

Optical band gap and refractive index of ternary $\text{Ge}_{20}\text{Se}_{77.5}\text{Bi}_{2.5}$ semiconducting glass

G. ACHAMMA, D. SUSHAMA, P. PREDEEP*

Condensed Matter Physics Lab, Sree Narayana College, Kollam, Kerala, India 691 001

The optical transmission spectra at normal incidence of amorphous ternary $\text{Ge}_{20}\text{Se}_{77.5}\text{Bi}_{2.5}$ glass has been measured in the range from 200nm – 800nm. From the transmission spectrum, the refractive index(n), the thickness(t) of the film, absorption coefficient ' α ' and extinction coefficient ' k ' have been obtained using Swanepoel's method. The optical band gap (E_g) has been calculated from the optical absorption model using Tauc's model. The variation of refractive index and extinction coefficient with photon energy are studied. The homogeneity of the glass composition was verified using XRD. Thin film of the alloy was prepared by a vacuum evaporation keeping substrate at room temperature and at base pressure of $\sim 10^{-5}$ Torr.

(Received March 23, 2007; accepted June 27, 2007)

Keywords: Ge-Se-Bi, Semiconducting glass, Optical transmission, Refractive index

1. Introduction

Ternary compounds of chalcogenide glasses find a wide range of applications. Chalcogenide glasses have extensive applications as electronic and optoelectronic device material [1]. This class of materials containing a large percentage of chalcogen elements is widely used in switching and memory devices [2,3]. An understanding of the dependence of various properties of such chalcogenide glasses on composition is important, because the continuously variable composition of these alloys may be utilized to prepare materials for particular applications.

The study of the optical constants of materials is interesting for many reasons. First, the use of materials in optical fibers and reflected coating requires accurate knowledge of their optical constants over wide ranges of wavelengths. Second, the optical properties of all materials are related to their atomic structure, electronic band structure and electrical properties. The index of refraction depends on the chemical composition of the glasses. Changes in the optical constants are in many cases very weak and very precise methods are necessary to determine them. There are many methods for optical characterization of thin films ranging from complicated computational techniques to ingenious experimental arrangements [4,5,6]. Optical transmission measurements are used extensively for the refractive index determination of transparent (or semiconducting) thin films deposited on fully or partly transparent substrates. R.Swanepoel [7,8] had developed a method for effectively analyzing the optical properties of amorphous thin films by analyzing the material's transmission spectrum. This method has the advantage that it is non destructive and yield the dispersion relation over a large range of wavelengths without any prior knowledge of the film's thickness.

For determining the optical constants, using only the transmission spectra, based upon Swanepoel has been used. This method is based on the upper and lower envelopes of the optical transmission spectra.

2. Experimental

A glassy alloy of $\text{Ge}_{20}\text{Se}_{77.5}\text{Bi}_{2.5}$ composition is prepared by melt quenching technique. High purity elements in appropriate atomic weight percentages were accurately weighed in to a quartz ampoule (length~14cm, internal diameter~1cm) and the ampoule was vacuum-sealed at a pressure of 10^{-6} Torr. The ampoule is kept inside a furnace where the temperature is raised to 1000°C at the rate of $3-4^{\circ}\text{C}/\text{min}$. The ampoule is frequently rocked for 24hrs at the maximum temperature to make the melt homogeneous. Quenching is done in ice water. The homogeneity of the glass composition was verified using XRD. Thin film of the alloy was prepared by a vacuum evaporation keeping substrate at room temperature and at base pressure of $\sim 10^{-5}$ Torr. The normal incidence transmission spectra have been measured by a UV/VIS/NIR Spectrometer, in the transmission range 200-800nm.

3. Results and discussion

According to Swanepoel, which is based on the approach of Manifacier et al [9], the refractive index in the region where the absorption coefficient α is ≈ 0 is calculated by the equation

$$n = [M + (M^2 - S^2)^{1/2}]^{1/2} \quad (1)$$

where

$$M = 2S (T_{\max} - T_{\min} / T_{\max} * T_{\min}) + (S^2 + 1)/2 \quad (2)$$

T_{\max} and T_{\min} are maximum and corresponding minimum of the transition spectrum at constant wavelength. and " n_2 " is the refractive index of the substrate (glass), typically $n_2 = 1.5$ for most glasses, So $T_{\max} \approx 0.92$. The

values of n_1 are calculated using different wavelengths corresponding to tangent points (at T_{max} and T_{min}). If n_1^1 and n_2^1 are the refractive indices at two adjacent tangent points at λ_1 and λ_2 , then according to the basic equation for interference fringes,

$$2nt = m \lambda \tag{3}$$

where m is an order number and the thickness is given by

$$t = \lambda_1 \lambda_2 / [4(\lambda_1 n_2^1 - \lambda_2 n_1^1)] \tag{4}$$

It should be noted that owing to optical absorption, this particular equation is not valid at the interference maxima and minima, but is valid at the tangent points referred to [7].

The refractive index (n) and the optical band gap (E_g) can be calculated by measuring the absorption coefficient (α), using the equation [7]

$$x = \exp(-\alpha t) \tag{5}$$

where x is the absorbance and t film thickness.

Fig.1 gives the dispersion curve of the refractive index with photon energy, from 200-800nm, for the given composition. It is observed that, the refractive index has the normal dispersion, according to Cauchy's Formula [10,11]. From the figure it is clear that the refractive index decreases with increase of photon energy.

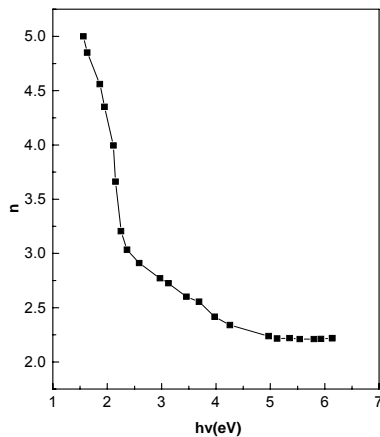


Fig. 1. Variation of refractive index with photon energy.

From the absorption coefficient data, extinction coefficient 'k' can be calculated as

$$k = \alpha \lambda / 4\pi \tag{6}$$

Fig. 2 shows the variation of extinction coefficient 'k' with the photon energy $h\nu$. From the figure it is clear that as $h\nu$ increases k also increases gives a broad peak, there after it goes on decreases. The changes obtained in the value of 'k' is due to change in the stoichiometry [12] and

internal strain [13] of the glassy alloy with the addition of Bi.

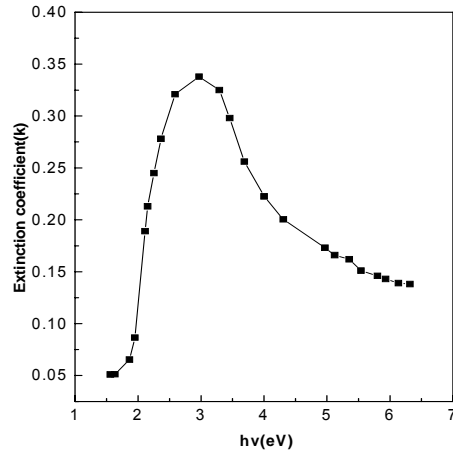


Fig. 2. Variation of extinction coefficient with photon energy.

A linear relation between $(\alpha h\nu)^{1/2}$ and the photon energy ($h\nu$), is presented for the given composition as shown in Fig. 3, which indicates that the indirect band gap transitions are predominant [14]. The optical band gap E_g can be calculated from the extrapolation of the linear portion of the line figure 4 to $(\alpha h\nu)^{1/2} = 0$, according to the relation [14,15,16].

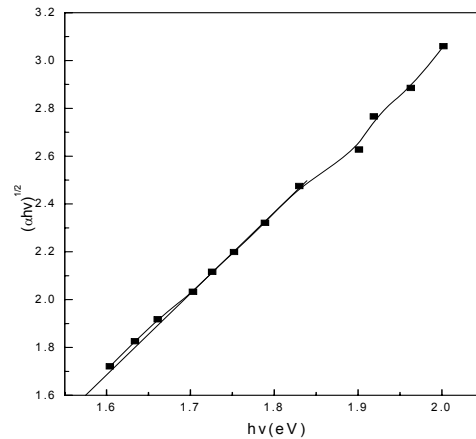


Fig. 3. Variation of $(\alpha h\nu)^{1/2}$ with $h\nu$ for $Ge_{20}Se_{77.5}Bi_{2.5}$ glass composition.

$$(\alpha h\nu)^{1/2} = B (E_g - h\nu) \tag{7}$$

where B - Tauc constant [17], is determined from the slope of the linear part in figure 3. This constant represents the degree of randomness of the structure of the amorphous solids [15]. It depends on the transition probability and the refractive index.

4. Conclusions

The optical properties of the given glass composition has been calculated. The variation in the value of the refractive index 'n' and extinction coefficient 'k' could be explained in terms of the changes introduced in the stoichiometry, crystalline size and internal strain of the glassy alloy due to the introduction of Bi.

References

- [1] D. Alder, *Sci. Amer.* **36**, 236 (1997).
- [2] S. R. Ovshinsky, *Phys. Rev. Lett* **21**, 1450 (1968).
- [3] R. Zallen, "The Physics of Amorphous Solids". (Wiley, New York, (1983)).
- [4] S. P. Lyashenko, V. K. Milolavaskii, *Opt. Spectrsc.* **16**, 80 (1964).
- [5] J. Wales, G. J. Lovitt, R. A. Hill, *Thin Solid Films* **1**, 137 (1967).
- [6] L. Vriens, W. Rippens, *J. Physics. D. Appl. Phys.* **22**, 199 (1989).
- [7] R. Swanepoel, *J. Phys. E: Sci. Instrum.* **16**, 1214 (1983).
- [8] R. Swanepoel, *J. Phys. E: Sci. Instrum.* **17**, 896 (1984).
- [9] J. C. Manificier, J. Gasoit, J. P. Fillard. *J. Phys. E: Sci. Instrum.* **9**, 1002, (1976).
- [10] F. A. Jenkins, H. E. White "Fundamentals of Optics" (London: Mc Graw-Hill), 479 (1985).
- [11] S. Sakaguchi et.al, *J. Non.Cryst.Solids.* **196**, 58 (1996).
- [12] K. Yamaguchi, N. Nakayama, H. Matsumoto, S. I. Kegami, *Jpn. J. Appl. Phys* **16**, 1203 (1977).
- [13] A. Ashour, N. El-Kdry, S. A. Mahmoud, *Thin Solid Films* **269**, 117 (1995).
- [14] H. T. El-Shair, A. E. Bekheet, *J. Phys. D. Appl. Phys.* **25**, 1122 (1992).
- [15] N. A. Bakr, M. I. Abdel- Hamid, *J. Mat. Res.* **10**, 2653 (1995).
- [16] K. Sedeek, E. A. Mahmoud, F. S. Terra, A. Said, S. M. Ei-Din, *J. Phys. D: P Appl. Phys.* **27**, 156 (1994).
- [17] J. Choi, A. Singh, E. A. Davis, S. J. Gurman, *J. non. Cryst. Solids* **198-200**, 680 (1996).

*Corresponding author: physics@asianetindia.com;
ppredeep@gmail.com