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EFFECT OF THE ELECTRIC FIELD ON THE D.C. CONDUCTIVITY OF BULK GLASSY $Te_{50}As_{50-x}S_x$ ALLOYS

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ABSTRACT

The d.c. electrical resistance has been measured as a function of temperature and electric field in bulk amorphous $Te_{50}As_{50-x}S_x$. It is found that the contribution of the conductivity activation process is due to conduction in the extended states and hopping in the localized states. It is also found that the electric field effect increases the conductivity and the activation energy.

INTRODUCTION

The effect of a high electric field on the conduction mechanism is of great interest in a-semiconductors because the heating effect is small due to the presence of localized states. In non-crystalline solids a close relationship exists between the mobility and the density of states. If the number of allowed states per unit volume is low, tunnelling between them is less likely. This implies localized states and low mobility. For amorphous chalcogenides, it is assumed that localized states form conduction and valence band tails [1], which may overlap. Electric field measurements on chalcogenide alloys have been made on thin films [2–6] and the results have been explained in terms of the Poole–Frenkel effect [7] or by thermal emission of screened coulombic carriers [6]. The chalcogenide glasses and amorphous Se show a non-ohmic mobility which extends to very low fields [8].

The aim of the present work is to investigate the effect of electric field and sulphur content on the d.c. conductivity and activation energy of bulk a-$Te_{50}As_{50-x}S_x$.

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EXPERIMENTAL

Amorphous samples of $Te_{50}As_{50-x}S_x$ (where $x = 0$, 11, 16 and 21 at.%) were prepared from the melt by the quenching technique which is described in our earlier paper [9]. The materials were sealed in evacuated (10^{-5} Torr) quartz ampoules. The ampoules were heated to 1100 °C and held at that temperature for 10 h with continuous agitation during heating to ensure complete mixing. The molten samples were then rapidly quenched in ice-water. X-ray examination of the samples indicated a complete absence of sharp peaks.

The I–V characteristic and the electrical resistance were measured on thin flake-shaped samples with the help of Keithley 610C electrometers and a fully automatic furnace. Two different pin electrodes (tungsten and stainless steel) were used. The observations were taken in the temperature range 300–400 K. The temperature was measured by a digital thermometer (Omega 2168 A).

RESULTS

Figure 1 shows the I–V characteristics of $Te_{50}As_{50-x}S_x$ at room temperature. The temperature dependence of the resistance at constant field in the

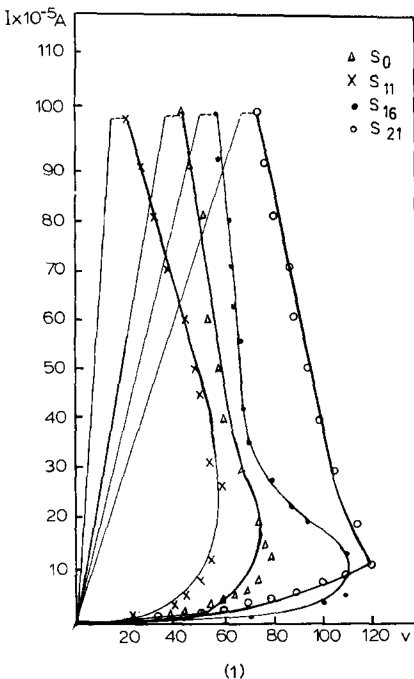

Fig. 1. I–V characteristic of $Te_{50}As_{34}S_{16}$ at room temperature.

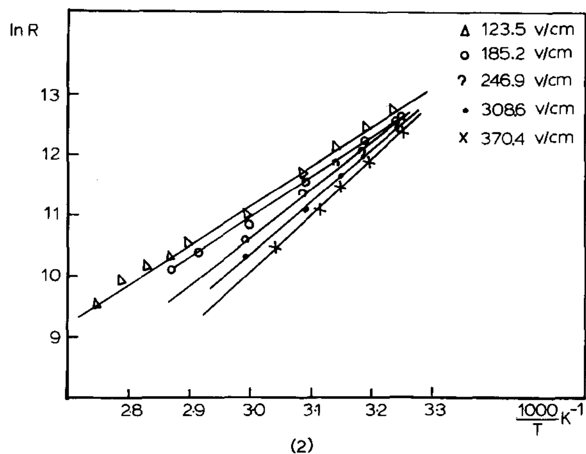

Fig. 2. ln R against $1/T$ of $Te_{50}As_{34}S_{16}$ at different constant electric fields.

ohmic and non-ohmic region is shown in Fig. 2. It is plotted in the form ln R against $1/T$. A straight-line behaviour is observed. A decrease in the resistance with increase in the electric field is observed for the samples,

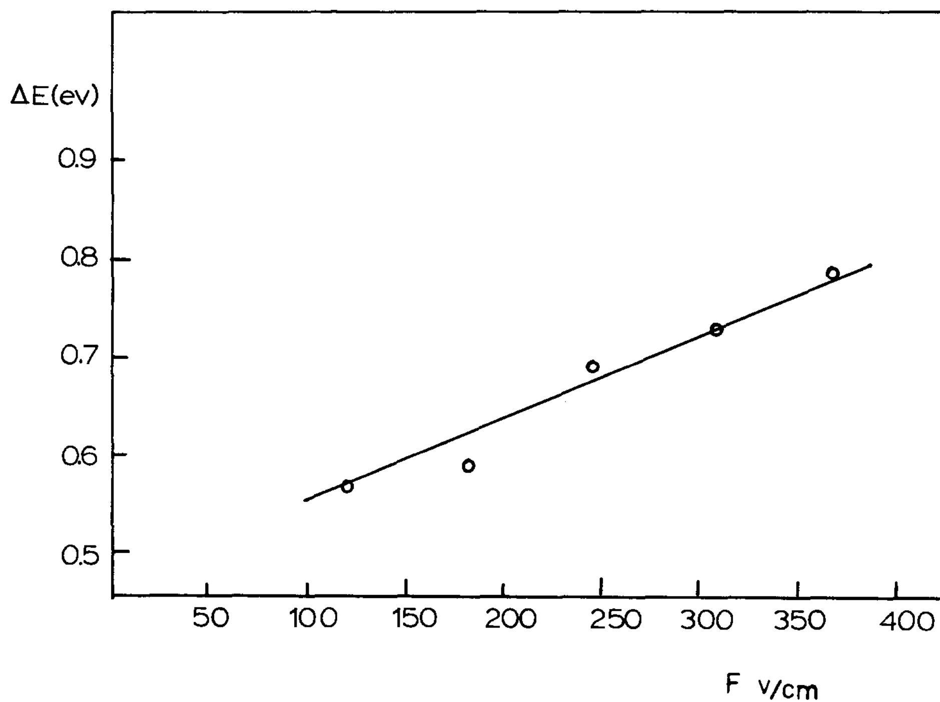

Fig. 3. The variation of ΔE with the electric field for $Te_{50}As_{34}S_{16}$.

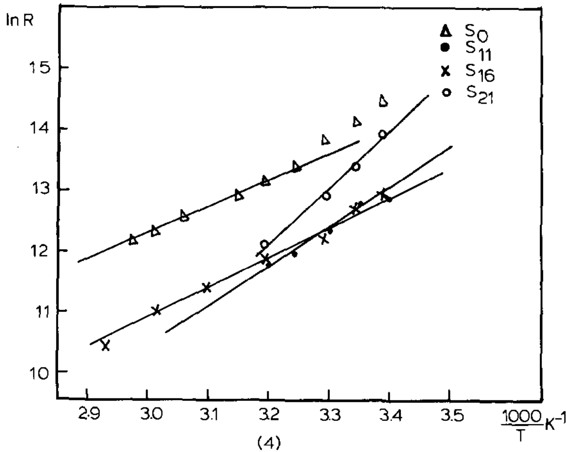

Fig. 4. ln R against $1/T$ for $Te_{50}As_{50-x}S_x$ at the same electric field.

which exhibit an activated temperature dependence of the form

$$R = r_0 \exp(\Delta E/KT) \tag{1}$$

with a single activation energy ΔE.

The variation of ΔE with the electric field F for the bulk sample is shown in Fig. 3. It is noticed that there is an increase in ΔE with an increase in F. Figure 4 shows the variation of the d.c. resistance with temperature for the $Te_{50}As_{50-x}S_x$ system at constant electric field. The variation in the activation energy ΔE with the S content is shown in Fig. 5.

Measurements of the current dependence on the applied field were carried out for $Te_{50}As_{34}S_{16}$. On plotting $\log I$ against $F^{1/2}$, a straight line is obtained over the entire range of the applied electric field, see Fig. 6. The slope of the line is consistent with a current field dependence of the form

$$I \propto \exp \beta F^{1/2}/KT \tag{2}$$

At first sight this could be interpreted as Poole–Frenkel emission with

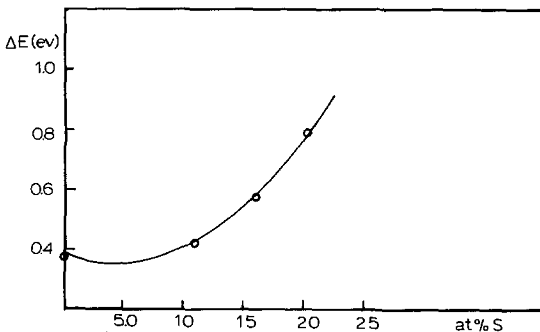

Fig. 5. The variation of ΔE with sulphur content.

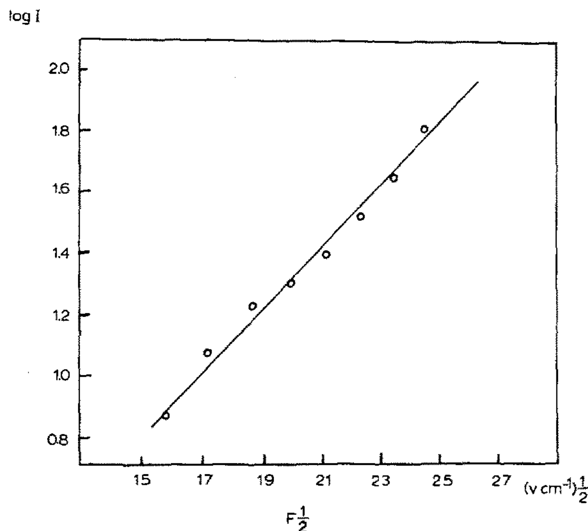

Fig. 6. log I against $F^{1/2}$ for $Te_{50}As_{34}S_{16}$.

$\beta = 2(e^3/4\pi\epsilon\epsilon_0)$, where ϵ the dielectric constant and ϵ_0 is the vacuum permittivity. This kind of result is common in amorphous materials [10].

DISCUSSION

The increase in conductivity due to the electric field could be attributed to one or more of the following effects.

(a) The emission of carriers from coulombic centres, because of the lowering of barriers with the application of electric field (i.e. Poole–Frenkel or Poole effects [7,11];

(b) The contact induced effect (space charge limited current);

(c) The thermal effect due to Joule heating.

Because the observed data could be fitted to log I versus $F^{1/2}$, the Poole–Frenkel effect can be considered in the present case. The independence of conductivity on the electrode materials and the high resistance of the samples rules out (b) and (c).

It is possible to see a well-defined Poole–Frenkel emisson which results from a field-assisted thermal ionization of carriers from traps, considering them to be charged when they are not occupied and neutral when filled. A coulomb interaction between the trap and the carrier was also taken into account. On the application of an electric field, the coulomb potential of the trap and the level of conduction band are perturbed in such a way that the potential barrier is lowered. In physical terms $\beta F^{1/2}$ is the decrease in ionization energy of a single coulombic potential well in the direction of an applied field. If the current from normal free carriers is less than that from

the ionizable centres, then the observed current will be generated by ionization of the centres. This effect controls the log I–$F^{1/2}$ characteristic of the semiconductors.

The increase in the activation energy with electric field can be understood by assuming that the contribution of the conductivity activation process is due to conduction in the extended states and hopping in the localized states. The effective activation energy of the system increases, in spite of the fact that the activation energy of the extended state conduction may remain constant [12].

Pai and Ing [13] found that at high fields the number of mobile holes depends on the field as exp γ $F^{1/2}$. They interpreted their results as being due to a Frenkel mechanism.

As can be seen from Fig. 4, the increase in the activation energy with the sulphur content (at.%) could be attributed to the following causes.

(a) As the sulphur concentration increases, the number of S–S bonds increases while the number of As–As bonds decreases, and also the average bond energy of S–S is more than the average bond energy of As–As [14], so that the activation energy of the system increases.

(b) The increase in randomness in the amorphous structure due to the increase in the sulphur content.

In the non-ohmic region, a fit with eqn. (2) is shown in Fig. 6. Therefore, we can consider the possible causes of the non-ohmic behaviour of such chalcogenide systems as being caused by the following effects.

(1) The direct influence of the electric field upon the hopping rate.

(2) The field-induced redistribution of electrons over the localized levels; this effect is referred to as the heating of localized levels [15].

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