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ELECTRICAL TRANSPORT PROPERTIES OF MANGANESE TELLURIDE

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Polycrystalline sample of manganese telluride (MnTe), has been studied by measuring their a.c. and d.c. electrical conductivities, thermoelectric power and dielectric constant in the temperature range 300-1000K. Negative sign of thermoelectric power shows the majority charge carriers are electrons. The electron mobility has been calculated by electrical conductivity and thermoelectric power data. The electrical transport mechanisms have been discussed according to data obtained using normal band model and polaron model of electrical transport.

Key Words: Electrical Transport; Polycrystalline; Manganese Telluride; Electron Mobility

Introduction

The crystal structure of MnTe is the NiAs type with lattice spacings $a = 4.12$Å and $c = 6.70$Å[1]. The magnetic susceptibility has been investigated by Squire[2] and by Serre[3]. They found that the susceptibility showed the behaviour of an antiferromagnetic compound, the Neel temperatures reported being 37°C and 55.6°C by Squire and Serre respectively. The heat capacity measurements on MnTe by Kelley[4] showed a hump in the heat capacity with its maximum at 34°C. Antiferromagnetic resonance absorption measurements for MnTe have been made by Maxwell and McGuire[5]. Squire[6] also found an anomaly in the electrical resistivity of this compound which showed a maximum around its Neel temperature (30°C). Studies on the structure and growth of MnTe films have also been carried out[7]. In the present paper, the electrical conduction mechanism of MnTe is discussed with the use of various electrical transport parameters namely, activation energy and charge carrier mobility obtained from measurements of the a.c. and d.c. electrical conductivities, thermoelectric power and dielectric constant.

Experimental Details

The material, MnTe (purity 99.99%) was procured from M/S Ventron, Alfa products, USA. Measurements have been taken on pressed pellets, made at a pressure of 6.5×10^6 gm cm^{-2}. The pellet has diameter 1.07cm and thickness 0.63cm. The pellet has been annealed at a temperature 800°C for 18 hrs before the measurements. D.C. electrical conductivity and thermoelectric power have been measured with the help of a digital multimeter (PM 2522/90 Philips, India) with an accuracy better than $\pm 0.25\%$ and $\pm 0.20\%$ for resistance

and e.m.f. measurements respectively. The dielectric constant and a.c. conductivity have been measured using an autocomputing digital LCR-Q meter (4910, Applied electronics Ltd., India) at a fixed frequency of 1kHz.

The dielectric constant of the compound has been determined at different temperatures by measuring the capacitance of the parallel plate capacitor with the pellet as the dielectric medium. The dielectric constant (ε') has been calculated using the relation[8]

$$\varepsilon' = \frac{11.3\ Ct}{A} \qquad \ldots (1)$$

where C is the capacitance in picofarad, t is the thickness of the pellet in cm and A is the surface area of the electrode in cm^2.

For the thermoelectric power measurements a temperature difference of $\Delta T \approx 20°C$ was produced across the two surfaces of the pellet. Chromel-alumel thermocouples have been used for temperature recording. The thermoelectric power (S) has been calculated using the relation

$$S = \Delta E/\Delta T \qquad \ldots (2)$$

where ΔE is the thermo e.m.f. developed across the pellet due to the temperature difference ΔT. The details regarding the sample holder assembly furnace and measuring techniques are given elsewhere[9].

Results

Variations of logarithms of a.c. and d.c. electrical conductivities ($\log \sigma_{a.c.}$ and $\log \sigma_{d.c.}$) with inverse of temperature ($10^3/T$) are shown in Fig. 1. Both curve show a positive slope below 400 K and a broad minimum near 400 K. This behaviour indicate the presence of water molecules and hydrate formation and suggests that the compound is hygroscopic. The curve for $\sigma_{d.c.}$ versus 1/T is linear in accordance with the well-known exponential relation

$$\sigma = \sigma_0(T) \exp\left(-\frac{W}{kT}\right) , \qquad \ldots (3)$$

with different slopes in the temperature range 500-750 K and 750-1000 K. In eq. (3), $\sigma_0(T)$ equals

$$\sigma_0(T) = 2e\left(\frac{2\pi kT}{h^2}\right)^{3/2} (m_e m_h)^{3/4} (\mu_e + \mu_h) \qquad \ldots (4)$$

Here $(\mu_e + \mu_h)$ varies with temperature as $T^{-3/2}$, making $\sigma_0(T)$ constant. W is the activation energy; m_e, μ_e and m_h, μ_h are effective masses and mobilities of electrons and holes, respectively and other symbols have their usual meanings. The activation energies and $\sigma_0(T)$ have been calculated from the slopes and intercepts of $\log \sigma_{d.c.}$ *versus* $10^3/T$ plot, respectively. The electrical transport parameters, activation energy (W), $\sigma_0(T)$ and charge carrier mobility in differ-

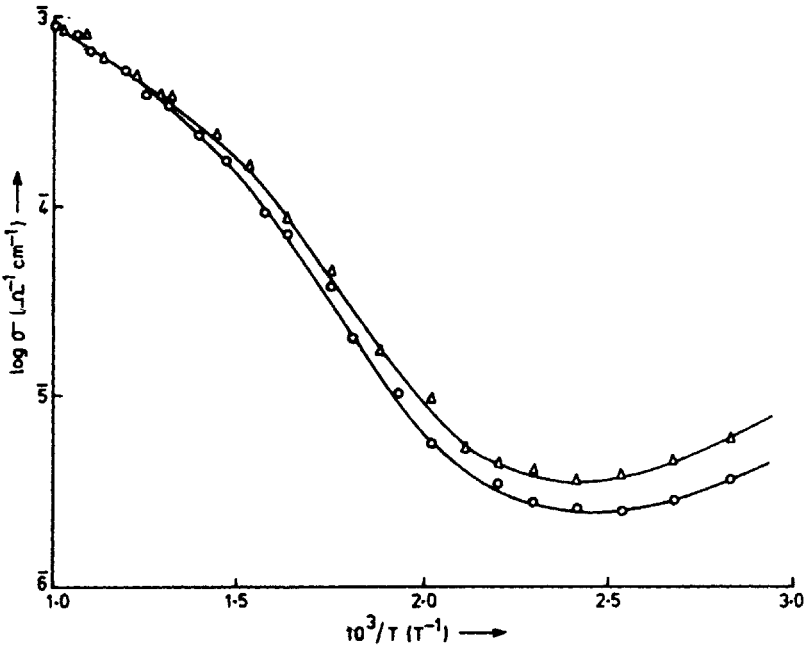

Fig 1 Variation of the logarithm of the a.c. (Δ) and d.c. (○) electrical conductivities with reciprocal of absolute temperature ($10^3/T$).

ent temperature region, have been tabulated in Table I. In the temperature range 300-750 K, a.c. conductivity is slightly higher than d.c. conductivity but above $T \sim 750$ K, the two conductivities become almost equal.

Table I

Electrical transport parameters of MnTe

Electrical Transport Parameters	Temperature range 300-750 K	Temperature range 750-1000 K
Activation energy (W)	0.58 eV	0.26 eV
$\sigma_0(T)$	3.71 ohm^{-1} cm^{-1}	1.8×10^{-2} ohm^{-1} cm^{-1}
Charge carrier mobility (μ)	5.41 cm^2/V-sec.	4.41×10^{-5} cm^2/V-sec.

The plot of S *versus* $10^3/T$ is shown in Fig. 2. Positive value of S over the entire temperature range, indicates that MnTe is a p-type semiconductor. It is observed that S first decreases slowly upto 750 K and then starts decreasing rapidly above this temperature. According to band model, the variation of S with temperature is given by the equation

$$S = \frac{\eta}{T} + K, \qquad \ldots (5)$$

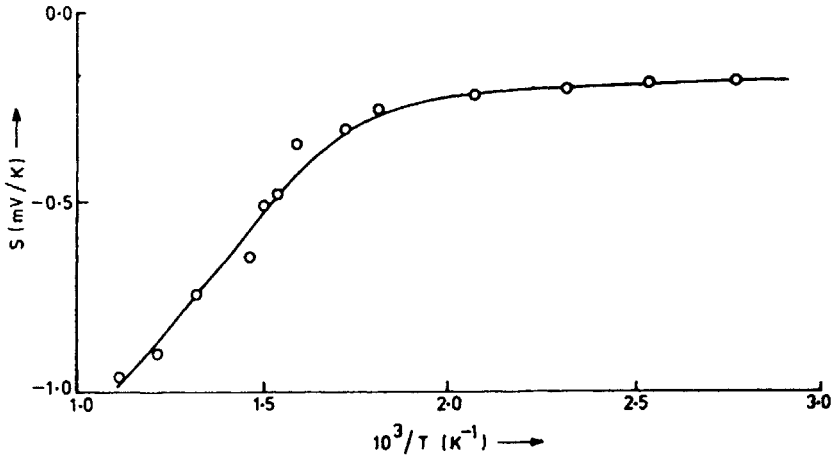

Fig 2 Variation of thermoelectric power (S) with reciprocal of absolute temperature ($10^3/T$).

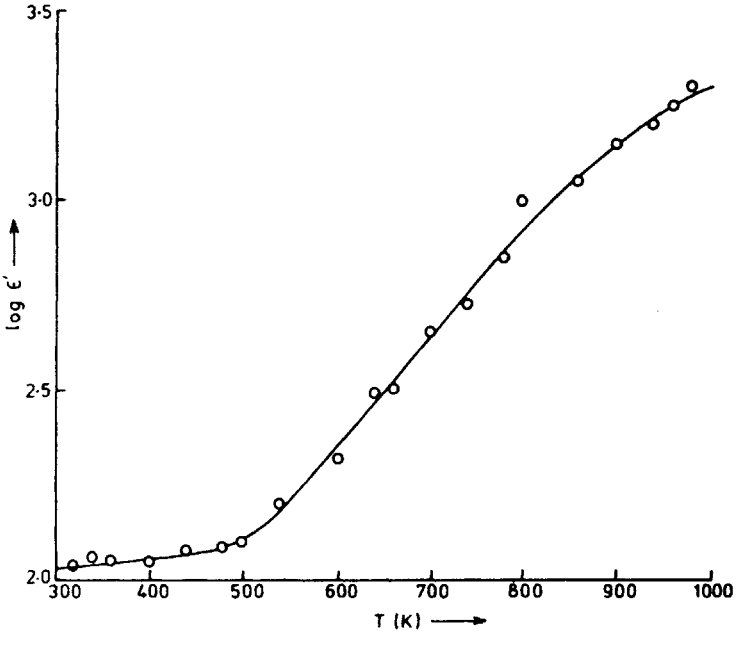

Fig 3 Variation of dielectric constant (ε') with absolute temperature (T).

where $$\eta = \frac{E_g}{2e}\left(\frac{c-1}{c+1}\right), \qquad \ldots (6)$$

$$K = -\left[\frac{2k}{e}\left(\frac{c-1}{c+1}\right) + \frac{3k}{4e}\log_e(a)\right] \qquad \ldots (7)$$

and

$$c = \frac{\mu_e}{\mu_h} \quad \text{and} \quad a = \frac{m_e}{m_h}$$

Here E_g is the energy band gap and the other symbols have their usual meanings. From the slope and intercept of S *versus* $10^3/T$ in Fig. 2 and using (5), η and K have been determined. By use of (6) and (7) we have calculated the values of (c) and (a) and alongwith $\sigma_0(T)$ given by (4), the values of hole mobilities has been deduced in different temperature range.

Fig. 3 shows the variation of log ε' with T. The dielectric constant increases with increase in temperature.

Discussion

The activation energy (E_a) estimated from the log $\sigma - (1/T)$ curve in the temperature range 300-750 K is about 0.58 eV, which is too small for intrinsic conduction. The activation energy reported for MnO by Ali *et al.*[10] is about 1.3 eV and by Crevecoeur and de Wit[11] about 0.90 eV. Moreover, the energy band gap determined from energy band calculation, is reported by Ksendrov as 4.7 eV[12] where the wide 2p band is separated from the low lying 3d-band by a band gap of about 2.5 eV at the Brillouin zone. Our estimated energy band gaps are 1.16 eV and 0.52 eV below and above 750 K respectively. These values of E_g are very low in comparison to the values reported by other workers and therefore cannot be assigned as a real energy band gap for this compound. It is more likely to be the energy required to excite an electron from the 3d-valence band to the empty 3d-band. The lower value of mobility (about 5.41 $cm^2\ V^{-1}\ sec^{-1}$) obtained by combining the electrical conductivity and thermoelectric data indicates the formation of some kinds of polarons[13] in this temperature range. This seems quite reasonable because the presence of narrow 3d bands may lessen the activation energy to some extent. The activation energy is reduced to an amount equal to the polaron binding energy since such polarons conduct according to the relation

$$\sigma = \sigma_0 \exp\left(\frac{E_g + h w_0}{kT}\right), \qquad \ldots (8)$$

where hw_0 is the polaron binding energy. Therefore, the actual activation energy will be less than the estimated values. The drop in activation energy above 750 K, appears due to change in the conduction mechanism. It is argued that the polarons of large or intermediate mobility change into small polarons. Low mobility polarons correspond to thermally activated hopping of localized small polarons[14]. The low mobility polarons become almost stable and do not contribute considerably to the electrical conduction and this is in agreement with the theory given by Toyozawa[15]. This results in a decrease in the activation energy.

The a.c. and d.c. electrical conductivities are almost equal in the temperature range 750-1000 K, which implies that the electrical conductivity is inde-

pendent of frequency and is entirely electronic, i.e., ionic contribution to the conductivity is negligible. This shows that the charge carriers above 750 K, a.c. conductivity is larger than d.c. conductivity. This suggests that some impurities are present in the compound due to which dielectric loss occurs, resulting in an increase in a.c. conductivity.

Dielectric constant increases slowly below 750 K. This is due to the ionic nature of the compound. The increase in dielectric constant is attributed to the presence of impurities, defects etc. which leads to space charge polarisation and dielectric loss. In the temperature region 750-1000K, the nature of thermally generated charge carriers increases exponentially, giving rise to space charge polarization. This increase in polarizability increases the dielectric constant of the material.

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