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# Electronic conduction in 40 MeV $^{28}Si^{5+}$ ion irradiated Se-Te-Pb thin films

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**Abstract.** Amorphous thin films of $Se_{80-x}Te_{20}Pb_x$ $(0 < x < 2)$ have been prepared by thermal evaporation. The effect of 40 MeV $^{28}Si^{5+}$ ion irradiation on the electronic conduction of $Se_{80-x}Te_{20}Pb_x$ $(0 < x < 2)$ thin films has been investigated. The DC electrical conductivity of the films increases by two to three order of magnitude with increase in irradiation fluence from $10^{12}$ to $5\times10^{13}$ ions/cm$^2$. The DC activation energy of conduction also increases with increase in irradiation fluence. Results have been explained on the basis of structural disorders and defects formed due to heavy ion irradiation.

**PACS.** 61.43.Dq Amorphous semiconductors, metals, and alloys – 61.82.Fk Semiconductors – 81.05.Gc Amorphous semiconductors – 73.61.Jc Amorphous semiconductors; glasses

## 1 Introduction

Chalcogenide glasses are candidates of interest for technological applications such as switching and memory devices, reversible phase change optical recordings, optical imaging and infrared optical fibres [1–3]. These glasses also exhibit many properties like photodoping, photocrystallisation, photodarkening and photobleaching [4]. They exhibit wide variety of changes in their structural properties, electronic transport properties and optical properties when they are exposed to light or heavy ion irradiation [5–7]. Their structure consists of a disordered network having some dangling bonds as defects [1]. When these glasses are irradiated with heavy ions or light, bond breaking and bond rearrangement of atoms take place resulting in the change in local structure order of the amorphous network. Research on amorphous chalcogenide glasses and thin films have attracted the attention of many workers in the recent years because of the challenging aspects of new concepts dealing the mechanism of radiation-induced phenomena in these systems. The effect of heavy ion irradiation on the optical band gap of $Se_{80-x}Te_{20}Pb_x$ $(0 < x < 2)$ thin films has recently been reported [3]. Detailed mechanisms describing the effects caused in the chalcogenide glasses by heavy ion irradiation or light illumination are only partially understood. To improve the knowledge about them it is important and necessary to carry out the electric transport studies in the pristine and ion irradiated samples. In the present paper an attempt has been made to analyse the 40 MeV $^{28}Si^{5+}$ ion induced changes on the electrical properties of amorphous $Se_{80-x}Te_{20}Pb_x$ $(0 < x < 2)$ thin films.

## 2 Experimental procedures

Bulk samples of $Se_{80-x}Te_{20}Pb_x$ $(0 < x < 2)$ were prepared by conventional melt quenching technique. Different values of $x$ in $Se_{80-x}Te_{20}Pb_x$ samples yielded different Se:Pb ratios in chalcogenide alloys. High purity elements [99.999%] obtained from Sigma-Aldrich USA were used for the synthesis of bulk samples. The elements in appropriate amounts were sealed in a quartz ampoule in a vacuum of the order of $10^{-5}$ mbar. Then the ampoule was placed in a vertical furnace at 700 °C and it was frequently inverted in order to ensure the homogeneous mixing of the constituents. After 48 h, it was quenched in an ice water bath. The material was separated from the ampoule by dissolving it in a solution of $HF+H_2O_2$ for about 48 hours. Using this as source material, thin films for all the compositions were prepared onto well-cleaned glass substrates at room temperature by thermal evaporation in a pressure less than $10^{-5}$ mbar. Thickness of the films (see Tab. 1) was measured by Tolansky's interference method [8]. Amorphous nature of the films was confirmed by the absence of any sharp peak in the X-ray diffraction (XRD) pattern. The composition analysis of the films was performed using Rutherford Back Scattering (RBS) technique at the Nuclear Science Center (NSC), New Delhi, India. The films were irradiated at room temperature with 40 MeV $^{28}Si^{5+}$ ion beam for the RBS experiment. A silicon surface barrier detector (having a depletion depth

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**Table 1.** DC activation energy $\Delta E$ and Optical bandgap ($E_g$) (Ref. [3]) of $Se_{80-x}Te_{20}Pb_x$ ($0 < x < 2$) at different fluence of irradiation.

| Sample Composition | Thickness (nm) | Electronic energy loss | Nuclear energy loss | Range (nm) | Optical band gap ($E_g$) and DC activation energy ($\Delta E$) (eV) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Unirradiated | | Irradiated with $10^{12}$ ions/cm$^2$ | | Irradiated with $3 \times 10^{12}$ ions/cm$^2$ | | Irradiated with $10^{13}$ ions/cm$^2$ | | Irradiated with $5 \times 10^{13}$ ions/cm$^2$ | |
| $x$ | | (eV/Å)$\times 10^2$ | (eV/Å)$\times 10^{-1}$ | | $E_g$ | $\Delta E$ | $E_g$ | $\Delta E$ | $E_g$ | $\Delta E$ | $E_g$ | $\Delta E$ | $E_g$ | $\Delta E$ |
| $x = 0$ | 424 | 4.213 | 6.091 | 11 880 | 1.68 | 0.67 | 1.70 | 0.68 | 1.72 | 0.69 | 1.73 | 0.70 | 1.76 | 0.73 |
| $x = 0.6$ | 475 | 4.224 | 6.117 | 11 850 | 1.39 | 0.30 | 1.40 | 0.31 | 1.41 | 0.32 | 1.43 | 0.34 | 1.46 | 0.36 |
| $x = 1.1$ | 202 | 4.233 | 6.138 | 11 820 | 1.36 | 0.25 | 1.38 | 0.27 | 1.40 | 0.29 | 1.44 | 0.31 | 1.48 | 0.34 |
| $x = 1.4$ | 507 | 4.238 | 6.151 | 11 810 | 1.34 | 0.23 | 1.35 | 0.25 | 1.37 | 0.26 | 1.40 | 0.28 | 1.44 | 0.31 |

of 60 $\mu$m) was used at back angle ($\sim$120° degree) to detect the Si ions back scattered from the sample. Since the masses of the constituents (Se, Te and Pb) are quite apart, the back-scattered Si ions appear in three groups well separated from each other, representing three different masses. The area of the peaks and Rutherford scattering cross section were used to determine relative concentration of Se, Te and Pb. The composition was verified at different parts of the films and was found to be uniform.

Thin films of about 1.0 cm$^2$ area were exposed to 40 MeV $^{28}Si^{5+}$ ion beam using 15UD NSC Pelletron New Delhi. The samples were mounted in a metallic cryostat placed in a vacuum chamber. The final vacuum attained in the chamber was better than $10^{-7}$ mbar. All the samples were irradiated at $LN_2$ temperature. Using SRIM (Stopping and Ranging of Ions in Materials) [8] calculations, we find that the electronic energy loss is maximum around 40 MeV of $^{28}Si^{5+}$ ion beam for $Se_{80-x}Te_{20}Pb_x$ ($0 < x < 2$) samples. So, in order to investigate the irradiation-induced changes at the higher electronic energy loss, we selected 40 MeV $^{28}Si^{5+}$ ion beam. The beam was scanned by an electromagnet scanner to cover the whole sample. All the samples were irradiated using different fluences ($10^{12}$, $3 \times 10^{12}$, $10^{13}$ and $5 \times 10^{13}$ ions/cm$^2$). The DC electrical conductivity of the films was determined in the temperature range 220–313 K. Electrical contacts (with electrode gap $\sim 10^{-3}$ m) in a coplanar geometry were made using silver paint. The straight line passing through the origin of the voltage-current plot verified the Ohmic nature of the contacts. The DC current was noted by using a digital picoammeter (DPM-111 Scientific Equipments, Roorkee). The samples were mounted inside a metallic cryostat. All the measurements were made in a running vacuum of the order of $10^{-3}$ mbar.

## 3 Results and discussions

The X-ray diffraction pattern of the $Se_{80-x}Te_{20}Pb_x$ ($0 < x < 2$) films is shown in Figure 1. It has been observed from the above figure that all the samples are amorphous in nature as there is no peak observed in their diffraction pattern.

The DC electrical conductivity of the $Se_{80-x}Te_{20}Pb_x$ ($x = 0.6$) films, irradiated with different fluences, as a function of temperature is shown in Figure 2. Samples

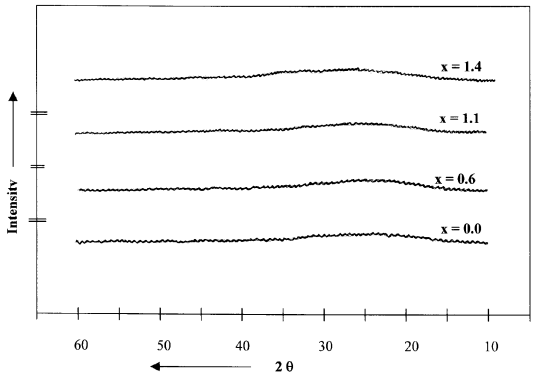


**Fig. 1.** X-ray diffraction pattern of $Se_{80-x}Te_{20}Pb_x$ ($0 < x < 2$) thin films.

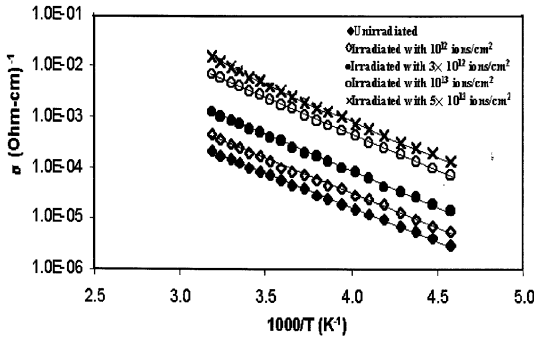


**Fig. 2.** DC conductivity variation with temperature of $Se_{80-x}Te_{20}Pb_x$ ($0 < x < 2$) thin films at different fluence of irradiation.

with other compositions also show similar trend. It may be noted from the above figure that the DC electrical conductivity increases with the increase in temperature as well as with increase in irradiation fluence from $10^{12}$ to $5 \times 10^{13}$ ion/cm$^2$. The DC conductivity is found to be activated over the entire range of temperature. The DC activation energy follows the conductivity equation over the entire temperature range given by

$$\sigma = \sigma_0 \exp(-E_a/kT) \quad (1)$$

where $\sigma_0$ is the pre-exponential factor, $k$ is the Boltzman constant, $T$ is the absolute temperature and $\Delta$E is the activation energy for electronic conduction. DC activation energy ($\Delta E$) is calculated from the slopes of

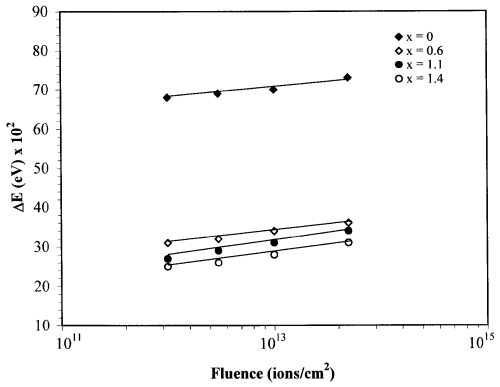


**Fig. 3.** DC activation energy ($\Delta E$) variation with irradiation fluence.

conductivity versus $1/T$ plots. The values of $\Delta E$ for all the samples unirradiated and irradiated with different fluences are listed in Table 1. It is obvious from the above table that $\Delta E$ increases with increase in irradiation fluence from $10^{12}$ to $5 \times 10^{13}$ ion/cm$^2$. The increase in conductivity of $Se_{80-x}Te_{20}Pb_x$ $(0 < x < 2)$ films may be attributed to the defects (structural disorders, dislocations, surface imperfections) upon heavy ion irradiation with 40 MeV Si ions.

When an ion with MeV energy incident on a solid target, it suffers mainly two types of energy losses namely electronic energy loss and nuclear energy loss. Nuclear energy loss introduces disorder deep into the target if the thickness of the sample is more than the projected range of the incident ions and this effect is negligible in this case However, in the present case electronic energy loss is more important because of the thinner samples. The energy deposition due to electronic energy loss on the surface or near to the surface of the films cause defects in the thin films. The defects produced by the electronic energy loss on the surface of films become mobile by the subsequent ions hitting the target. An increased mobility of the defects with the increase in irradiation fluence may results in increase in DC conductivity of $Se_{80-x}Te_{20}Pb_x$ $(0 < x < 2)$ films [10]. It has been reported that the DC conductivity of the Pb-Se-Ge samples irradiated with 75 MeV Ni ion increases with increase in irradiation fluence, but the activation energy decreases with increase in irradiation fluence resulting from the increase in tailing of band edges by heavy ion irradiation [6]. However, in the present case the DC activation energy increases with increase in irradiation fluence as shown in Figure 3.

Also in our previous attempt, we reported the effect of heavy ion irradiation irradiation on the optical band gap of $Se_{80-x}Te_{20}Pb_x$ $(0 < x < 2)$ films. It has been reported that the optical band gap of $Se_{80-x}Te_{20}Pb_x$ $(0 < x < 2)$ films increases with increase in irradiation fluence [3]. The optical band gap of $Se_{80-x}Te_{20}Pb_x$ $(0 < x < 2)$ films irradiated with different fluences of irradiation is listed Table 1. It can be seen form the above table that the increase in DC activation energy and the optical band gap of $Se_{80-x}Te_{20}Pb_x$ $(0 < x < 2)$ films follow a similar trend upon irradiation with 40 MeV $^{28}Si^{5+}$ ions.

## 4 Conclusions

40 MeV $^{28}Si^{5+}$ ion induced changes in the electrical properties of $Se_{80-x}Te_{20}Pb_x$ $(0 < x < 2)$ thin films have been investigated. The DC conductivity of films measured as a function of temperature increases with increase in temperature and irradiation fluence and is found to be activated over the entire temperature range for all the irradiation fluences. The activation energy for conduction also increases with increase in irradiation fluence. The results have been explained on the basis of structural defects induced in $Se_{80-x}Te_{20}Pb_x$ $(0 < x < 2)$ films upon irradiation with heavy ions.

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