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A comparative study of the density of defect states in bulk samples and thin films of glassy $Se_{90}Sb_{10}$

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Abstract. The present paper reports the comparative study of density of defect states (DOS) between bulk samples and thin films of glassy $Se_{90}Sb_{10}$. These glasses have been prepared by the quenching technique. Thin films of these glasses have been prepared by vacuum evaporation technique. Space-charge-limited conduction (SCLC) has been measured at different temperatures. The density of localized states near Fermi level is calculated by fitting the data to the theory of SCLC for the case of uniform distribution of localized states for bulk as well as for thin films. A comparison has been made between the density of states calculated in these two cases.

Keywords. Chalcogenide glasses; localized states; space-charge-limited conduction; density of defect states.

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1. Introduction

Numerous potential applications of chalcogenide glasses are proposed in the civil, medical and military areas [1–6]. It is possible to produce electrical switches, xerographic and thermoplastic media, photoresistant and holographic media, optical filters, optical sensors, thin films, waveguides, non-linear elements, etc. [1–6]. It has been found that Se-based alloys are more useful compared to pure Se, due to their greater hardness, high photosensitivity, higher crystallization temperature and smaller aging effect compared to pure a-Se [7].

The transport mechanism of charge carriers in amorphous semiconductors has been the subject of intensive theoretical and experimental investigations for the last few decades. These studies have been stimulated by the attractive possibilities of using the structure disorder in amorphous semiconductors for the development of better, cheaper and more reliable solid-state devices [8,9].

A study of the electrical conduction of any medium gives us an insight into the transport mechanism of the prevailing charge carriers. In low-field conduction, the mobility and free carrier concentration are assumed to be constant with the field. However, application of a high field to a free carrier system may influence both the mobility and the number of charge carriers.

High field effects are most readily observed in materials with a small number of equilibrium carriers, because heating effects are kept reasonably small. For the same reason, the study of high field effects is particularly favoured in low-conductivity solids, e.g., amorphous semiconductors. High field effects have been studied in amorphous semiconductors by various workers [10–14]. However, more work is required in this direction.

In our previous work [15], the density of defect states has been calculated in glassy $Se_{100-x}Bi_x$ system in bulk as well as in thin films using SCLC measurements. A comparison of these results showed that the density of defect states was two orders of magnitude higher in bulk compared to thin film of the same composition. It is interesting to see whether this type of variation does exist in other binary alloys or not.

The present paper reports the comparative study of density of defect states (DOS) between bulk samples and thin films of glassy $Se_{90}Sb_{10}$. The density of localized states near Fermi level is calculated by fitting the data to the theory of SCLC for the case of uniform distribution of localized states. The results show that the density of defect states for thin films is one order of magnitude higher than that for bulk samples, for the present alloy.

2. Experimental

2.1 *Preparation of materials*

Glassy alloy of $Se_{90}Sb_{10}$ is prepared by the quenching technique. High purity 5 N materials are sealed in quartz ampoules (length ∼5 cm and internal diameter ∼8 mm) with a vacuum of $\sim 10^{-5}$ Torr. The ampoule containing the material is held at 800°C for 10–12 h, where the ampoule is constantly rocked to make the melt homogeneous. The melt is cooled rapidly by removing the ampoule from the furnace and dropping it to ice-cooled water.

2.2 *Preparation of pellets and thin films*

The glassy alloys of $Se_{90}Sb_{10}$ thus prepared are ground to a very fine powder and pellets (diameter ∼12 mm and thickness ∼0.5 mm) are obtained by compressing the powder in a die at a load of 10 tons. Thin films of the same glassy alloy are prepared by vacuum evaporation technique keeping glass substrate at room temperature in coating unit (IBP-TORR, Type EPR-002). Vacuum-evaporated indium electrodes at the bottom are used for the electrical contact. The thickness of the film is ∼500 nm. The coplanar structure (length ∼1.2 cm and electrode separation ∼0.44 mm) was used for the present measurements (see figure 1). A vacuum ($\sim 10^{-5}$ Torr) was maintained in the entire temperature range (200–460 K).

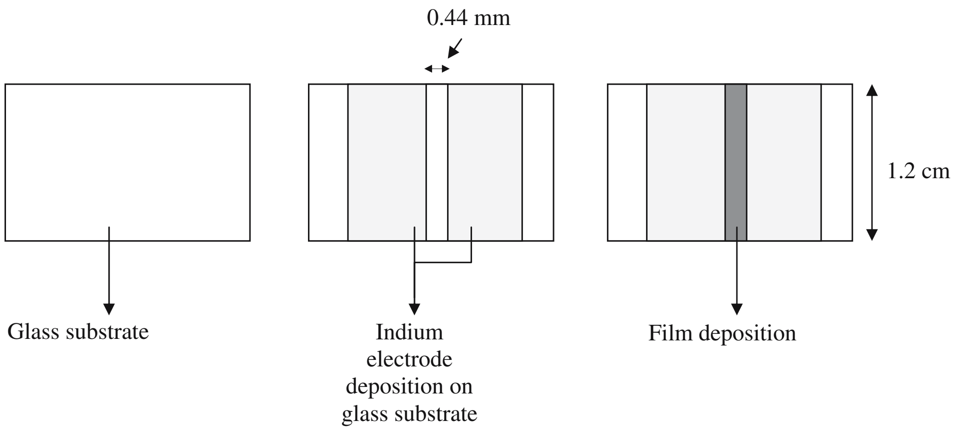

Figure 1. Coplanar structure of thin film.

2.3 *SCLC measurement procedure*

For the measurement of SCLC, the pellet is mounted in between two steel electrodes of a metallic sample holder. A DC voltage (0–400 V) is applied across the sample to measure I–V characteristics. The resulting current is measured by a digital Pico-Ammeter (Model: DPM-111). The temperature of the pellet is controlled by mounting a heater outside the sample holder and measured by a calibrated copper–constantan thermocouple mounted very near to the pellet. A vacuum of about 10^{-2} Torr is maintained during measurements.

The thin film samples are mounted in a specially designed metallic sample holder. A vacuum ($\sim 10^{-2}$ Torr) is maintained throughout the measurements. Temperature of the film is controlled by mounting a heater inside the sample holder, and measured by a calibrated copper–constantan thermocouple mounted very near to the film. A DC voltage (0–440 V) is applied across the sample to measure I–V characteristics. The resulting current is measured by a digital Pico-Ammeter (Model: DPM-111). I–V characteristics are reported at various fixed temperatures. The heating rate is kept quite small (0.5 K/min) for these measurements.

3. Results and discussions

3.1 *High field conduction measurements*

In the present work I–V characteristics of thin films and pellets of a-$Se_{90}Sb_{10}$ are examined at various temperatures as plotted in figures 2 and 3. Results of I–V characteristics at different temperatures show that in the glassy sample studied here, ohmic behaviour is observed at low electric fields ($E < 10^3$ V/cm). However, at high electric fields ($E \sim 10^4$ V/cm), a superohmic behaviour is observed in both thin films and pellets. Here, ln I/V vs. V curves are found to be straight lines. Figure 4 shows such curves in the case of $Se_{90}Sb_{10}$ glassy alloy and figure 5 in the case of $Se_{90}Sb_{10}$ thin film. It is clear from these figures that the slopes S of ln I/V vs. V curves are temperature-dependent. At low voltage, the injected charge carrier density is lower than the thermally generated carrier density leading to the ohmic behaviour. At higher voltage it may be suggested that the conduction in this region is dominated by a trap-limited SCLC mechanism. According to the theory of SCLC, in the case of a uniform distribution of localized states having density g_0, the current (I) at a particular voltage (V) is given by [16]

$$I = (2eA\mu n_0 V/d)[\exp(SV)]. \quad (1)$$

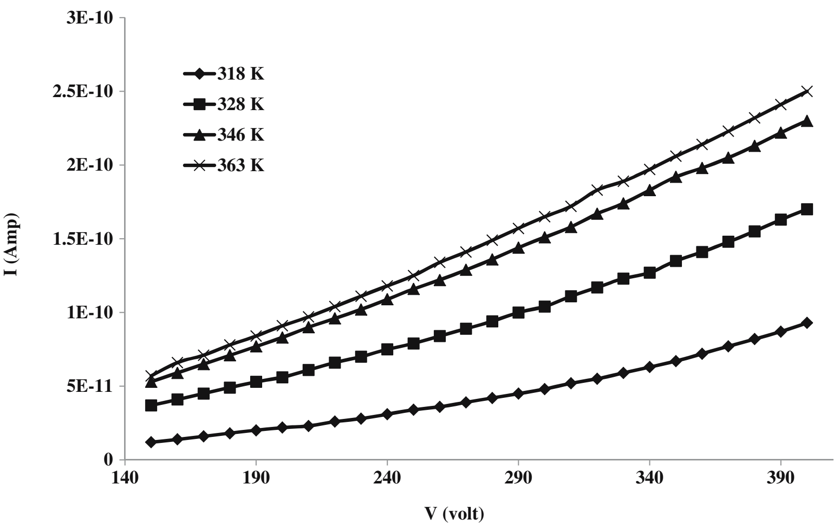

Figure 2. I–V characteristics for glassy $Se_{90}Sb_{10}$ pellets at different temperatures.

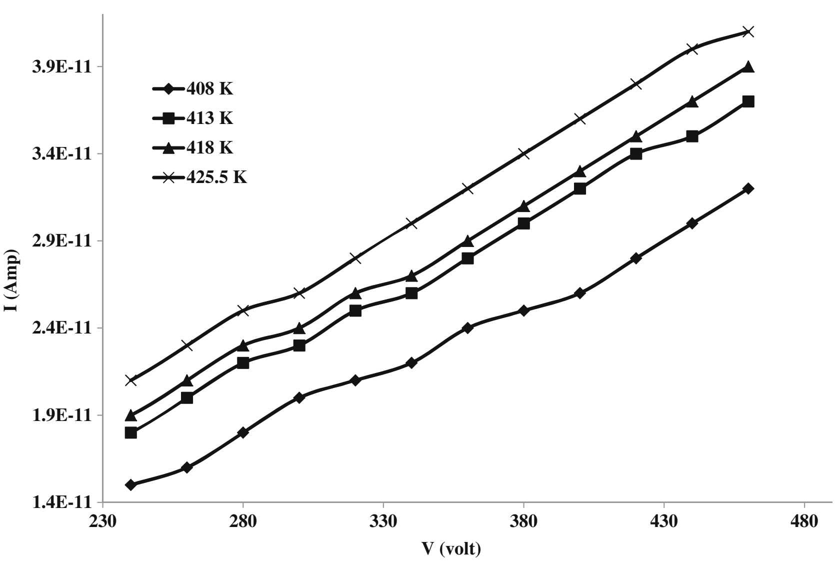

Figure 3. I–V characteristics for glassy $Se_{90}Sb_{10}$ thin films at different temperatures.

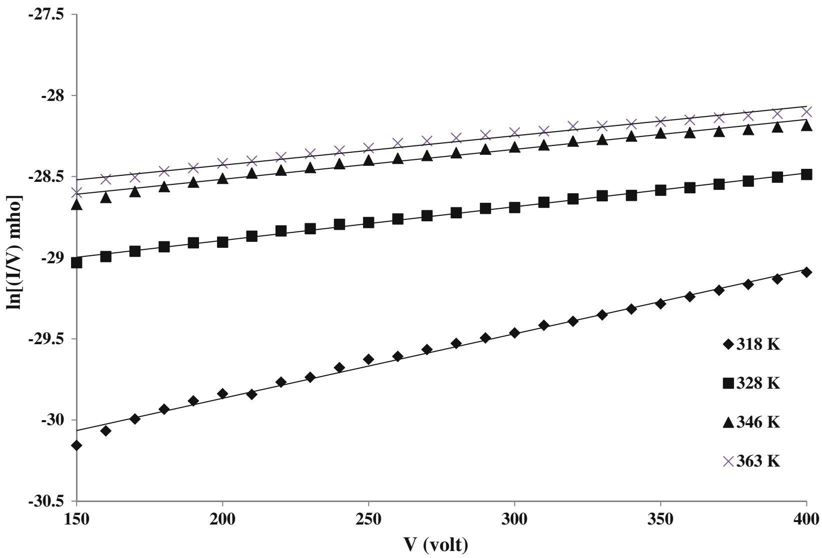

Figure 4. Plot of ln I/V vs. V for glassy $Se_{90}Sb_{10}$ pellets at different temperatures.

Here, e is the electronic charge, A is the cross-sectional area of the film, n_0 is the density of free charge carriers, d is the electrode spacing and S is given by

$$S = 2\varepsilon_r\varepsilon_0/eg_0kTd^2, \tag{2}$$

where ε_r is the static value of the dielectric constant, ε_0 is the permittivity of free space, g_0 is the density of traps near the Fermi level and k is the Boltzmann's constant.

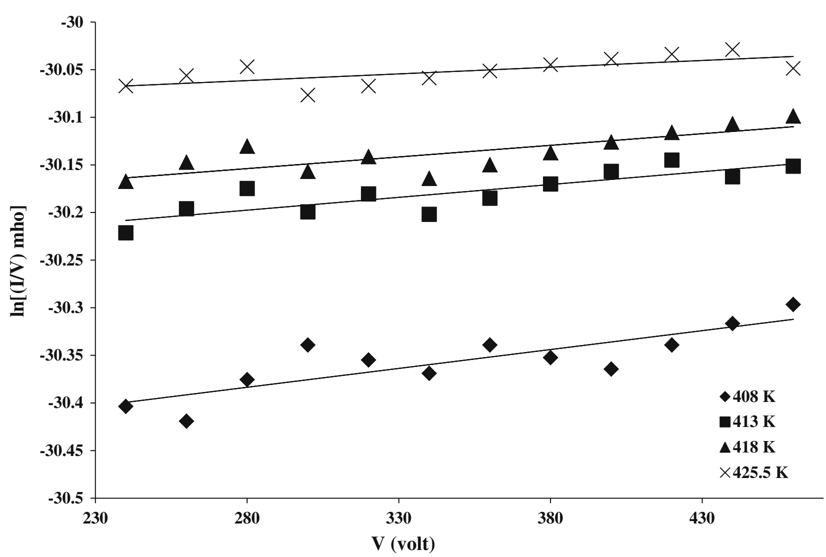

Figure 5. Plot of ln I/V vs. V for glassy $Se_{90}Sb_{10}$ thin films at different temperatures.

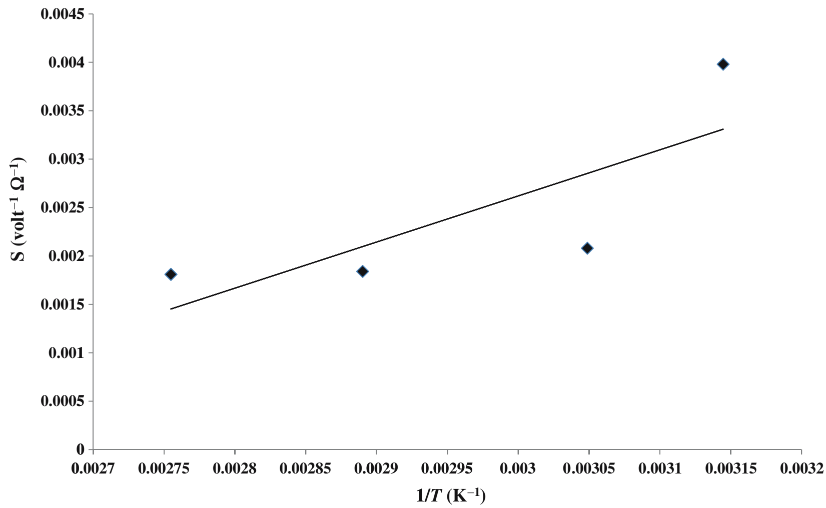

Figure 6. Plot of S vs. $1/T$ for glassy $Se_{90}Sb_{10}$ pellets.

According to eqs (1) and (2), for SCLC, ln I/V vs. V curves should be straight lines, the slopes S of which should decrease with increase in temperature. The values of these slopes are plotted as a function of temperature in figures 6 and 7 for the pellets and thin films of $Se_{90}Sb_{10}$ glassy system. It is clear from the figure that the slope S of ln I/V vs. V curves is inversely proportional to the temperature of the sample. These results indicate the presence of SCLC in the present samples.

Thin films contain a large number of defects due to dangling bonds that give rise to a large number of localized defect states. These localized states act as carrier trapping centers and after trapping the injected charge from electrodes, they become charged, thereby

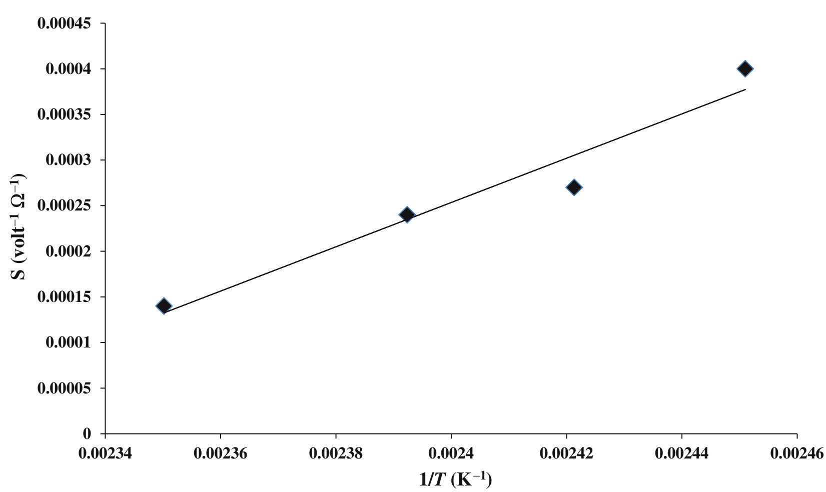

Figure 7. Plot of S vs. $1/T$ for glassy $Se_{90}Sb_{10}$ thin films.

Table 1. Values of slope S vs. $(1/T)$ curves and density of defect states g_0 for $Se_{90}Sb_{10}$ glassy pellets and thin films.

Samples	Slope S vs. $(1/T)$ curves	Density of defect states g_0 (eV^{-1} cm^{-3})
$Se_{90}Sb_{10}$ pellets	4.76	4.78×10^{13}
$Se_{90}Sb_{10}$ thin films	2.43	1.91×10^{14}

expected to build up a space charge. This build up of space charge then plays the key role in the determination of SCLC process.

Using eq. (2), we have calculated the density of localized states from the slopes of figures 6 and 7. The value of the relative dielectric constant ε_r is taken to be 70 which is the measured dielectric constant value of glassy $Se_{90}Sb_{10}$.The results of these calculations are given in table 1.

4. Conclusions

I–V characteristics of glassy $Se_{90}Sb_{10}$ have been studied in bulk as well as in thin films. At low fields (10^2 V/cm), an ohmic behaviour is observed. However, at high fields (10^3–10^4 V/cm), a superohmic behaviour is observed, in both the cases.

The density of defect states has been obtained by fitting high field data to the theory of SCLC in case of uniform distribution of traps. The results indicate that the defect density in thin films is almost one order of magnitude higher than in bulk samples.

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