Optical and Electrical Properties of Chalcogenide Glass Thin Film

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Abstract *Chalcogenide glasses are solid state materials that can switch from one state to another state. It has immense applications in phase change memory devices and opto-electronic devices. The present work investigated the optical and electrical properties of $In_3Te_7Se_{90}$ amorphous semiconductor deposited on non-conducting glass substrate by thermal evaporation technique in vacuum 10^{-6} torr pressure. The amorphous nature of the thin film was characterized by X-ray Diffraction (XRD) which confirms the amorphous nature of the film. Energy Dispersive X-ray Scattering (EDS) shows the presence of compositional elements in thin film. Scattering Electron Microscope (SEM) image shows surface topology and development of grains. The absorption spectra of the thin film in the presence of Ultra Violet –Visible (UV-Vis) shows indirect band gap. The electrical study of the thin film suggests that the conduction is due to thermally assisted tunneling of the carriers in the localized state. This material is suitable for optical disk applications.*

Key words: Thin film, DC Conductivity, Band gap, Absorption coefficient

1. Introduction

Chalcogenide glasses exhibit phase change properties under the influence of light,heat ,pressure etc. Se based chalcogenide glasses are many applications in solid state electronic devices. Since pure selenium is fragile and have short life time; therefore elements from group II-VI are added to make it more robust. These chalcogenide glasses are non-linear, low phonon energy and transparent in IR region which make it useful for optical switching. Se-Te alloys have crystallization temperature, greater hardness, higher photosensitivity and smaller aging effects [1-4]. Optical band gap (E_g), extinction coefficient (k) and refractive index (n) are important parameters to study the amorphous semiconducting thin film. Chalcogenide galss is found to exhibit the change in refractive index under the influence of UV-Vis light which makes those material to use in memory devices. In this present work authors aim to study the optical constants and electrical properties of the $In_3Te_7Se_{85}$ thin film

2. Experimental

Chalcogenide glass alloy $In_3Te_7Se_{90}$ was prepared from high purity constituent elements (99.999%) in stoichiometric ratio by using melt quench technique. The constituent elements were sealed in quartz ampoules under a vacuum of 10^{-5}- 10^{-6} torr. The ampoule was kept inside a furnace at 800^0C for 12 hrs so that all elements were melted. The temperature was raised at the rate of 2^0C/min. During the heating process, the ampoule was shaken continuously so as to make it homogeneous. Quenching was done in ice water and the ingots were taken out by breaking the ampoule. Thermal evaporation technique was used to deposit the film on glass substrate at a pressure of 10^{-6} torr.The film prepared was kept at deposition chamber for almost 24 hours so that metastable thermodynamic equilibrium is maintained. Amorphous nature of as-prepared glass alloy was confirmed by XRD. Glassy alloy's Surface topography and composition have been studied by SEM image and EDS respectively. The optical measurement was carried out by using UV/Vis spectrophotometer (Model: Camspec M550 double beam) in spectral wavelength range 190–1100 nm. For electrical measurements the deposited film on glass substrate has length ~1.5 cm, electrode gaps ~0.4-1.2 mm and thickness ~400 nm. A DC voltage of 1.5 V was applied across the sample and the resulting current measured by a Keithley electrometer (6514). The DC conductivity was carried out in specially designed metallic sample holder with vacuum 10-4 Torr. The temperature of the film was controlled by mounting a heater inside the sample and measured by calibrated copper-constantan thermocouple near film.

3. Results and discussion

XRD analysis of thin film was carried out by A Regaku Ultima IV X-ray Diffractometre. The radiation source Cu $K\alpha_1$ with λ = 1.54 A^0, diffraction angle in the range of 5^0 to 90^0 with scan speed of 2^0/min and a chart speed of 1 cm/min were maintained [5]. The XRD pattern of graph is shown in Fig 1.In this pattern of XRD, since there is no sharp peak, therefore it confirms the amorphous nature of bulk alloy. Surface morphology of the thin film was analysed by Scanning Electron Micrograph (SEM) apparatus JEOL (Model JSM 6380). SEM image of thin film is shown in Fig 2. SEM image shows the growth of nuclei.The dissociation energy for Se-In, Se-Se, Se-Te are 257.5 KJ/mol, 239.3 KJ/mol,and 259.8 KJ/mol respectively [6].This shows that Se-Te bonds require more energy to be dissociated which makes it robust.

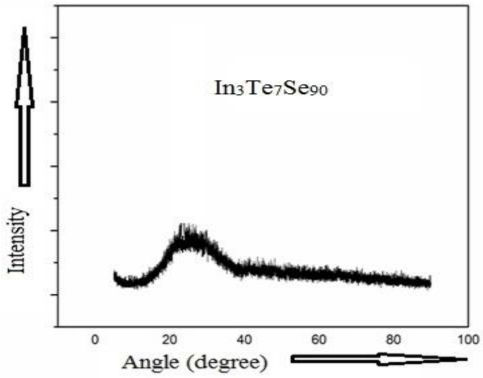

Fig.1 X-ray Diffraction (XRD) pattern of $In_3Te_7Se_{90}$ thin film

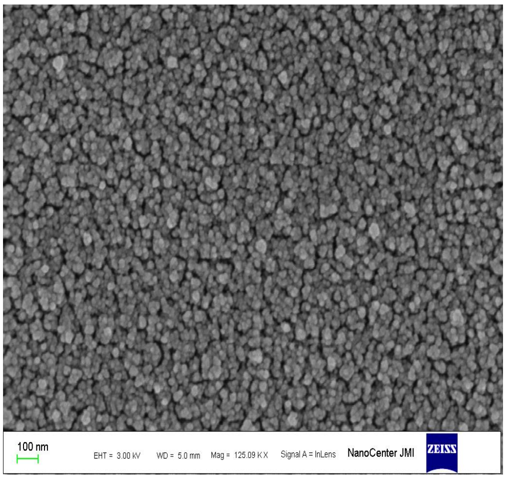

Fig.2 SEM image of as-prepared $In_3Te_7Se_{90}$ thin film

The elemental composition of as-prepared $In_3Te_7Se_{90}$ thin film was checked by using the Energy Dispersive X-ray (EDX) spectroscopy as shown in Fig 3. This image confirms the presence of constituent's elements In, Te, and Se.

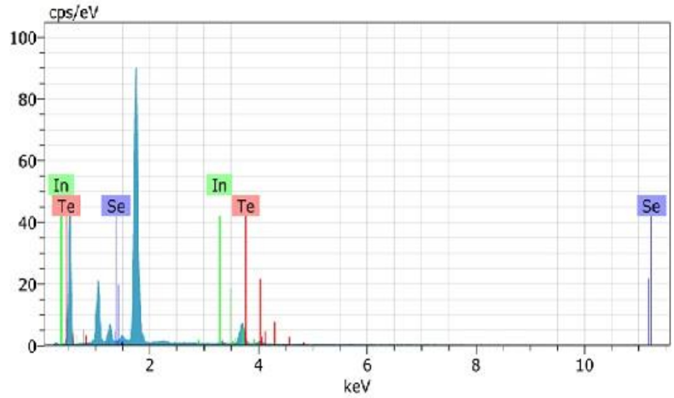

Fig.3 EDS of as-prepared $In_3Te_7Se_{90}$ thin film

The UV-Vis absorption spectra $In_3Te_7Se_{90}$ thin film has been recorded in the wavelength range of 190-1100 nm by UV-Vis Spectrophotometre Model Comspec M550. It has been observed that absorption coefficient increases linearly with increase of photon energy as shown in Fig 4(a).Energy of the band tail also called Urbach's energy and optical band gap has been measured using Urbach's Rule [7] and Tauc relation [8] respectively. Urbach's energy (width of the band tail due to localised states in amorphous semiconductor) can be calculated as

absorption coefficient $\alpha = \alpha_0 \exp (h\upsilon/E_u)$ (1)

where, α_0 is constant and E_u is called Urbach energy

The Tauc relation between absorption coefficient and optical band gap is given as

$\alpha h\upsilon = A (h\upsilon - E_g)^n$ (2)

Where A is a constant called band tailing parameter and E_g is called optical band gap. The index 'n' is associated with the type of transition which has values ½, 2 for direct and indirect transitions respectively [9-11]. In present thin film of $In_3Te_7Se_{90}$ obeys indirect transition rule ie. n = 2 and it has been shown in Fig 4(b).The slope of the graph gives the optical band gap.The optical parameters of $In_3Te_7Se_{90}$ thin film at a frequency of 700 nm are given in Table 1.

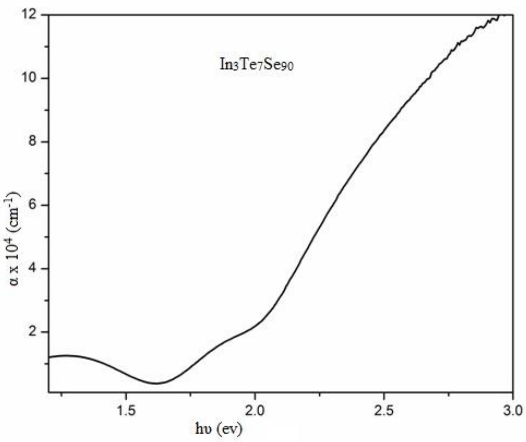

Fig. 4(a) absorption coefficient (α) versus hυ of $In_3Te_7Se_{90}$ thin film

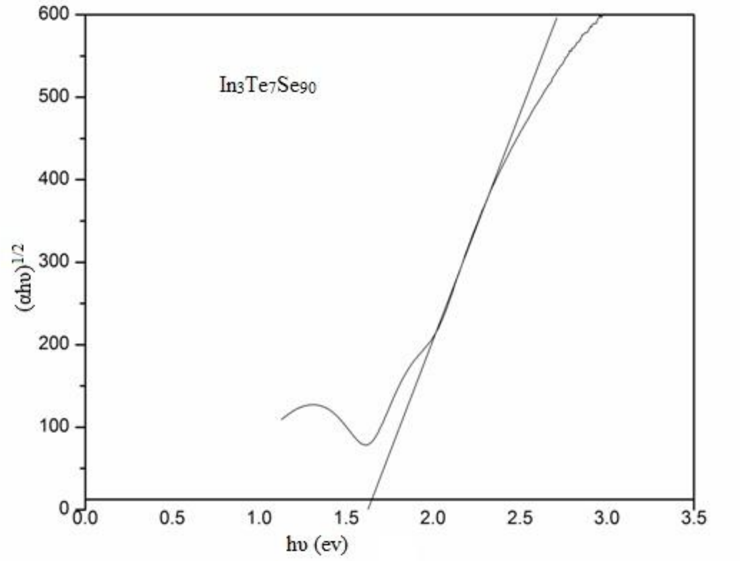

Fig. 4(b) plot between $(\alpha h\upsilon)^{1/2}$ versus hυ of $In_3Te_7Se_{90}$ thin film

Table 1

The optical parameters of $In_3Te_7Se_{90}$ thin film at a frequency of 700 nm

Sample	E_g (eV)	$\alpha \times 10^4$ (cm^{-1})	K	N	E_u (eV)
$In_3Te_7Se_{90}$	1.6	1.54	0.073	3.14	0.49

The DC conductivity of the $In_3Te_7Se_{90}$ thin film of thickness 450 nm was studied in the temperature range of 300 K-390 K using DC probe method. The DC conductivity can be expressed by Arrhenius relation [12-14] as follows:

$$\sigma_{dc} = \sigma_0 \exp(\Delta E/KT) \quad (3)$$

where ΔE is called activation energy. K is Boltzmann constant and σ_0 is pre-exponential factor.

From Fig 5 it is clear that conductivity is less temperature this can be attributed to the fact that charge carriers are frozen at low temperatures, however as soon the temperature increases the degree of charge carrier ionization of impurities increases results in rapidly increase in conductivity. The calculated values of conductivity (σ_{dc}) ,activation energy (ΔE) and σ_0 are given in Table 2.

Fig. 5 shows graph between 1000/T versus lnσ of $In_3Te_7Se_{90}$ thin film

Table 2

Electrical parameters of $In_3Te_7Se_{90}$ thin film at a frequency of 1 KHz and at 310 k temperature

Sample	σ_{dc} ($\Omega^{-1}cm^{-1}$)	ΔE (eV)	σ_0 ($\Omega^{-1}cm^{-1}$)
$In_3Te_7Se_{90}$	3.1×10^{-8}	0.07	3.6×10^{-7}

The above values of conductivity and activation energy are in the range of localized states [15-16]. The electronic band gap and optical band gap follow the same trend.

4. Conclusion

Bulk alloy of $In_3Te_7Se_{90}$ has been deposited on ultra clean glass substrate at room temperature by thermal evaporation technique.XRD analysis confirms the amorphous nature of the thin film and EDS shows the presence of constituent elements in the thin film. Optical absorption measurement shows the indirect band transition. The value of optical constants such as extinction coefficient (k), refractive index (n) and optical band gap (E_g) have been determined. The DC conductivity was found in the order of 10^{-8} at room temperature. These measured values of optical and electrical parameters suggest the investigated amorphous semiconductor thin film of $In_3Te_7Se_{90}$ is suitable for optio-electronic devices and optical memory.

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