. The transport properties of SnTe bulk crystals as well as epitaxial films have been reported by various workers [4–8]. They concluded that the band structure of SnTe consists of two valence bands and a conduction band. The influence of the deposition conditions of SnTe films grown on different substrates on their structural, galvanomagnetic and optical properties have also been thoroughly investigated. Ota and Zemel [9] have studied the effect of inhomogeneities on the transport properties of these films. Santhanam and Chaudhuri [10] prepared epitaxial films of SnTe on heated mica substrates and have reported their galvanomagnetic properties. Goswami and Jog [11] studied the structural properties of SnTe epitaxial films deposited on NaCl and mica substrates by an electron diffraction technique. The hot wall technique has been used by Zeleva [12] to prepare epitaxial films of SnTe on NaCl, PbS and mica substrates.

However there seem no reliable data on SnTe alloy films. In the present communication, we have reported the electrical resistivity, temperature coefficient of resistivity (t.c.r.), hall coefficient, hall mobility and their composition dependence in tin–tellurium alloy films (200 nm) deposited onto the glass substrate at room temperature.

2. Experimental details

Alloys of desired composition were prepared from high purity (99.999%) tin and tellurium obtained from the Nuclear Fuel Complex (India). Precalculated amounts were taken in evacuated quartz ampoules and heated up to 700° C for about 75 h. Tin–tellurium alloys were evaporated on to the chemically and ultrasonically cleaned glass substrate by a flash evaporation technique at a pressure of 2×10^{-6} torr. The substrate was kept at room temperature during deposition. Prior to deposition, the charge was powdered to 200 mesh and sprinkled over the hot molybdenum boat at a controlled rate using a rotating hooper and a chute to avoid accumulation of excess charge on the boat. An average rate of deposition of 15 nm sec^{-1} was maintained. The film thickness was monitored by a quartz crystal thickness monitor.

The prepared films were annealed for 3 h at 200° C at a pressure of 10^{-5} torr and then allowed to cool to room temperature. The electrical leads for measurements were connected to the films using Zn–Sn solder. The resistivity was determined by the four probe technique of van der Pauw [13] by mounting the film on a cold finger whose temperature could be varied from liquid nitrogen temperature (77 K) to 150° C. Hall coefficient and mobility were obtained using the relation $E_y = R_H B_Z J_X$ and $\mu = \sigma R_H$ where μ is carrier mobility, σ is electrical conductivity and R_H is the Hall coefficient. The actual thickness of the film was measured with a multiple beam interferometer.

3. Results and discussion

Resistivity against composition curves at various temperatures for $Sn_{1-x}Te_x$ films of 200 nm thickness are shown in Fig. 1. The resistivity has been found a complex function of composition and shows an oscillatory behaviour. The maxima and minima in the resistivity are obtained for compositions corresponding to $x = 0.2$, 0.4 and $x = 0.3$, 0.6, respectively, which may be attributed to their random and ordered structures. It means that there is a minimum in the resistivity at the compositions where an ordered arrangement of the atoms is possible. It has been observed that ordering has maximum effect at compositions around $x = 0.6$. The resistivity at this composition is found to be quite low when compared with pure elements. The periodicity of the lattice can thus be achieved to a large extent at this critical composition. It has been suggested [14] that larger value of $\varrho_{\mathrm{order}}/\varrho_{\mathrm{disorder}}$ around these critical compositions may generally be assigned to the presence of superstructures. The X-ray powder diffraction pattern for compositions $x = 0.4$ and 0.6 taken using CuKα radiation are shown in Fig. 2. The intense lines can clearly be seen for composition $x = 0.6$ indicating its more ordered structure. Similar observation was earlier

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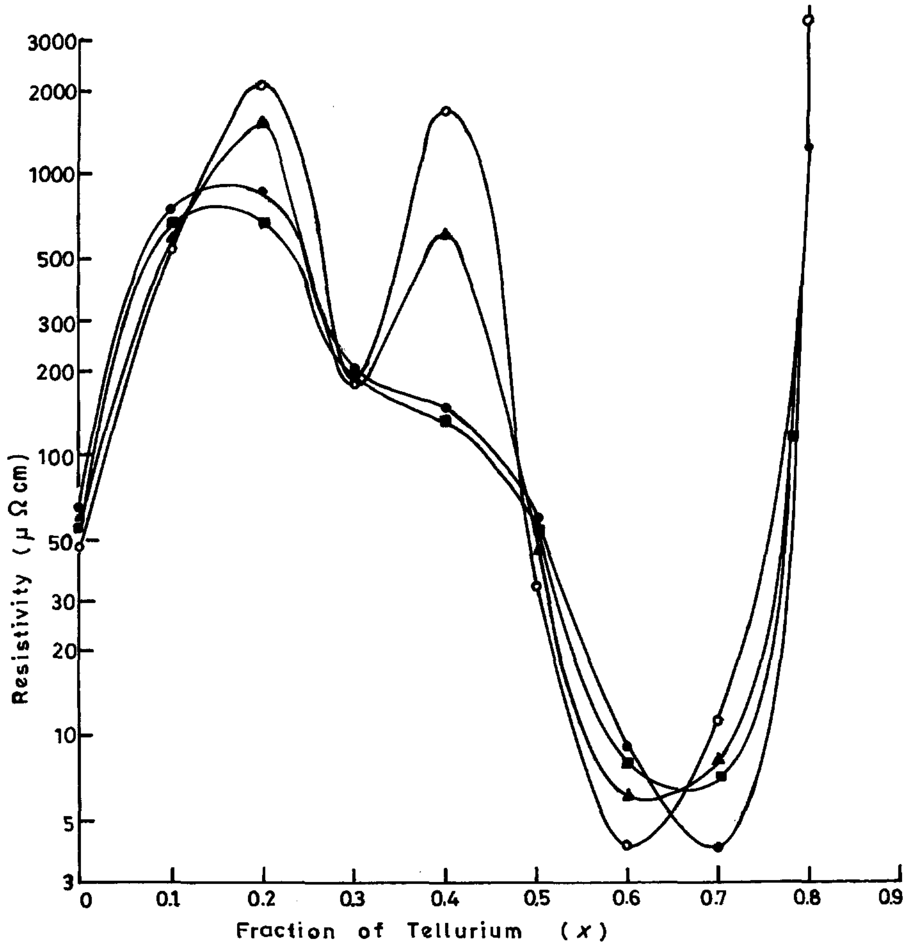

Figure 1 Composition dependence of resistivity of $Sn_{1-x}Te_x$ films at various temperatures. (○) 30° C; (■) 60° C; (▲) 90° C; (●) 120° C.

made for vacuum deposited gold copper alloy films [14].

The dependence of resistivity upon temperature is shown in Fig. 3. It appears that the resistivity for the composition $x = 0.1$ and 0.8 is proportional to absolute temperature within the experimental temperature range [15]. The decrease in resistivity of films for $x = 0.2$ and 0.4 with temperature can be very well understood by considering the activated tunnelling of charge carriers from one crystallite to another. The conductivity by tunnelling of charge carriers in metallic island films is given as [16]

$$\sigma \propto \frac{1}{r} R^2 e^2 D \exp\left(\frac{-e^2/\varepsilon R}{kT}\right) \qquad (1)$$

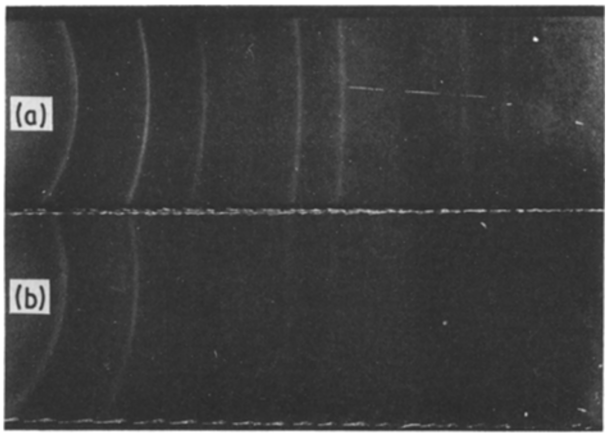

Figure 2 X-ray photographs (Debye Scherror) of $Sn_{1-x}Te_x$ films for ordered stucture for (a) $x = 0.6$ and disordered structured for (b) $x = 0.4$ of $Sn_{1-x}Te_x$ films.

where e is the electronic charge, r is the crystalline size, R is the distance between two crystallites, k is the Boltzman's constant, T is the absolute temperature, and D is the probability that an electron can tunnel from one crysallite to another.

The numerator of the exponential term corresponds to total activation energy required for a charge carrier to tunnel from one crystallite to another. Equation 1 predicts the conductivity of the film to be an exponent function of inverse absolute temperature. Fig. 4 shows inverse absolute temperature dependence of log of resistivity for Sn–Te alloy films of different composition. The activation energies obtained from the slopes of these plots are given in the Table I. The two activation energies observed for the films corresponding to compositions $x = 2$, 0.6, 0.7 and 0.8 may be attributed to two valence bands [6].

TABLE I Electronic parameters in $Sn_{1-x}Te_x$ alloy films for various alloy compositions

Fractional composition ($Sn_{1-x}Te_x$) x	Activation energy, $\times 10^{-3}$ (eV)		Carrier mobility at 30° C ($cm^2 v^{-1} sec^{-1}$)	Carrier concentration at 30° C, $\times 10^{21}$ (cm^{-3})
	First	Second		
0.1	22.0	–	2.0	5.74
0.2	120.0	200.0	3.9	0.76
0.3	8.2	–	4.7	6.99
0.4	97.0	–	1.1	3.34
0.5	26.0	–	4.7	37.90
0.6	28.0	47.0	11.3	138.00
0.7	28.0	115.0	9.6	59.20
0.8	41.0	94.0	1.0	10.40
0.9	–	–	4.2	0.41

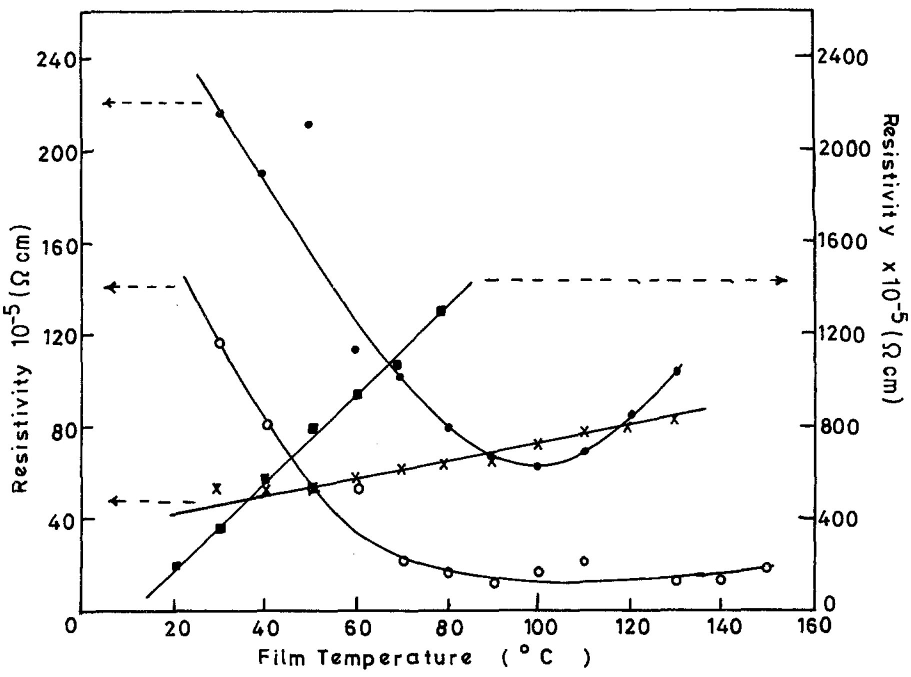

Figure 3 Dependence of resistivity upon temperature of $Sn_{1-x}Te_x$ films of various compositions. (x) $x = 0.1$; (●) $x = 0.2$; (○) $x = 0.4$; (■) $x = 0.8$.

The variation of activation energy of Sn–Te alloys with composition is shown in Fig. 5. The curves seem nearly similar in character to that of resistivity against composition (Fig. 1), which reveal the ordered and random nature of the systems. The higher value of the activation energy has been found for compositions $x = 0.2$ and 0.4 which may be due to their poor crystallinity and short ranged order in films. Also dangling bonds may be assumed to be available offering higher binding to the charge carriers resulting in higher values of activation energy. The ordered systems for compositions $x = 0.3$ and 0.6 however show its low value.

The temperature dependence of temperature coefficient of resistivity for Sn–Te alloy films with various compositions is shown in Fig. 6. It is believed that in metals the collision frequency among the free carriers increases with rise in temperature leading to a smaller mean free path and thus higher resistivity and positive t.c.r. Semiconductors on the other hand show negative t.c.r. due to an increase in the number of charge carriers with a rise in temperature. Observations reveal that the films with composition $0.7 > x > 0.17$ have

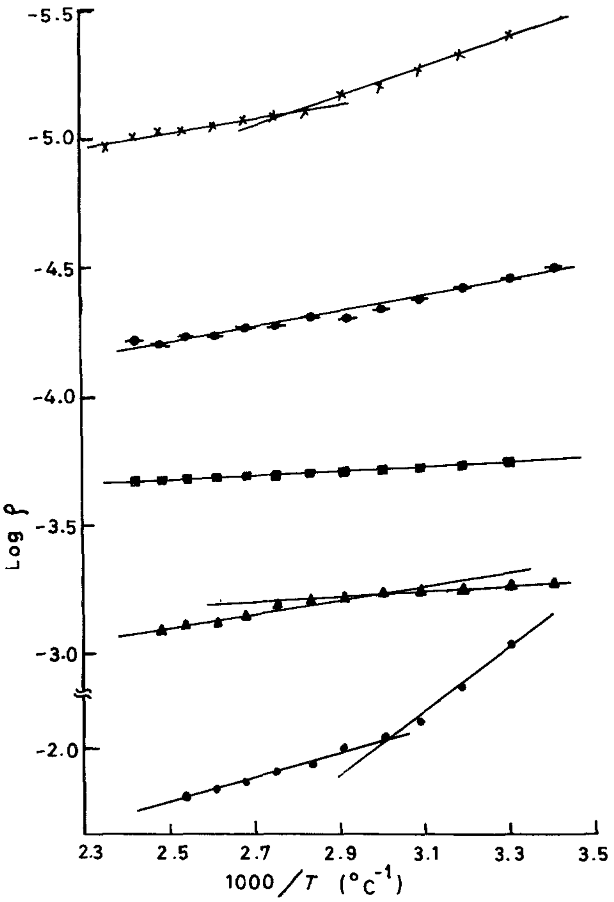

Figure 4 Log of resistivity against inverse temperature plot for some $Sn_{1-x}Te_x$ films. (▲) $x = 0.1$; (■) $x = 0.3$; (-●-) $x = 0.5$; (×) $x = 0.6$; (●) $x = 0.8$.

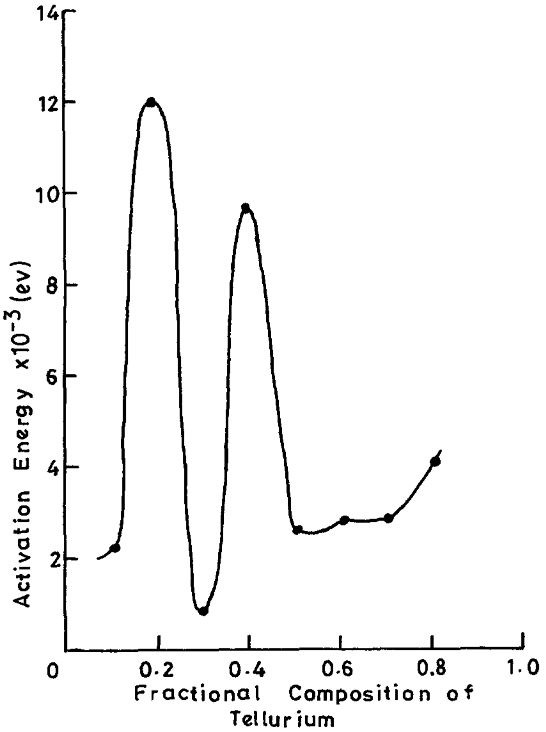

Figure 5 Dependence of first activation energy on composition of $Sn_{1-x}Te_x$ films for charge carrier to tunnel from one crystallite to another.

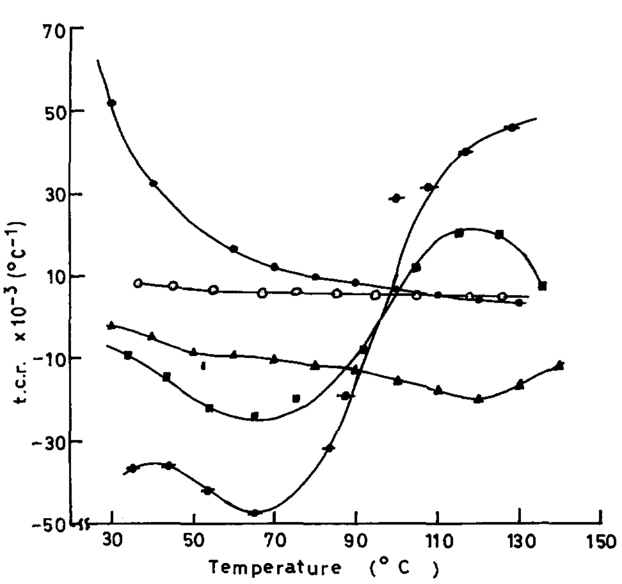

Figure 6 Temperature dependence of temperature coefficient of resistivity for various $Sn_{1-x}Te_x$ films. (○) $x = 0.1$; (■) $x = 0.2$; (-◆-) $x = 0.4$; (▲) $x = 0.7$; (●) $x = 0.8$.

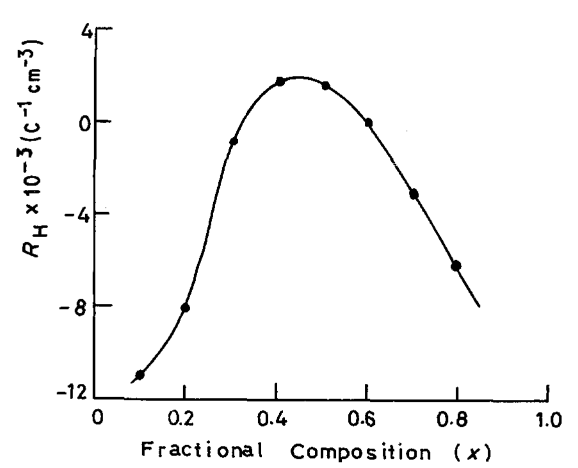

Figure 8 Variation of Hall coefficient of $Sn_{1-x}Te_x$ films with film composition at room temperature.

negative t.c.r. at room temperature, whereas films with composition x nearer to 0 and 1 show it to be positive. Fig. 7 shows the typical variation of t.c.r. with fractional composition of tellurium. It has been found that the ordered films have higher value of t.c.r. than the disordered films.

The variation of Hall coefficient of Sn–Te alloy films with composition is shown in Fig. 8. It has been observed that charge carriers are holes for composition $0.6 > x > 0.3$ whereas electrons for $0.3 > x > 0.6$. The change in the sign of charge carriers observed for films under investigation may be explained on the basis of autodoping of tin telluride with excess of tin for $x < 0.3$ and excess of tellurium for $x < 0.6$. It has been suggested [17] that p-type conductivity observed in vacuum deposited HgTe films was due to the excess of tellurium which tends to produce more strongly p-type material. The carrier concentration calculated at room temperature for various Sn–Te alloy compositions is given in Table I. The data on the change in carrier mobility with composition is also shown in Table I and plotted in Fig. 9. Observations reveal that carriers are more mobile in Sn–Te alloy films with compositions $x = 0.3$ and 0.6. It means that the ordered systems have higher carrier mobility than that of disordered ones. A similar inference has been made from resistivity plots (Fig. 1) that carriers have to suffer minimum total scattering for compositions nearer to $x = 0.3$ and 0.6.

Acknowledgements

The authors wish to thank Dr M. S. Hundal for his help in the X-ray studies and Mr Sawinder Singh (USIC) for technical assistance in this programme. One of us (I.S.A.) is grateful to the Department of Science and Technology, Government of India, for providing a Senior Research Fellowship.

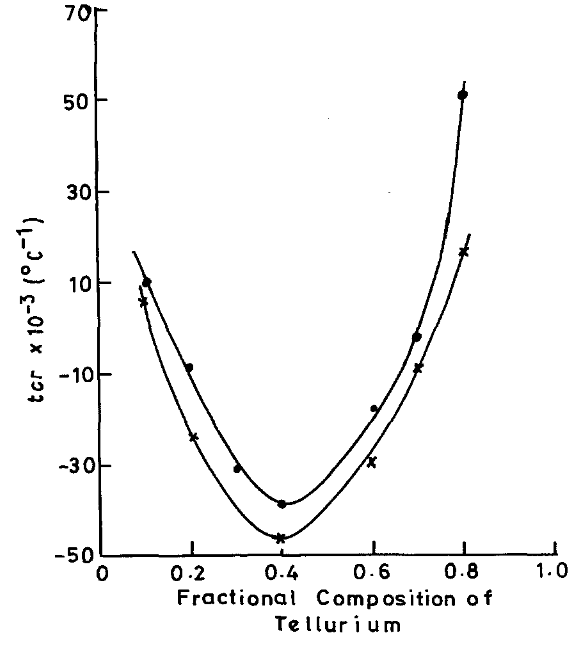

Figure 7 Composition dependence of t.c.r. at (●) 30° C and at (x) 60° C.

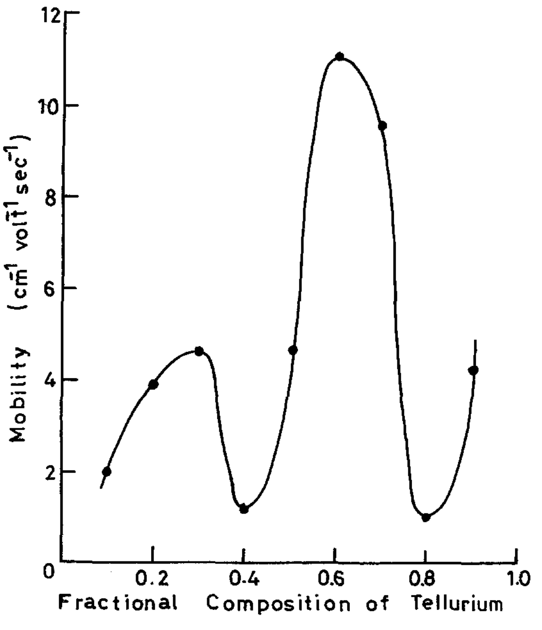

Figure 9 Dependence of carrier mobility on film composition in $Sn_{1-x}Te_x$ films.

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Received 15 July
and accepted 18 November 1985