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# HIGH FIELD CONDUCTION IN AMORPHOUS $Se_{70}Te_{30-x}Zn_x$ THIN FILMS

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The present paper reports the d. c. conductivity measurements at high electric fields in vacuum evaporated thin films of amorphous $Se_{70}Te_{30-x}Zn_x$. Current - voltage (I-V) characteristics have been measured at various fixed temperatures. In all the samples, at low electric fields, ohmic behavior is observed. However, at high electric fields, non ohmic behavior is observed. The experimental data fits well with the theory of space charge limited conduction (SCLC) in the high electric field region. From the fitting of the data, the density of defect states near Fermi level is calculated. Composition dependence of DOS is discussed in the paper.

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## 1. Introduction

The chalcogenide glassy semiconductors are some of the widely used amorphous semiconductors for a variety of applications in optics, electronics and optoelectronics, such as ultra fast optical sensors, holography, infrared lenses, ionic sensors etc. These glasses generally exhibit p- type electrical conduction due to the pinning of the Fermi level arising from the trapping of the charge carriers at localized gap states [1 - 2]. The transport mechanism of charge carriers in amorphous semiconductors has been a subject of intensive theoretical and experimental investigations for the last few years. 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 [3 - 4].

Due to their low conductivity, amorphous semiconductors are most suitable for high field conduction studies, as joule heating is negligibly small in these materials at moderate temperatures. Some such studies have already been reported in chalcogenide glassy semiconductors [5 – 15]. However, the results have been explained by considering different mechanisms by different workers. More experimental work is required to understand high field conduction in chalcogenide glasses.

The present paper reports the high field conduction measurements in glassy system Se –Te - Zn, where the properties have been found to be highly composition dependent. The experimental data fits well with the theory of space charge limited conduction (SCLC) in the high electric field region. From the fitting of the data, the density of defect states (DOS) near Fermi level is calculated. Composition dependence of DOS is also discussed in the present paper.

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## 2. Experimental

Glassy alloys of $Se_{70}Te_{30-x}Zn_x$ (x = 2, 4, 6, 8) are prepared by quenching technique. High purity (99.999 %) materials are weighed according to their atomic percentages and are sealed in quartz ampoules (length ~ 5 cm and internal diameter ~8 mm) with a vacuum ~ $10^{-5}$ Torr. The ampoules containing the materials are heated to 800 $^0$C and held at that temperature. The temperature of the furnace is raised slowly at a rate ~ 3 – 4 $^0$C/min. During heating, all the ampoules are constantly rocked, by rotating a ceramic rod to which the ampoules are tucked away in the furnace. This is done to obtain homogenous glassy alloys.

After rocking for about 10 hours, the obtained melts are cooled rapidly by removing the ampoules from the furnace and dropping to ice-cooled water. The quenched samples are taken out by breaking the quartz ampoules.

Thin films of these glasses are prepared by vacuum evaporation technique keeping glass substrates at room temperature. Vacuum evaporated indium electrodes at bottom are used for the electrical contact. The thickness of the films is ~ 500 nm. A planar geometry of the amorphous films (length ~ 1.3 cm, electrode gap ~ 0.12 mm) is used for the electrical measurements.

For the measurements of high field conduction, thin film samples were mounted in a specially designed sample holder where the vacuum ~$10^{-2}$ Torr is maintained throughout the measurements. A d. c. voltage (0 to 400 V) was applied across the sample and resultant current was measured by digital pico-ammeter. I – V characteristics were measured at various fixed temperatures in these films. The temperature of the films was controlled by mounting a heater inside the sample holder and measured by a calibrated copper- constantan thermocouple mounted very near to the films. Before measuring I-V characteristics, thin films were annealed in a vacuum ~ $10^{-2}$ Torr near glass transition temperature for two hours in the same sample holder which is used for current ~ voltage measurements.

## 3. Results and discussion

I – V characteristics of thin films of a- $Se_{70}Te_{30-x}Zn_x$ (x = 2, 4, 6, 8) are examined at various temperatures. At low fields (<$10^3$ V/cm), ohmic behaviour is observed in all the samples where I vs V curves are found to be straight lines. However, at higher fields (~ $10^4$ V/cm), super - ohmic behaviour is observed at all measuring temperatures. Fig. 1 shows such type of behaviour in glassy $Se_{70}Te_{28}Zn_2$. Similar behaviour is observed in other compositions of the present glass system also.

Several amorphous dielectric and semiconducting thin films exhibit at high electric field E, current vs voltage characteristics of the form [16-20]:

$$I = I_0 \exp (\beta E^{1/2}/ k T) \tag{1}$$

Where β is a constant is given by

$$\beta = (e^3/ \lambda \pi \varepsilon_0 \varepsilon_r)^{1/2} \tag{2}$$

When λ = 1, eqn. 2 reduces to the pool-Frenkel coefficient given by

$$B_{PF} = (e^3/ \pi \varepsilon_0 \varepsilon_r )^{1/2} \tag{3}$$

When λ = 4, eqn.(2) reduces to the Schottky coefficient given by

$$\beta_{Sch} = (e^3/ 4 \pi \varepsilon_0 \varepsilon_r )^{1/2} \tag{4}$$

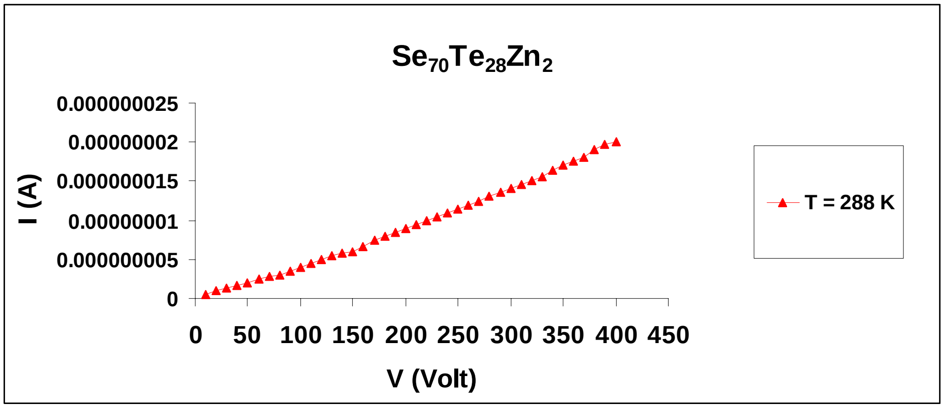


*Fig.1. Plot of I vs V for glassy alloy $Se_{70}Te_{28}Zn_2$ at various temperatures*

It is clear from the above that in Schottky as well as in case of Pool-Frenkel effect, ln I vs $V^{1/2}$ curves are expected to be straight lines following Eq(1). However, there are some differences [21] which distinguish between the Schottky effect and the Poole-Frenkel effect.

To test the above high field conduction theories in our case, we plotted ln I vs $V^{1/2}$ curves at various temperatures and found that such curves are not straight lines having good correlation coefficient in all the glassy alloys studied here.

According to the theory of space charge limited conduction (SCLC), in the case of uniform distribution of localized states, where $g(E) = g_0$, the current I at particular voltage V is given by the relation [16]:

$$I = (e\, A\, \mu\, n_0 V / d) \exp(S\, V), \tag{5}$$

Where d is electrode spacing, $n_o$ is the density of the thermally generated charge carriers, μ is the mobility, e is the electronic charge, A is the area of cross section of thin film and S is given by

$$S = 2\, \varepsilon_r\, \varepsilon_o / e\, g_o\, k\, T\, d^2 \tag{6}$$

As evident from equation (5) and (6), in the case of space charge limited conduction, a plot of ln I /V vs V should be linear and slope of these lines should decrease inversely proportional to temperature.

In the present case, at higher fields, ln (I / V) vs V curves are found to be straight lines with good correlation coefficient at all the measuring temperatures for all the glassy alloys studied here. To demonstrate this, the measurement data of ln ( I / V) as a function of V for various temperatures is shown in Fig. 2 in case of glassy $Se_{70}Te_{28}Zn_2$. Similar behaviour is observed in other glasses also.

The slope of ln (I / V) vs V for various temperatures is shown in Fig. 3 in case of glassy $Se_{70}Te_{28}Zn_2$. It is clear from this figure that the slope S decreases with the increase in temperature as expected from equation 6. This confirms the validity of SCLC theory in case of uniform distribution of localized states. Similar behaviour is observed in other glasses also

Using equation 6, the density of localized states is calculated from the slope of the Fig. 3.The value of relative dielectric constant $\varepsilon_r$ are measured using a General radio capacitance bridge model 1620-AP, employing the there terminal technique. The results of these calculations are given in table 1 as a function of Zn concentration. It is clear from this table that $g_0$ increases with Zn concentration in a - Se-Te-Zn system except at 4 at % of Zn.

*Table 1. Composition dependence of density of localized states ($g_0$) in glassy$Se_{70}Te_{30-x}Zn_x$.*

| Sample | Slope of S vs 1 /T | $\varepsilon_r$ | $g_o$ ( $eV^{-1}.cm^{-3}$) |
|---|---|---|---|
| $Se_{70}Te_{28}Zn_2$ | 6.8158 | 10 | 1.30 X $10^{14}$ |
| $Se_{70}Te_{26}Zn_4$ | 18.451 | 10 | 4.83 X $10^{13}$ |
| $Se_{70}Te_{24}Zn_6$ | 3.3021 | 10 | 2.69 X $10^{14}$ |
| $Se_{70}Te_{22}Zn_8$ | 1.4892 | 10 | 5.98 X $10^{14}$ |

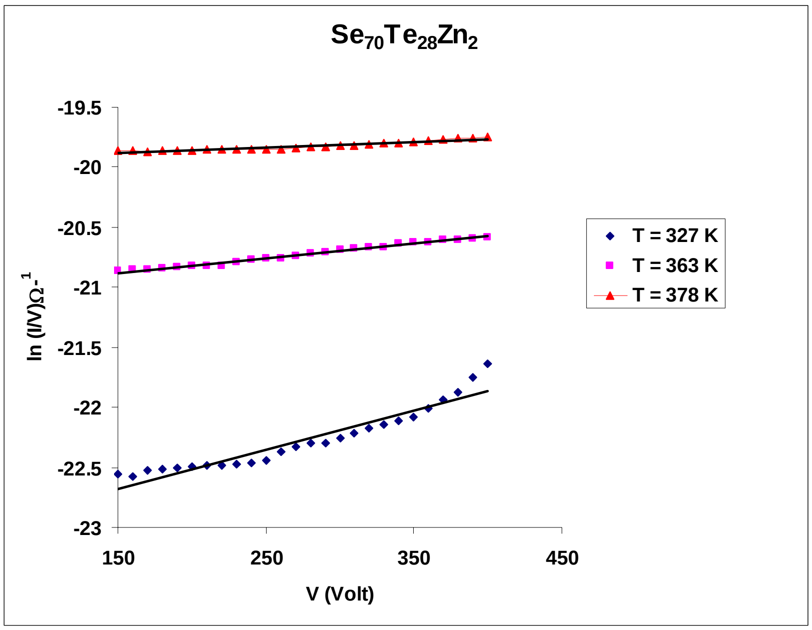


*Fig. 2. Plot of ln (I / V) vs V for glassy alloy $Se_{70}Te_{28}Zn_2$ at various temperatures.*

When iso-electronic atom Te is added to amorphous selenium, the density of defect states increases, and hence the residual potential increases in xerographic characterizations. Onozuka et al.[17] observed that, on introducing Cl to Se-Te system, the residual potential is decreased. This result was interpreted on the basis of a structural defect model where Te was assumed to form positively charged impurities due to small electronegativity of Te as compared to Se [18] while Cl atoms having higher electronegativity than Selenium [18], form negatively charged impurities, thereby compensating the effect of Te [17].

Along the same lines, one can expect that Zn, having lower electronegativity, as compared to Se and Te [18], introduces positively charged defects, thus increasing the density of defect states in the Se-Te-Zn system.

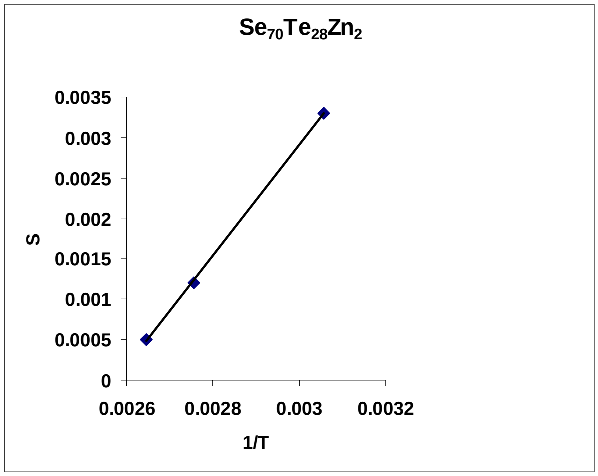


*Fig. 3. Plot of S vs 1/T for glassy alloy $Se_{70}Te_{28}Zn_2$ at various temperatures*

## 4. Conclusion

I-V characteristics have been studied in amorphous thin films of $Se_{70}Te_{30-x}Zn_x$ (x = 2, 4, 6, 8). At low field (<$10^3$ V/cm), an ohmic behaviour is observed. At high fields (~ $10^4$ V/cm), a super-ohmic behaviour is observed. 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 indicate that DOS increases with the increase of Zn concentration. This is explained in terms of the electronegativity of the host and the additive elements.

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