INVESTIGATION OF THE EFFECT OF FILM THICKNESS ON THE OPTICAL PROPERTIES OF AMORPHOUS $Se_{85-X}Te_{15}Sb_X$ THIN FILMS

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ABSTRACT

Amorphous thin films of *$Se_{85-x}Te_{15}Sb_x$ (x = 0.0, 0.5, 2.5, and 5.0 at. %)* deposited by flash evaporation technique, have been investigated in the wavelength range of 500nm-3000nm. It is found that the effect of increasing antimony content and film thickness on the as-deposited films led to increase in the absorption coefficient. The optical band gap energy decreased with increase in antimony concentration but increased with increase in film thickness.

Keywords: Amorphous Chalcogenide, Alloy, Film Thickness, and Optical Property.

INTRODUCTION

Chalcogenides are the elements occupying column six of the periodic table - sulfur, selenium and tellurium. The common factor linking these elements is the presence of six electrons in their outer valence shell [1]. The optical properties of chalcogenide glasses make them candidate materials for a variety of optical applications like in remote infrared sensors, optical computing, optical data storage, planar waveguides, Bragg diffraction gratings, and optical switching devices [2]. Chalcogenide glasses have received little attention until recently due to traditional silicon technology. However, the use of silicon as an electronic/optoelectronic material is rapidly approaching its physical limitations, making chalcogenide materials to receive attention worldwide. Chalcogenide glass of selenium exhibits reversible transformation property useful in optical memory devices. However, pure amorphous selenium is thermally unstable and less photosensitive to electromagnetic radiation. To overcome these problems, selenium is usually doped with other elements like lead (Pb), indium (In), antimony (Sb), tellurium (Te), germanium (Ge), bismuth (Bi), which improves its crystallization temperature, aging effect and sensitivity [3]. Addition of a third element (like Sb) to binary selenium alloy such as Se-Te expands the glass forming area and also creates compositional and configurational disorder in the system.

The study investigates optical properties of amorphous *Se_{85} $Se_{85-x}Te_{15}Sb_x$ (x = 0.0, 0.5, 2.5, and 5.0 at. %)* ternary system. Although optical properties of this system have been studied, the effect of film thickness has not been studied in detail. Addition of Sb to Se-Te binary system at lower atomic percentages is said to improve its optical properties, photosensitivity and thermal stability [3, 4].

MATERIALS AND METHODS

The bulk samples of *$Se_{85-x}Te_{15}Sb_x$ (x = 0.0, 0.5, 2.5, and 5.0 at. %)* were prepared by melt quenching method. The appropriate amounts of high purity of selenium, tellurium and antimony (99.999%) were weighed according to their atomic percentages in powder form on an electronic balance (LIBROR AEG-120, Japan). This was followed by sealing in quartz ampoules evacuated to 5.5×10^{-5}mbar to avoid sample contamination (Edwards AUTO 306 Vacuum system, UK). The ampoules were heated in a rotating furnace to a maximum of 720ºC for 12 hours to ensure a homogeneous mixture. The temperature was raised slowly at a rate of 4ºC per minute to avoid unnecessary build up of vapour pressure in the glass ampoules. Subsequently, the ampoules were quenched in ice-cooled water to form amorphous films [5]. The ampoules were broken to obtain the solid alloy that was crushed into powder for flash evaporation.

Thin films of glassy selenium-tellurium-antimony alloys were prepared by flash evaporation technique at a vacuum pressure of 3.5×10^{-5}mbar (Edwards AUTO 306 Vacuum system, UK).Thickness of the thin films has been measured by computerized KLA-Tencor Alpha-Step IQ surface profiler with a resolution of 10nm (KLA-Tencor Corporation, USA). Transmittance (T) and reflectance (R) data were obtained from SolidSpec.3700 DUV Spectrophotometer (Solidspec. 3700 DUV

Spectrophotometer, Japan) in the spectral range from 500nm to 3000nm. The optical band gap energy was evaluated according to Tauc's method [6].

RESULT AND DISCUSSION

Nature of the as-Deposited Thin Films

The amorphous nature of the deposited thin films was confirmed by X-Ray Diffraction method (Phillips PW3710, UK: CuK$_\alpha$ radiation, λ = 1.5405Å). The recorded X-Ray Diffraction (XRD) patterns for the studied as-prepared 215nm $Se_{85-x}Te_{15}Sb_x$ *(x = 0.0, 0.5, 2.5, and 5.0 at. %)* thin films of thickness 215nm compared to that of the bare glass substrate are shown in Fig. 1. The absence of diffraction peaks indicated amorphous and glassy nature of the films. The humps are due to the glass substrate [7].

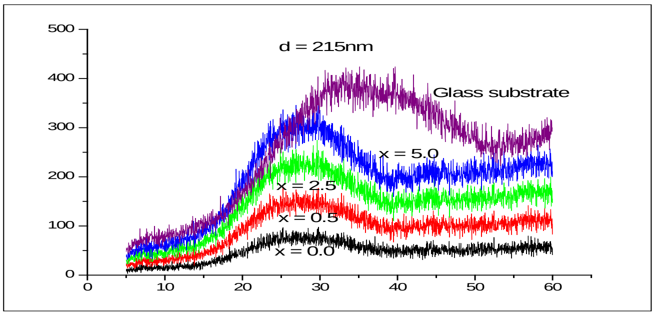

Figure 1. X-Ray Diffraction pattern for a 215nm thin films

Transmittance and Reflectance

For maximum transmission [8];

$$T = \exp - (\alpha d) , \qquad (1)$$

where d is film thickness and α is the absorption coefficient.

The absorption coefficient, extinction coefficient, k and spectral wavelength, λ is given by;

$$\alpha = 4\pi k / \lambda , \qquad (2)$$

Transmittance and Reflectance against wavelength (nm) for $Se_{85-x}Te_{15}Sb_x$ *(x = 0.0, 0.5, 2.5, and 5.0 at. %)* thin films at different thicknesses is shown in Fig. 2. Observed zero transmittance at 500nm was as a result of high light absorption at this wavelength [9]. Transmittance decreased with increase in antimony content due to antimony defects in the as deposited thin films. As the film thickness increased, transmittance decreased which was an indication of increase in light absorption by the films. The increase of reflectance with film thickness at specific wavelengths was due to the effect of decreased transmittance.

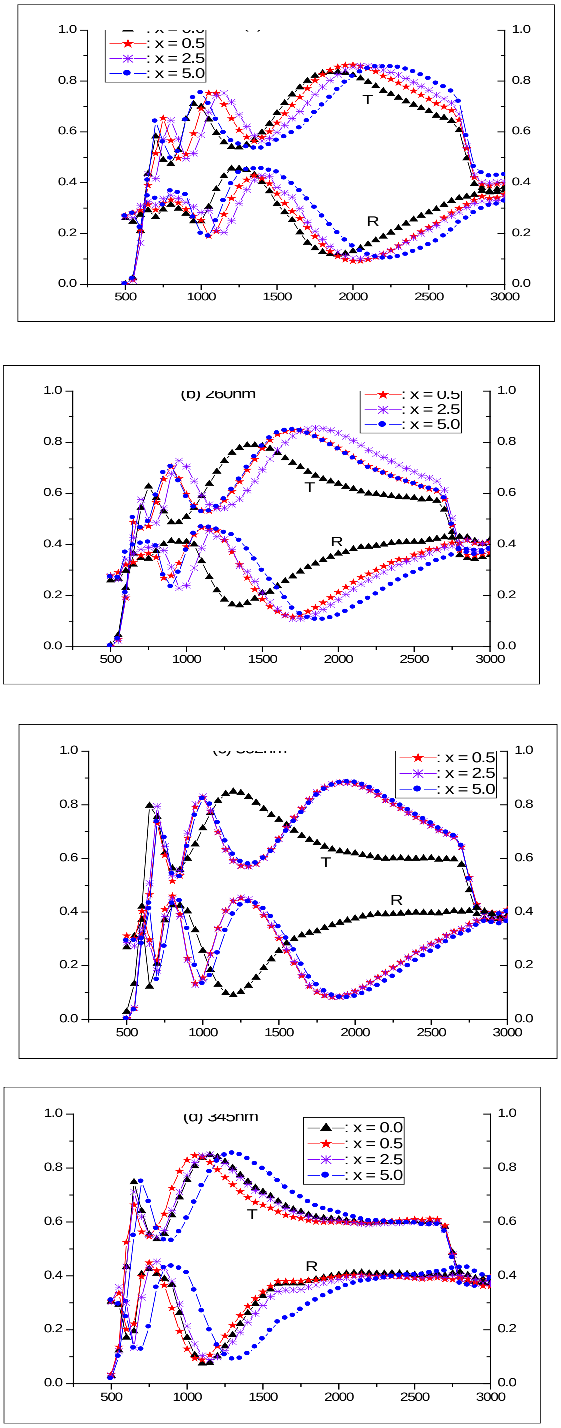

Figure 2. Transmittance and Reflectance against wavelength (nm) at different film thicknesses: (a) 215nm, (b) 260nm, (c) 302nm, and (d) 345nm

Absorption Coefficient and Extinction Coefficient

The optical absorption coefficient (Fig. 3(a)) increases with an increase in antimony content at a wavelength of 700nm. This may be an indication of increased photosensitivity of the as-deposited thin films with antimony addition.

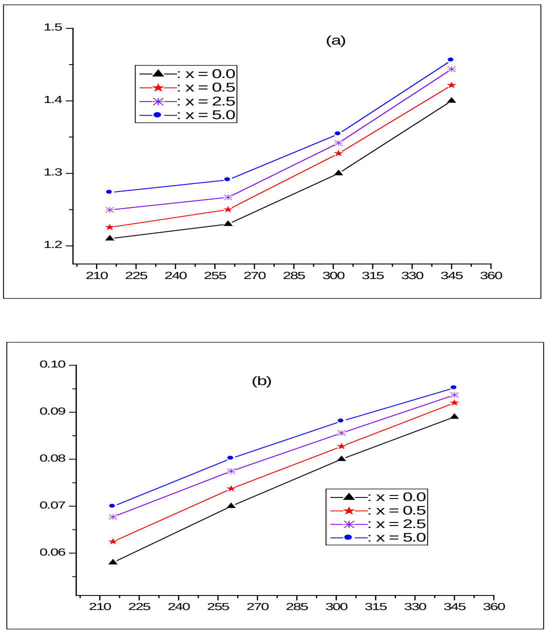

Figure 3. (a) Absorption coefficient and (b) Extinction coefficient against film thickness at different atomic percentages of antimony; λ = 700nm

Absorption coefficient increased with increase in film thickness since thicker films increases the absorption path length of the as deposited thin films decreasing the transmittance. Increase in extinction coefficient values with increase in antimony concentration and film thickness has been observed from Fig. 3 (b). This may be due to increased absorption coefficient of the as-deposited thin films. The absorption coefficient values found were in the order of $10^4 cm^{-1}$. This trend fits well with already published work [3, 10].

Refractive Index and Dielectric Constant

Refractive index was calculated based on the maximum and minimum transmittance envelops, T_M and T_m, respectively [11].

$$n = \left[N + (N^2 - S^2)^{1/2}\right]^{1/2}, \tag{3}$$

where $N = 2S\dfrac{T_M - T_m}{T_M T_m} + \dfrac{S^2 + 1}{2}$,

S is the refractive index of the glass substrate (1.51)

Real (ε_1) and imaginary (ε_2) parts of dielectric constant are given by [12];

$$\varepsilon_1 = n^2 - k^2, \tag{4}$$

$$\varepsilon_2 = 2nk. \tag{5}$$

Refractive index increased with increase with the antimony concentration as observed from Fig. 4 (a) at a wavelength of 700nm. Increase in refractive index as the antimony content increased may be due to increased polarizability of the system. The high polarizability of the chalcogenide glasses causes them to exhibit the highest intrinsic nonlinear response.

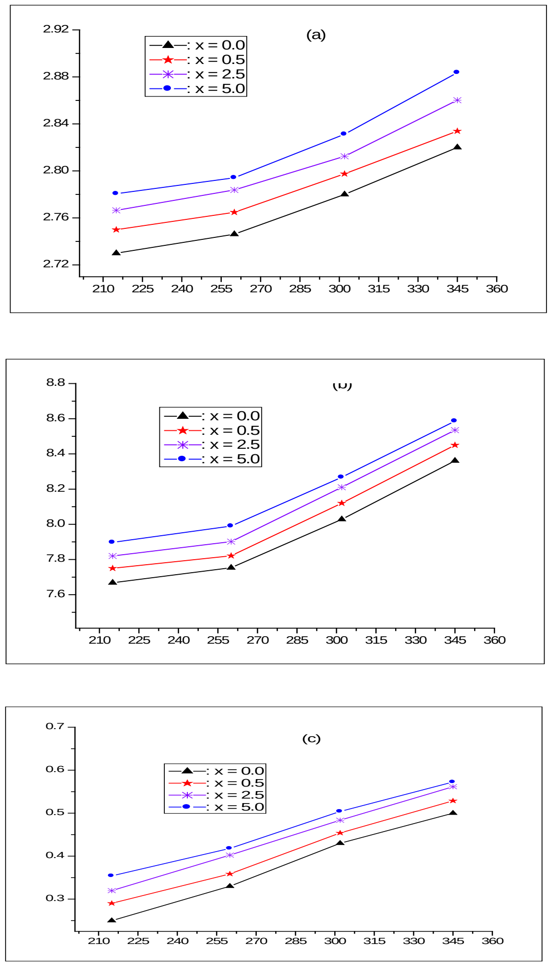

Figure 4. (a) Refractive index, (b) Real part of dielectric constant, and (c) Imaginary part of dielectric constant against film thickness at different antimony concentrations; λ = 700nm

The refractive index generally increased with increase in film thickness which could be due to increase in the film density due to the doping of Se with heavier Sb atoms. The real part and imaginary parts of the dielectric constant varied with film thickness due to the effect of the refractive index and extinction coefficient.

Optical Band Gap Energy

Figure 5 shows a plot of energy band gap (eV) against film thickness at different antimony concentrations and at a wavelength of 700nm. Decreased band gap energy with antimony addition is due to distortion of the material valence band, resulting in decreased band gap energy. When antimony is added to selenium binary system, it introduces defect states in the amorphous selenium-tellurium glass structure and this reduces the optical band gap energy of the system [3, 13]. The band gap energy of the as deposited $Se_{85-x}Te_{15}Sb_x$ *(x = 0.0, 0.5, 2.5, and 5.0 at. %)* thin films varied with film thickness due to high density of dislocations resulting from antimony impurity in the system.

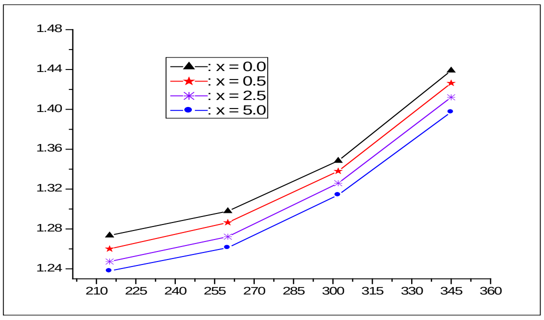

Figure 5. Energy band gap (eV) against film thickness (nm) at different antimony concentration; λ = 700nm

CONCLUSION

The study investigated the effect of film thickness on the optical properties of flash evaporated, as-deposited, amorphous $Se_{85-x}Te_{15}Sb_x$ *(x = 0.0, 0.5, 2.5, and 5.0 at. %)* thin films. It is found that transmittance and band gap energy decreased with increase in antimony content, while absorption coefficient, extinction coefficient, refractive index, reflectance, real and imaginary parts of dielectric constant increased with increase in antimony content. Further, as the film thickness increased from 215±10nm to 345±10nm, transmittance decreased but band gap energy, reflectance, absorption coefficient, extinction coefficient, refractive index, real and imaginary parts of dielectric constant increased.

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