High field conduction in amorphous thin films of $\text{Se}_{70}\text{Te}_{30-x}\text{Cd}_x$ in dark and in the presence of light

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Glassy alloys of $\text{Se}_{70}\text{Te}_{30-x}\text{Cd}_x$ ($x = 2, 4, 6$) are prepared by the quenching technique. Amorphous thin films of these alloys are prepared by the vacuum evaporation technique. Current–voltage ($I-V$) characteristics have been studied at various temperatures in the films in dark and in the presence of light. For this purpose, a dc voltage ($0 – 300$ V) was applied across the film. $I-V$ characteristics show that, at low electric fields, an ohmic behaviour is observed. However, at high electric fields ($E \sim 10^4$ V/cm), the current becomes super ohmic. Analysis of the data shows the absence of space charge limited currents in amorphous $\text{Se}_{70}\text{Te}_{30-x}\text{Cd}_x$ thin films as $\ln I/V$ versus $V$ curves are not found to be straight lines with high correlation coefficient. Instead, $\ln I$ versus $V^{1/2}$ curves are found to be straight lines having high correlation coefficient. The slope of these curves decreases with the increase in temperature. A more detailed analysis shows that the dominant mechanism of conduction is of Poole-Frenkel type in dark as well as in the presence of light.

Keywords: Chalcogenide glasses, Amorphous semiconductors, High field conduction, Poole-Frenkel effect, Thin films

IPC Code: H01L

1 Introduction

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 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, since 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$^{1-13}$ and the results have been interpreted in terms of space charge limited conduction$^{1-7}$ or in terms of high field conduction due to Pool-Frenkel or Schottky effect$^{8-13}$. Se-Te alloys have drawn great attention due to their higher photosensitivity, greater hardness, and higher crystallization temperature as compared to pure glassy Se. The addition of third element in binary chalcogenide glasses is found to be useful in obtaining stable glassy alloys due to cross-linked structure. The present paper reports the high field conduction in amorphous $\text{Se}_{70}\text{Te}_{30-x}\text{Cd}_x$ ($x = 2, 4, 6$) films in dark and in the presence of light.

2 Experimental Details

Glassy alloys of $\text{Se}_{70}\text{Te}_{30-x}\text{Cd}_x$ ($x = 2, 4, 6$) were prepared by quenching technique. High purity (99.999%) materials were weighed according to their atomic percentages and sealed in quartz ampoules (length ~ 5 cm and internal diameter ~ 8 mm) with a vacuum ~ $10^{-5}$ Torr. The ampoules containing the materials were heated to 600°C and held at that temperature for 10-12 hr. The temperature of the furnace was raised slowly at a rate of 3-4°C/min. During heating, all the ampoules were constantly rocked, by rotating a ceramic rod to which the ampoules were tucked away in the furnace. This was done to obtain homogeneous glassy alloys.

After rocking for about 10 hr, the obtained melts were cooled rapidly by removing the ampoules from the furnace and dropping to ice-cooled water. The cooling rate was nearly 500°C/s. The quenched samples were taken out by breaking the quartz ampoules. The glassy nature of the materials was checked by XRD technique.

The thin films of glassy alloys were prepared by a standard coating unit (IBP-TORR, type: EPR-002) at a base pressure of $10^{-5}$ torr. The vacuum coating unit consists of a deposition chamber inside which proper arrangement was done to deposit the desired materials. The materials to be deposited were placed on molybdenum boat inside the chamber from where
it was thermally evaporated to glass substrate, which was held at a height of about 15 cm from the boat. The substrates used in the present work were made of 7059 corning glass. Before depositing glassy alloy on the substrate, indium was deposited to make electrodes. The thickness of the films was ~ 500 nm. The co-planar structure (length ~ 1.2 cm and electrode separation ~ 0.1 mm) was used for the present measurements (see Fig. 1). The amorphous nature of thin film was ascertained by X-ray diffraction.

For the measurements of high field conduction, thin films samples were mounted in a specially designed sample holder. A vacuum ~10⁻² Torr was maintained throughout the measurements. A d.c. voltage (0 to 300 V) was applied across the sample and the resultant current was measured by a digital electrometer (Keithely model: 614). I–V characteristics were measured at various fixed temperatures in the range 305-343K in these films in dark and in the presence of light. 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 hrs in the same sample holder.

3 Results and Discussion

A study of I-V characteristics is a matter of importance for properly analyzing the conduction mechanism in thin films. In the present paper, I-V characteristics of thin films of Se₇₀Te₃₀₋ₓCdₓ (x = 2, 4, 6) are examined at various fixed temperatures in the range 305-343 K in these films in dark and in the presence of light. At low fields (<10³ V/cm), an ohmic behaviour is observed in all the samples. However, at higher fields (~10⁴ V/cm), non-ohmic behaviour is observed.

According to the theory of space charge limited conduction, in the case of uniform distribution of localized states g(E)= g₀, the current (I) at a particular voltage (V) is given by the following relation

\[ I = (eAμn₀V/d) \exp(SV) \]  \hspace{1cm} ...(1)

where \( d \) is the electrode spacing, \( n₀ \) the density of the thermally generated charge carriers, \( μ \) the mobility, \( e \) the electronic charge, \( A \) the area of cross-section of thin films and \( S \) is given by

\[ S=2ε_ε_0/e \ g₀ \ k \ T \ \ d^2 \]  \hspace{1cm} ...(2)

As evident from Eqs (1) and (2), in case of space charge limited conduction, the ln \( I/V \) versus \( V \) curves should be straight lines and slope (S) of these curves should decrease linearly with the increase of temperature.

In the present case, at higher fields, ln \( (I/V) \) versus \( V \) curves are not found to be straight lines with high correlation coefficient at all the measuring temperatures in dark as well as in the presence of light. The results for amorphous thin film of Se₇₀Te₃₀Cd₂ in dark as well as in the presence of light are plotted in Fig. (2). Similar results were obtained for amorphous thin films of Se₇₀Te₂₈Cd₄ and Se₇₀Te₂₇Cd₆ in dark as well as in the presence of light (results are not shown here). The slopes of ln \( (I/V) \) versus \( V \) curves also do not decrease linearly with the increase in temperature. These results indicate the absence of space charge limited conduction in the present samples.

Several amorphous dielectric and semiconducting thin films exhibit at high electric field \( E \), current versus voltage characteristics of the form

\[ I = I_o \ \exp(β E^{1/2}/k \ T) \]  \hspace{1cm} ...(3)

where \( β \) is a constant given by:

\[ β = (e^3/λπε_0ε_r)^{1/2} \]  \hspace{1cm} ...(4)

when \( λ = 1 \), Eq. (2) reduces to the Poole-Frenkel coefficient given by:

\[ β_{PF} = (e^3/πε_0ε_r)^{1/2} \]  \hspace{1cm} ...(5)

when \( λ = 4 \), Eq. (2) reduces to the Schottky coefficient given by:

\[ β_{Sch} = (e^3/4πε_0ε_r)^{1/2} \]  \hspace{1cm} ...(6)

In Schottky as well as in Poole-Frenkel effect, ln \( I \) versus \( V^{1/2} \) curves are expected to be straight lines following Eq (3). However, there are some
differences which distinguish between the Schottky effect and the Poole-Frenkel effect. In the case of Schottky effect, $\ln I / T^2$ versus $1 / T$ curves for various fixed voltages would be linear. However, such curves will not show linearity in Poole-Frenkel effect. Moreover, the extrapolated portion of $\ln I$ versus $V^{1/2}$ curves should pass through a single point at zero applied voltage at different temperatures in the case of Schottky effect. This does not happen in the case of Poole-Frenkel effect. The value of the activation energy is expected to be greater than or equal to 0.98 eV in case of Schottky effect while it is less than 0.98 eV in the case of Poole-Frenkel effect.

In the present samples, $\ln I$ versus $V^{1/2}$ curves are found to be straight lines with high correlation coefficient at various temperatures in dark as well as in the presence of light. To demonstrate this, we have plotted such curves for amorphous thin film of Se$_{70}$Te$_{28}$Cd$_2$ in Fig. 3 in dark as well as in the presence of light. The slope ($S$) of these curves decreases linearly with temperature for all the three samples in dark as well as in the presence of light (see Fig. 4). To distinguish between Schottky and Poole-Frenkel conduction, we have plotted $\ln I / T^2$ versus $1000 / T$ curves for various fixed voltages in dark as well as in the presence of light, which were found to be non-linear for all the three films. Such curves for amorphous thin film of Se$_{70}$Te$_{28}$Cd$_2$ are shown in Fig. 5. The extrapolated portion of $\ln I$ versus $V^{1/2}$ curves does not pass through a single point at zero applied voltage at different temperatures.

These results indicate that conduction is Poole-Frenkel type in the present samples. Fig. 6 plots $\ln I$ versus $1000 / T$ curves at various fixed voltages in dark as well as in the presence of light for amorphous thin film of Se$_{70}$Te$_{28}$Cd$_2$, which are found to be straight lines. This type of behaviour indicates that current is thermally activated following a relation

$$I = I_0 \exp \left( -\Delta E / kT \right) \quad \ldots (7)$$

![Fig. 2—Plots of $\ln I / V$ versus $V$ for amorphous thin films of Se$_{70}$Te$_{28}$Cd$_2$ at various temperatures in dark as well as in presence of light.](image-url)
Fig. 3—Plots of $\ln I$ versus $V^{1/2}$ for amorphous thin films of Se$_{70}$Te$_{28}$Cd$_2$ at various temperatures in dark as well as in presence of light.

Fig. 4—Plots of $S$ versus $1000/T$ for amorphous thin films of Se$_{70}$Te$_{30-x}$Cd$_x$ ($x = 2, 4, 6$) in dark as well as in presence of light.
Fig. 5—Plots of \( \ln (I/T^2) \) vs \( 1000/T \) for amorphous thin films of Se\(_{70}\)Te\(_{28}\)Cd\(_2\) at various voltages in dark as well as in presence of light.

Fig. 6—Plots of \( \ln I \) versus \( 1000/T \) for amorphous thin films of Se\(_{70}\)Te\(_{28}\)Cd\(_2\) at various voltages in dark as well as in presence of light.

Table 1—Activation energy in dark as well as in the presence of light at different voltages in amorphous thin films of Se\(_{70}\)Te\(_{30-x}\)Cd\(_x\) (\( x = 2, 4, 6 \))

<table>
<thead>
<tr>
<th>Sample</th>
<th>Voltage (V)</th>
<th>Activation energy (eV)</th>
<th>In dark</th>
<th>In presence of light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Se(<em>{70})Te(</em>{28})Cd(_2)</td>
<td>150</td>
<td>0.672</td>
<td>0.263</td>
<td></td>
</tr>
<tr>
<td></td>
<td>170</td>
<td>0.663</td>
<td>0.280</td>
<td></td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>0.663</td>
<td>0.277</td>
<td></td>
</tr>
<tr>
<td>Se(<em>{70})Te(</em>{26})Cd(_4)</td>
<td>150</td>
<td>0.616</td>
<td>0.262</td>
<td></td>
</tr>
<tr>
<td></td>
<td>170</td>
<td>0.618</td>
<td>0.265</td>
<td></td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>0.606</td>
<td>0.254</td>
<td></td>
</tr>
<tr>
<td>Se(<em>{70})Te(</em>{24})Cd(_6)</td>
<td>150</td>
<td>0.615</td>
<td>0.184</td>
<td></td>
</tr>
<tr>
<td></td>
<td>170</td>
<td>0.598</td>
<td>0.172</td>
<td></td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>0.594</td>
<td>0.178</td>
<td></td>
</tr>
</tbody>
</table>

where \( \Delta E \) is the activation energy, which may correspond to energy of trap levels from the band edges, and \( k \) is the Boltzmann constant. From the slopes of \( \ln I \) versus \( 1000/T \) curves, we have calculated \( \Delta E \) at various voltages in dark as well as in the presence of light. Such values are given in Table 1 for all the glassy alloys. The different values of \( \Delta E \) at different voltages indicate that there is a energy distribution of trap levels instead of a single trap level. The decrease of \( \Delta E \) in presence of light as compared to the results in dark further supports this view point as the position of Fermi level is shifted towards the band edges in this case. The values of activation energy in dark as well as in presence of light are less than 0.98 eV, which further confirms the presence of Poole-Frenkel conduction in present case.

4 Conclusions

\( I-V \) characteristics have been studied in amorphous thin films of Se\(_{70}\)Te\(_{30-x}\)Cd\(_x\) (\( x = 2, 4, 6 \)). At low fields (<10\(^3\) V/cm), an ohmic behaviour is observed. However, at high fields (~ 10\(^4\) V/cm), a super ohmic behaviour is observed.
Analysis of the observed data shows the absence of space charge limited conduction in amorphous thin films of Se$_{70}$Te$_{30-x}$Cd$_x$ ($x = 2, 4, 6$) in which $\ln I/V$ versus $V$ curves are not found to be straight lines with high correlation coefficient and the slopes of these curves do not decrease linearly with temperature.

Instead of the above, $\ln I$ versus $V^{1/2}$ curves are found to be straight lines with high correlation coefficient. The slope of these curves decrease linearly with increase in temperature. This suggests that the conduction process is either of the Schottky emission at the electrodes or of the Pool-Frenkel bulk mechanism. A detailed analysis shows that conduction is Poole-Frenkel type in the present thin films in dark as well as in the presence of light.

References