Optical Characterization of Sb Doped Se-In Glassy System and Its Applications in Optical Devices

Received on 04 March, 2020, accepted on 04 October, 2021

Anjani Kumar[1,a)], S. Shukla[2], Sudhir K. Sharma[1], S. Kumar[3] and R.K. Shukla[1]
[1]*Department of Physics, School of Basic & Applied Sciences, Harcourt Butler Technical University, Kanpur-208002, India*
[2]*Department of Physics, U.I.E.T., C. S. J. M. University, Kanpur-208024, India*
[3]*Department of Physics, Christ Church College, Kanpur-208001, India*
[a)]Corresponding author: **anjanikumar.hbti@yahoo.com**

Abstract: *Thin films of a-$Se_{75}In_{25-x}Sb_x$ (where x = 0, 5, 10 and 15) glassy samples are prepared by vacuum thermal evaporation technique in the presence of vacuum on properly well cleaned glass substrate. The transmittance of as-deposited thin films is measured within the wavelength range 400-2100 nm. The optical parameters like refractive index (n), extinction coefficient (k), absorption coefficient (α), real and imaginary dielectric constants (ε' &ε") have been calculated in the measured range of wavelength, by Swanepoel's strategy using optical data of transmission spectra. The optical band gap (E_g) has also been calculated by Tauc's relation. It is found that various optical parameters display a discontinuity at x = 10 suggesting a mechanically stabilized shape at this atomic concentration and can be described on the basis of chemically ordered network (CON) model and the topological model. On the basis of various optical parameters these amorphous chalcogenide systems can be used in various optical device applications such as optical fibers, solar cells and IR optical devices.*

INTRODUCTION

Chalcogenide semiconductors have definitely emerged as multipurpose components and had been used to fabricate technological vital devices: Infra Red detectors, digital and optical switches and optical recording media [1-5]. The low feature vibrational frequencies of chalcogenide bonds permit them to transmit far out into the infrared range [6]. These glassy semiconductors displayed a number of photo-stimulated phenomena when exposed radiations of respective wavelength range [7]. In fashionable, those phenomena are related to the changes inside the optical constants and absorption edge shift [8], permitting these substances in the fabrication of a huge number of optical gadgets. Therefore, the determination of the optical parameters of chalcogenide amorphous semiconductors may be very important, no longer most effective in order to realize the simple mechanisms underlying these phenomena, but additionally to expand and utilize their technological programs. The know-how of actual and imaginary elements of complex refractive index, as a feature of wavelength, is important to make effective use of those materials for opto-electronic devices. Furthermore, the potential to manipulate the refractive index of a semiconductor is vital in the layout of many photonic gadgets. Chalcogenide semiconductor substances are dispersive so that the refractive index is depending on wavelength. Because of their capacity applications as the energetic layers in solar cells [9], and as switching factors for memory applications [10], currently, Se-In chalcogenides, in both amorphous and crystalline forms, have attracted a great deal of interest. This system has been extensively studied for solar energy and photovoltaic sensors. It is also an important material in the field of infrared detectors due to its high electron and hole mobility and low energy gap at room temperature [11].These materials are also used for the fabrication of high-speed, Hall and photo voltaic devices and are especially attractive because of easy availability, low cost and simple handling [12].

The special characteristics of chalcogenide binary alloys are usually affected by the third element doping. Several researchers [13, 14] have reported the impurity outcomes inside the optical characteristics of numerous binary chalcogenides and observed them pretty compositional based. It has also been observed that the effect of impurities depends strongly at the composition of the glass, the chemical nature of the impurity and also the approach of the doping

In view of the above, here the effect of Sb incorporation on the optical transmission characteristics of $Se_{75}In_{25}$ binary glassy system has been studied by using relative easy Swanepoel's approach for evaluating numerous optical parameters [15].

EXPERIMENTAL DETAIL

Bulk samples of $Se_{75}In_{25-x}Sb_x$ (where x = 0, 5, 10 and 15) system were prepared by melt quenched technique. Thin films of glassy alloys of $Se_{75}In_{25-x}Sb_x$ were prepared by vacuum evaporation approach. Then optical transmission spectra of chalcogenide thin films of $Se_{75}In_{25-x}Sb_x$ (where x = 0, 5, 10 and 15) are measured by NIR spectrophotometer. These interference fringes can be used to evaluate numerous optical constants.

RESULT AND DISCUSSION

Determination of refractive index and extinction coefficient

Fig. 1 shows the transmission spectra as a function of wavelength for thin films of $Se_{75}In_{25-x}Sb_x$ system. The plot shows fringes due to interference at various wavelengths. The various optical parameters were determined using Swanepoel's method [15] which is based on the idea of Manificier et al. of creating upper and lower envelopes of the optical transmission spectra.

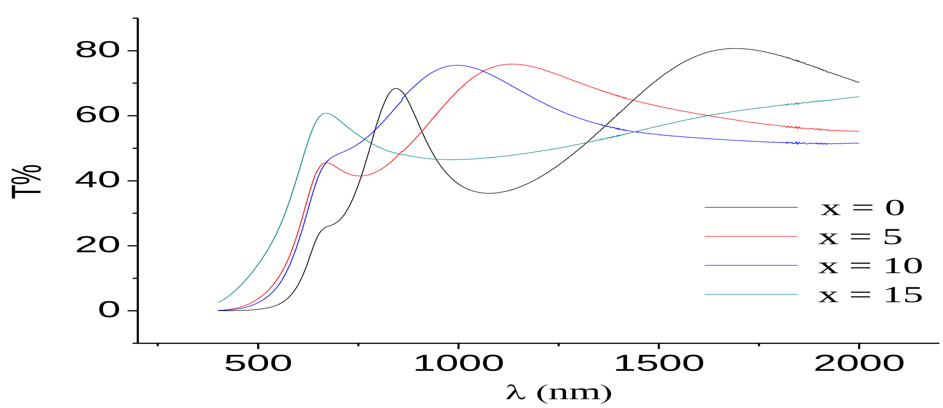

FIGURE 1. Plot of the transmittance (T) with wavelength (λ) in $Se_{75}In_{25-x}Sb_x$ (where x = 0, 5, 10 and 15) thin films.

The refractive index, n of the film in the transparent region (α = 0) is given by

$n = [N+ (N^2-s^2)^{1/2}]^{1/2}$ (1)

where $N = (2s/T_m)-(s^2+1)/2$ (2)

where T_m is the envelope values at the wavelengths in which the lower envelope and the experimental transmission spectrum are tangent and s is the refractive index of the substrate.

In the region of weak and medium absorption, where $\alpha \neq 0$, transmittance decreases mainly due to the effect of absorption coefficient (α) and Eq.(2) modifies to

$N = [2 s (T_M-T_m) / T_M T_m] + (s^2+1) /2$ (3)

where T_M is the envelope values at the wavelengths in which the upper envelope and the experimental transmission spectrum are tangent.

If n_1 and n_2 are the refractive indices of two adjacent maxima or two adjacent minima at wavelengths λ_1 and λ_2, respectively, then according to the basic equation for interference fringes:

$2nd = m \lambda$ (4)

where 'm' is an order number. The thickness is given by

$d = \lambda_1 \lambda_2/ 2(\lambda_1 n_2 - \lambda_2 n_1)$ (5)

The extinction coefficient k, which is a measure of fraction of light lost due to scattering and absorption per unit distance of the participating medium is calculated by the relation $x = \exp(-4\pi kd/\lambda)$. The absorbance, x is given in terms of the interference extremes using the following relation [15]:

$x = [E_M -\{E_M^2-(n^2-1)^3(n^2-s^4)\}^{1/2}]/ [(n-1)^3(n-s^2)]$ (6)

Where $E_M = [(8n^2s/ T_M) + (n^2-1) (n^2-s^2)]$ (7)

The variation of values of n and k with wavelength for different compositions of $Se_{75}In_{25-x}Sb_x$ glassy system are shown that n and k decreases with an increase in λ. This behavior is due to increase in transmittance and decrease of absorption coefficient with λ. The reduction in refractive index with λ indicates the normal dispersion behavior of the material. A minimum in composition dependence of n and k is obtained at 10 at. % of Sb concentration (see Table 1).

Determination of dielectric constants

The real (ε') and imaginary (ε'') parts of the dielectric constants for $Se_{75}In_{25-x}Sb_x$ thin films can be calculated with the help of n and k by using following equations:

$\varepsilon' = n^2 - k^2$ (8)

$\varepsilon'' = 2nk$ (9)

Results show that variation of ε' and ε'' with λ follows the same trend as followed by n and k. It is evident from the Table 1 that ε' and ε'' are minimum at 10 at.% of Sb.

TABLE 1. Optical parameters for $Se_{75}In_{25-x}Sb_x$ (where x = 0, 5, 10 and 15) thin films**.**

Glassy Samples	Refractive Index (n)	Extinction Coefficient (k)	Real dielectric constant (ε')	Imaginary dielectric constant (ε'')
$Se_{75}In_{25}$	3.50	4.52×10^{-2}	12.35	0.57
$Se_{75}In_{20}Sb_5$	2.84	5.70×10^{-2}	8.00	0.70
$Se_{75}In_{15}Sb_{10}$	2.55	4.16×10^{-2}	6.51	0.52
$Se_{75}In_{10}Sb_{15}$	3.12	6.28×10^{-2}	9.73	0.80

Determination of absorption coefficient and optical band gap

The absorption coefficient (α) of the $Se_{75}In_{25-x}Sb_x$ thin films can be calculated from the values of k and λ using the known formula $k = \alpha\lambda/ 4\pi$ and α is found to increase with increase in hν. The calculated values of αis also listed in Table 2. A discontinuity in α is also found at 10 at.% of Sb concentration (see Table 2).

In chalcogenide glasses, the optical absorption edge spectra generally contain three distinct regions: (i) high absorption region ($\alpha = 10^4$ cm^{-1}), which involves the optical transition between valence band and conduction band and determines the optical band gap. The absorption coefficient in this region is given by

$$\alpha\nu h = B\,(h\nu - E_g)^p \qquad (10)$$

where E_g and B are known as optical energy gap and band tailing parameter respectively. In the above mentioned equation, p =1/2 for a direct allowed transition, p = 3/2 for a direct forbidden transition, p = 2 for an indirect allowed transition and p = 3 for an indirect forbidden transition.

(ii) For α less than about ~ 10^4 cm^{-1} there is usually an Urbach tail where α depends exponentially on the photon energy and is given by

$$\alpha\,\nu h = \alpha_0 \exp(h\nu / E_e), \qquad (11)$$

where α_0 is a constant and E_e is the width of the band tail of localized states in the band gap which generally represents the degree of disorder in amorphous semiconductor.

(iii) The region ($\alpha \leq 10^2$ cm^{-1}) involves low energy absorption and originates from defects and impurities.

The analysis of the absorption coefficient has been carried out to obtain the optical band gap. The optical band gap (E_g), has been determined from absorption coefficient data as a function of photon energy (hν), using the Eq.(10). After fitting all the values of p in the Tauc's relation, the value of p equals to 2 is found to hold good leading to indirect transitions. The graph between $(\alpha h\nu)^{1/2}$and hν for $Se_{75}In_{25-x}Sb_x$ films is shown in the Fig. 2. The non-linear nature of the graph provides evidence that the transition in the forbidden gap is of indirect type. The values of E_g are given in Table 2 for the samples under consideration. It is clear from the table that E_g decreases with the addition of Sb content and show a discontinuity for x = 10.

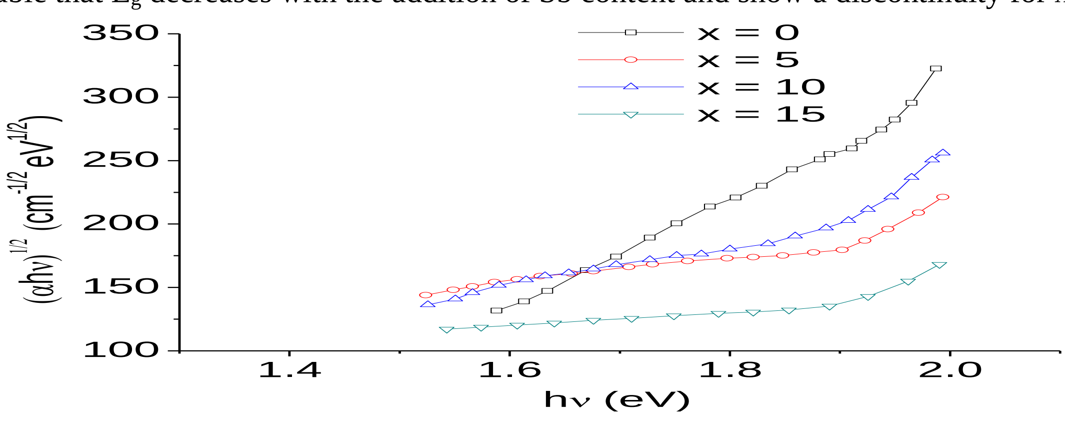

FIGURE 2. Plot of $[\alpha h\nu]^{1/2}$ against photon energy (hν) in $Se_{75}In_{25-x}Sb_x$(where x = 0, 5, 10 and 15)thin films.

TABLE 2. Optical band gap and absorption coefficient for a-$Se_{75}In_{25-x}Sb_x$(where x = 0, 5, 10 and 15)thin films

Glassy Samples	**Optical band gap (E_g) in eV**	**Absorption coefficient (α) in cm^{-1} at 650 nm**
$Se_{75}In_{25}$	1.65	3.53×10^4
$Se_{75}In_{20}Sb_5$	1.57	1.70×10^4
$Se_{75}In_{15}Sb_{10}$	1.61	2.16×10^4
$Se_{75}In_{10}Sb_{15}$	1.54	1.03×10^4

In the present measurements, discontinuity is observed at 10 at.% of Sb concentration in $Se_{75}In_{25-x}Sb_x$ for various optical parameters. As mentioned in previous communication of Shukla et al. [16], many approaches have been proposed to explain the compositional dependence of various physical properties of chalcogenide amorphous semiconductors. One of these approaches is the so-called chemically ordered network (CON) model, In this model, the structure of glassy material is assumed to be composed of cross-linked structural devices of the steady chemical compounds (hetropolar bonds) of the gadget and excess, if any, of the elements (homopolar bonds). Due to chemical ordering, aspects (such as extremum, a alternate in slope) bought for the range of characteristics at the so referred to as the tie line or stoichiometric compositions at which the structure of amorphous material is made up of cross-linked structural components incorporating of hetropolar bonds only. The tie line compositions, where the features seen have chemical origin, are also referred as the chemical threshold of the system.

Other tactics are the so-called topological models in which the properties can be mentioned in terms of the average coordination number <z>. Therefore the variation in optical parameters for different compositions of $Se_{75}In_{25-x}Sb_x$ can be explained in terms of <z>. The average co-ordination number <z> is evaluated by using the standard method and found 2.55 at 10 at.% of Sb.

In the present case a discontinuity in several optical parameters is observed at 10 at. % of Sb having $\langle z \rangle = 2.55$.Saffarini et al. [17] have also reported the similar kind of discontinuity in their study of compositional dependence of the compactness (δ) for Ge-Bi-S chalcogenide amorphous semiconductors. This discontinuity could be understood by assuming that the structure of this particular composition with $\langle z \rangle = 2.56$ is a layered one with a network dimensionality D = 2 and it can be argued that the said discontinuity marks the 2D→3D structural transition in these amorphous materials. The discontinuity observed by us in various optical parameters at $\langle z \rangle = 2.55$ may be considered, along the same lines, due to the above mentioned results. A similar kind of discontinuity was once also mentioned by using us in our previously communication. These all glassy systems are transparent to close to IR region and hence can be used as Infrared optical lenses and additionally infra red detectors. 0 and 15 atomic % doped Sb samples can be used as core materials and 10 and 5 atomic % doped Sb samples can be used as cladding materials, on the basis of optical band gap 15 atomic % doped Sb samples can be used for solar cell applications.

CONCLUSION

The optical transmission spectra of thin films of $Se_{75}In_{25-x}Sb_x$ (x = 0, 5, 10 and 15) are basically measured in the wavelength range 400-2100 nm by NIR spectrophotometer. Various optical constants have been calculated by Swanepoel approach using optical transmission data. Lowering the value of n, k, ε' and ε'' with increase in wavelength has been observed and it is also found that these optical parameters show a discontinuity at 10 at % of Sb suggesting a mechanically stabilized structure at this concentration and can be explained on the basis of two models chemically ordered network (CON) model and the topological model. These amorphous materials can be used as IR lenses, IR detectors, optical fiber communications and solar cell applications also.

REFERENCES

1. S. R. Elliot, Physics of amorphous materials, Longman publication, London 1991.
2. Ishu Sharma, S. K. Tripathi, P. B. Barman, J. Appl. Phy. **110**, 043108-1-7 (2011).
3. F. Chen, J. Zhang, C. Cassagne, G. Boudebs ,J. American Ceramic Society, **103**, 5050-5055 (2020).
4. Q. Li, R. Wang, Fu Xu, X. Wang, Z. Yang, X. Gai, Opt. Mater. Exp.**10**1413-1420 (2020).
5. A. Seddon, Phys. Stat. Solidi B, **250(5)** 1020-1027 (2013)
6. P. J. S. Ewen, C. W. Shinger, A. Zakery, A. Zekak, A. E. Owen, SPIE Infrared Optoelectron. Mater Dev, **1512,** 101-107 (1991).
7. M. S. Iovu, S. D. Shutov, M. Popescu, J. Non-CrystSolids, **299-302**, 924 -928 (2002).
8. V. M. Lyubin, M. Klebanov, B. Sfez, B. Ashkinadze , Mat. Lett., **58**,1706-1708 (2004).
9. B. Pejjai, V. R. M. Reddy, K. Seku, H. Cho, M. R. Pallavolu, T. Thi Thuy Le, Dong-seob Jeong, T. R. R. Kotte, C. Park, Korean J. Chem. Engg., **35** 2430–2441 (2018)
10. S. Marsillacx, J. C. Bernede, A. Conan, J Mater Sci 31, 581-587 (1996).
11. A. H. Welker, Z. Naturforsch, **7(a)** 744 (1952).
12. A. G. Milnes, Deep impurities in semiconductors. New York: Wiley, 1973, p. 45.
13. A. A. Al-Ghamdi, Vacuum, **80**, 400-405 (2006).
14. S. A. Fayek, S. M. El-Sayed. NDT & E International **39(1)**, 39-44 (2006).
15. R. Swanepoel, J Phys E, **16** 1214-1222 (1983).
16. S. Shukla, S. Kumar, Physica B, **405** 4307–4312 (2010).
17. G. Saffarini, J. M. Saiter, Chalcogenide Letters, **3**49-53 (2006).