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Study of femtosecond nonlinear optical coefficients for Bi doped $Se_{85-x}Te_{15}Bi_x$ chalcogenide thin films

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The present work reports the influence of selenium replacement by bismuth on the nonlinear optical parameters of ternary $Se_{85-x}Te_{15}Bi_x$ (x=0, 1, 2, 3, 4, 5 atomic %) chalcogenide thin films. Calculation of nonlinear refractive index (n_2), two-photon absorption coefficient (β_2) and third-order susceptibility ($\chi^{(3)}$) by well known Z-scan technique with femtosecond laser pulses were done. The Z-scan spectra for $Se_{85-x}Te_{15}Bi_x$ upto Bi= 4 atomic % results in self- focusing behavior of n_2 is positive while for Bi=5 atomic % n_2 is negative. The behavior of n_2 by using different physical parameters are exlpained. The comparison of experimental and theoretical values of n_2 with pure silica are also studied. The presence of the valley at focus in open aperture Z-scan graph demonstrates strong reverse saturable absorption. The figure of merit (FOM) for the Se-Te-Bi chalcogenide thin films is found to be less than 1 and are beneficial for all-optical switch devices.

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Keywords: Chalcogenide glasses, Nonlinear refractive index (n_2), Two-photon absorption coefficient (β_2), Third-order susceptibility ($\chi^{(3)}$), Z-scan technique

1. Introduction

The present curiosity in optical limiting devices for defense application is motivating passionate research to characterize new nonlinear materials. A large number of materials are available in literature for optical limiters. Among these, chalcogenide glasses are of significant interest because of non-resonant type third order nonlinearity with response time of < 1 picosecond and highest nonlinear refractive index [~ 1000 times higher than silica] [1-3]. In recent research scenario, researchers showed great interest towards active plasmonics device made by chalcogenide glasses. This interest is because of their higher bandwidth, fast response time and high nonlinear enhancement factor [4]. Chalcogenide glasses can be used as highly sensitive sensors [5], changed environmental conditions [6]. Due to high optical losses, these materials can be also used in photonic applications [7]. Moreover, due to their linear and nonlinear optical properties, chalcogenide glasses are advantageous materials for optical switches, optical imaging, Raman amplification [8], optical regenerators, parametric amplifiers [9], electro-optic modulators[10], supercontinuum generation, and so on [11-12].

In this regard, the Se-Te combination is regarded as the prototypical semiconducting chalcogenide, playing a significant role in applications including nonlinear optics, higher photosensitivity, higher hardness, higher crystallisation temperature, and reduced ageing impact [13-14].

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Because of modifications in their optoelectrical properties, it is considered as innovative hopeful uses of multicomponent chalcogenide systems, several investigations that are based upon Se-Te chalcogenide additives are of keen interest [15].

Out of these, bismuth is chosed as a dopant which further demonstrate noteworthy impact on the host Se-Te material by a variety of changes, like phase transformation, carrier type reversal and change in optoelectrical properties that explains fundamental mechanisms inside the system [16-17].

This composition is also advantageous for night vision and thermal imaging devices, which are currently in high demand due to their better transmission in the IR range. In a BMW class 5 car, thermal imaging and night vision systems utilises to extend driver's detection range in low-light and foggy conditions to more than 300 metres, gaining more than 7 seconds (average speed-100 km/h) [18].

To attain high performance of optical limiting devices, it can be necessary to evaluate the nonlinear parameters of the materials. Some of the famous techniques used for the calculation of nonlinear properties are four wave mixing (FWM)[19] , nonlinear interferometry[20], ellipse rotation [21] and Z-scan technique[22] . However, out of these above mentioned techniques, a Z-scan technique is widely used by researchers due to its uncomplicated setup and results. Optical limiting devices requires strong nonlinear response and with the increase of irradiance transmission decreases for optical limiters. The efficiency of the optical limiters is analyzed using limiting threshold [23]. Various process are based on optical limiting response for different material. In amorphous semiconductor, the optical limiting is described using two photon absorption and n_2. The optical limiting property of chalcogenide thin films are studied by researchers [24-26].

Optical limiting study of As_2S_3 were described by Ganeev et. al. [24] in accordance with two photon absorption. Sunita et. al. [25] have reported the optical limiting response of Zn_x-S_y-$Se_{100-y-x}$ chalcogenide glasses. The optical limiting behavior of Nano colloidal $Ge_{28}Sb_{12}Se_{60}$ chalcogenide thin film were studied by R. Tintu et. al. [26].

In this work, preparation of homogeneous Se-Te-Bi chalcogenide glasses were done. The third order nonlinear optical properties of prepared thin films are characterized by Z-scan method (800 nm). The behavior of n_2 in accordance of optical band gap (E_g), linear refractive index (n) and lone pair electrons in the present study are analyzed and discussed. Our present study is focused at the explanation of the affecting parameters like change in glass composition on n_2, $\chi^{(3)}$ etc. of Se-Te-Bi chalcogenide thin films. $\chi^{(3)}$ real, imaginary and absolute value are also studied. The experimental and theoretical calculated values of n_2 and of pure silica are compared.

2. Experimental details

Glassy alloys of $Se_{85-x}Te_{15}Bi_x$(x= 0, 1, 2, 3, 4, 5) system are synthesised through eminent melt quenching method. Firstly, samples used in the composition are weighed by highly précised physical balance and are kept in a pre-cleaned quartz ampoule. The quartz ampoule is vacuum-packed under the pressure of 10^{-4} torr by rotary and diffusion pump. The materials in the sealed ampoule is melted in a furnace by slowly increasing temperature up to a range 300–1000^{0}C according to the melting temperature of the materials inside the ampoule and retained it for 24 hours with regularly agitated to have homogeneous mixing of constituents. Ice cold water has been utilized for quenching of the melt. Ingot of glass has been obtained by breaking the ampoules. To make the powder form of obtained glass, the ingot has been grinded by mortar and pestle. For nonlinear optical study, the thin films of the resultant bulk glasses were coated on cleaned and dried glass slide by thermal evaporation technique (10^{-5} torr).

The Z-scan technique which can be utilised for the analysis of n_2, β_2, real and imaginary part of $\chi^{(3)}$. Z-scan results are achieved with the help of mode-locked femtosecond Ti: Sapphire laser (Model: Coherent Libra-HE) with an operating wavelength of 800 nm, an 80-fs pulse width, and a 1 KHz repetition rate as the light source. The sample has an incident laser intensity of around 2.23 TW/cm^2. A plano convex lens with a focal length of around 10 cm has been employed to concentrate the laser light. A silicon photodiode (OSI optoelectronics PIN-10D detector) is used to capture the light which transmits across the material. The estimated Rayleigh range, $z_0 = kw_0^2/2$, is further calculated using beam waist radius at focus, which is 19 m. Here, k is the wave vector, and 1.4 mm is the predicted Rayleigh range.

3. Results and discussion

The appearance of nonlinear absorption in thin films can occurs because of two-photon absorption or direct multiphoton absorption or saturable absorption etc. Open aperture Z-scan method is unresponsive to nonlinear refraction and symmetrical graphs with respect to the focus will be observed with maximum transmittance (i.e saturable absorption) or minimum transmittance (i.e multi photon absorption). β_2 in two photon absorption process are associated with the linear absorption coefficient (α_0) using the relation:

$$\alpha(I) = \alpha_0 + \beta_2 I \quad (1)$$

In this relation $\alpha(I)$ is the change in α_0. β_2 of studied samples are computed by Z-scan method. In this method, to collect energy from incident light and eliminate the aperture. By exploiting the difference in between normalized transmittance (z=0) and the base line, β_2 is evaluated by subsequent relation:

$$\beta_2 = \frac{2\sqrt{2}\Delta T}{I_0 L_{eff}} \quad (2)$$

Here, I_0 - incident intensity. L_{eff} is the effective sample thickness that is:

$$L_{eff} = \frac{1-exp(-\alpha_0 L)}{\alpha_0} \quad (3)$$

Here, L shows sample thickness. Calculated thickness came out to be 500±50 nm, and as a result it was smaller amount than Rayleigh range($L<z_0$) and regarded as thin media claimed by Shaik & Bahea [27]. Fig. 1 reveals open aperture Z-scan graph of Se-Te-Bi films. Theoritical fitting were applied to the experimental graphs for the characterization of two-photon absorption. Fig. 1 circle shows the experimental results and theoretical fits are shown by solid lines. Graph depicts formation of valley at focus, as the sample is translated from –z to z direction towards the focus and also a strong reverse saturable absorption (RSA) can be seen. The calculated value of β_2 increases from 0.7 x 10^{-8} to 1.39 x 10^{-8} with increase in Bi content from 0 to 5 atomic percent as shown in Table 1. Increased behavior of β_2 has been ascribed in accordance with Shaik & Bahea and Van Stryland theory [27, 28]. In agreement with this theory, β_2 can be associated with E_g using $\beta_2 \propto \frac{1}{(E_g)^3}$. As E_g decreases, the possibility of two-photon absorption has been increased. As Bi content is added into Se-Te matrix, E_g decreases from 1.46 to 1.24 eV. The decrease in E_g has been described by taking into account the electronegativity difference between the elements present. The formation of valence band in chalcogenide glasses are due to the presence of lone pair p- orbitals, as stated by Kastner et al. [29].

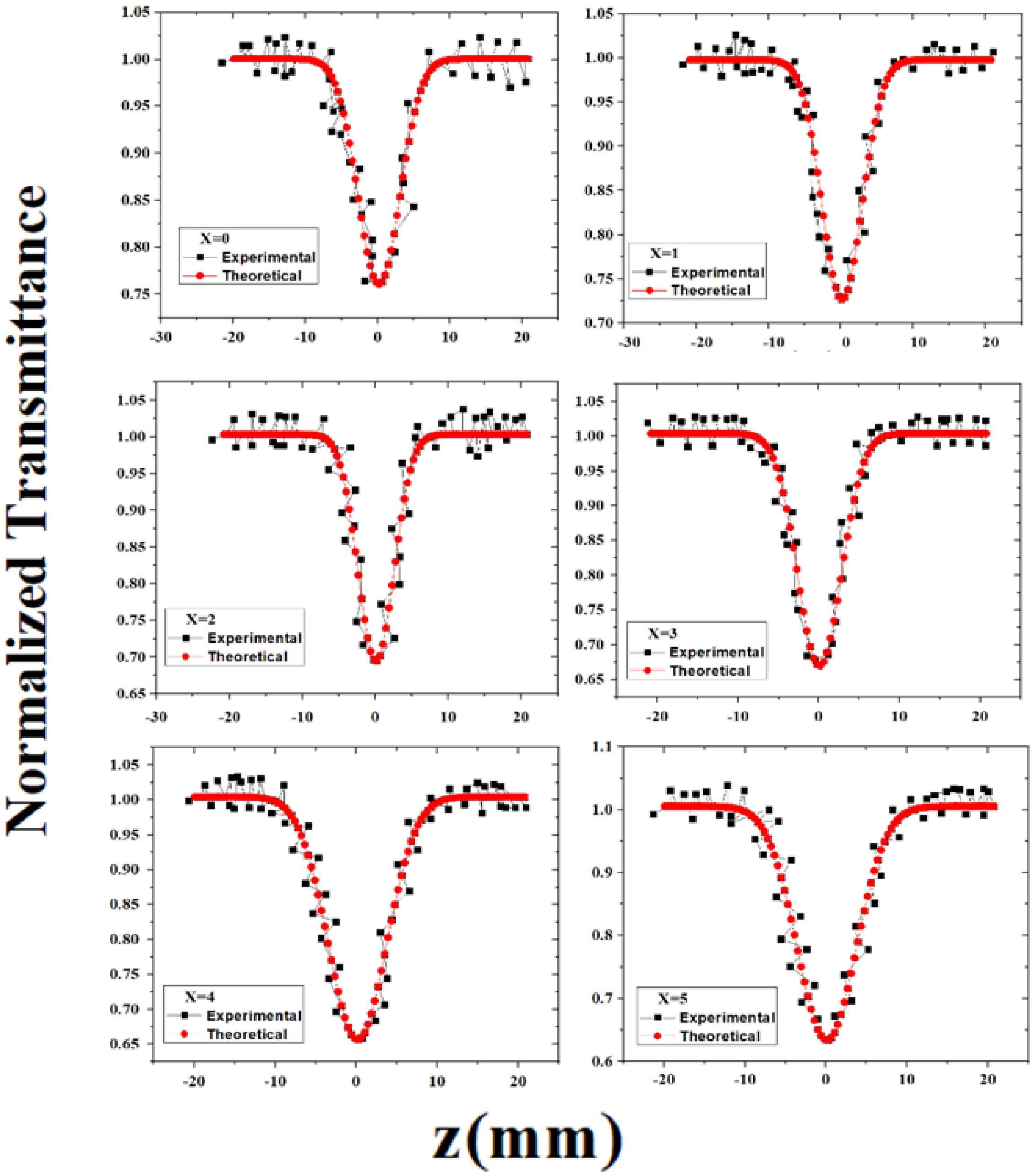

Fig. 1. Normalized open aperture transmittance for $Se_{85}Te_{15}Bi_x$ thin films at 800 nm.

In comparison to electronegative atoms, the lone pair electrons are having the highest energy closest to electropositive atoms. When electropositive elements are added to the matrix, as a result the lone pair states energy increases, as well as it broadens the valence band. The electronegativities of Se is 2.4 , Te is 2.1, and Bi is 2.0 . This is further accountable for band tailing and accordingly reduces the optical bandgap. Consequently, TPA increase with the increased Bi to Se-Te matrix. The behaviour of TPA with E_g is shown in Fig .2.

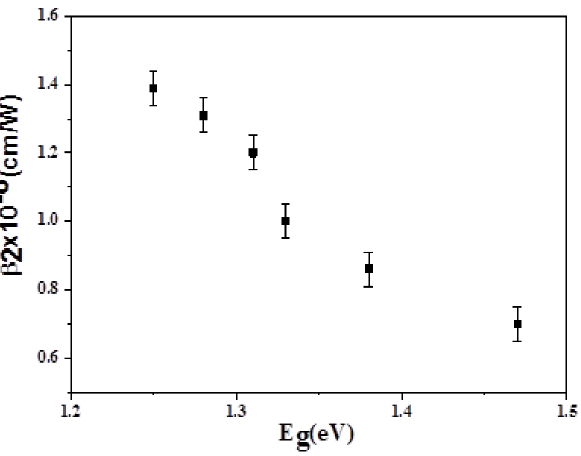

Fig. 2. TPA coefficient versus E_g for $Se_{85}Te_{15}Bi_x$ thin films.

Further, two photon absorption has strong influence on the measurement of n_2 by Z-scan method. For closed aperture measurements contribution from material of absorptive and refractive nonlinearities are present . To discard effect of nonlinear absorption, the closed aperture Z-scan data of prepared thin films are divided with open aperture data. After that the resulting Z-scan curve are fitted theoretically using the normalized transmittance. The variability between normalized peak and valley transmittance are estimated by Z-scan technique via; the relation

$$\Delta T_{P-V} = 0.406(1-S)^{0.25}|\Delta\Phi_0| \quad (4)$$

S represents aperture transmittance and $|\Delta\Phi_0|$ shows on-axis phase shift. The involvement of a specific material is governed by characterizing $|\Delta\Phi_0|$ due to the nonlinear refraction. Further $|\Delta\Phi_0|$ was used to study n_2 by following relation:

$$n_2 = \frac{|\Delta\Phi_0|}{kL_{eff}I_0} \quad (5)$$

where $k=2\pi/\lambda$ is wave number.

Fig. 3 depicts closed aperture results at laser intensity 2.23 TW/Cm^2. The small shift between experimental and theoretical plot ascribed the little variation in the Gaussian shape of the laser pulse. Peak-valley trace in closed aperture Z-scan (Fig. 3) indicates that the studied thin films show switching between self-focusing(n_2>0) and self- defocussing(n_2<0) nonlinearity. The appearance of peak after the valley upto Bi=4 atomic percent in the Fig. 3 indicates the self-focusing effect. While for Bi=5 atomic percent, the presence of peak before the valley which shows the negative n_2. The negative nonlinear refractive index for Bi=5 atomic percent is attributed by taking into consideration the reverse saturable absorption (RSA). Bi content increases from 0 to 5 atomic percent, RSA increases because of increased two photon absorption. Accordingly, the possibility of negative n_2 increases [30]. Similar, switching behavior of n_2 was reported by S. Divya *et al.* [31] for TiO_2/CeO_2 nanocomposites. In this system, by changing the CeO_2 content, the n_2 switched from negative to positive value. The switching behavior of n_2 was studied by T. Cassano *et al.* [32] for poly (2-5 dialkoxy-p-phenylenevinylene) polymers. J. Francisco *et al.* [33] have studied the self-focusing phenomena of Bacteriorhodopsin using Z-scan method. The author discussed the change in sign of n_2 due to light induced transition between the photochromic states. The switching behavior of the studied system has potential application in the area of photonic technology. Since the studied system have negative nonlinear refractive index, therefore used in optical sensors like night vision devices [34].

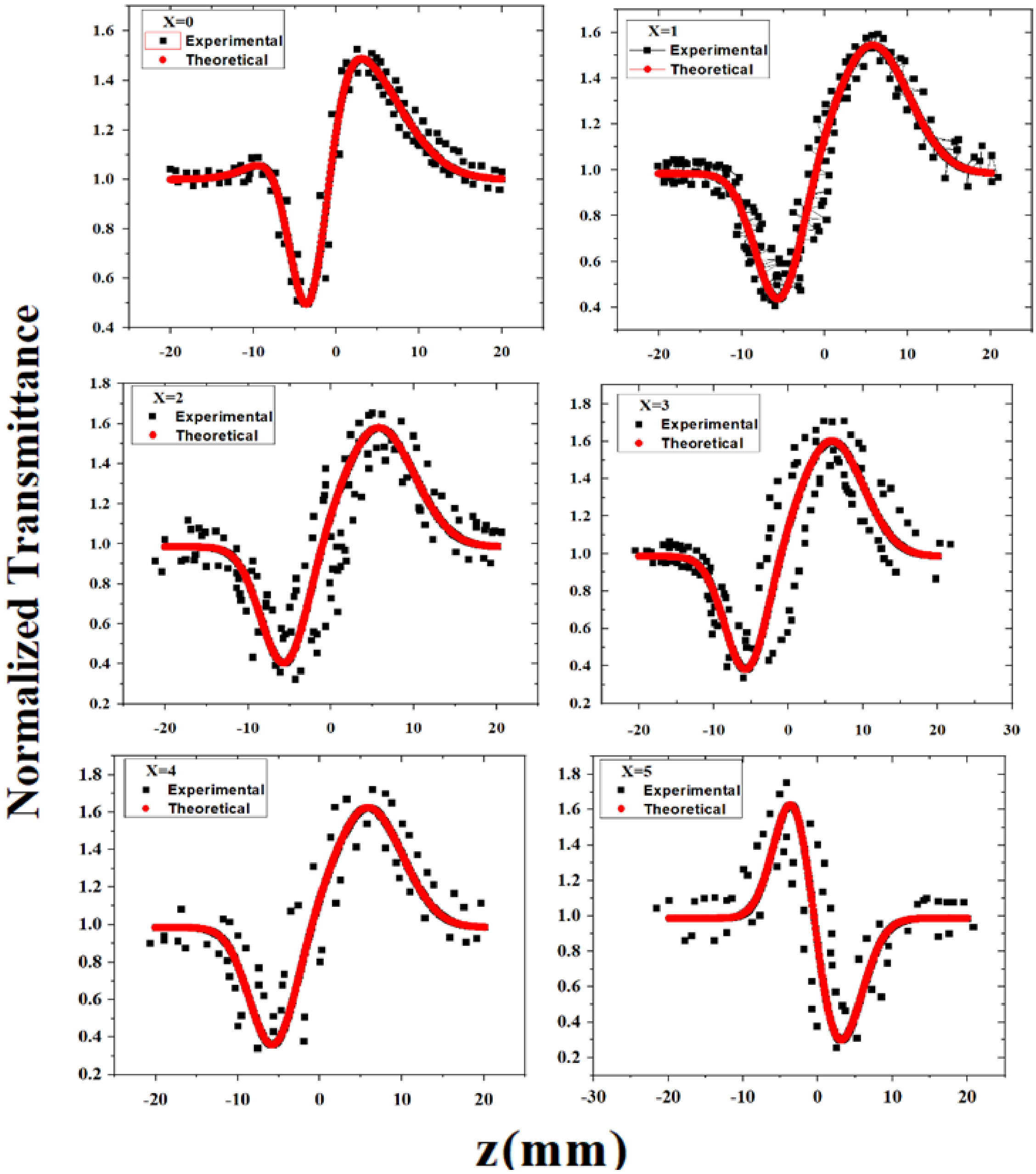

Fig. 3. Normalized closed aperture transmittance for $Se_{85}Te_{15}Bi_x$ thin films at 800 nm.

The calculated values of n_2 lies in the range of (3.3 to -5.66) X 10^{-13} (cm^2/W) which are in accordance with most of the related published papers [23, 25]. It is evident from the Table 1 that as Bi content is added, the n_2 will increase upto Bi= 4 atomic percent and further as Bi content will increase, n_2 will decrease. The change in n_2 values with change in Bi content is pointed out simply to emphasis the fact that by suitable variation in Bi content to the host Se-Te matrix, a glass system with tunable optical nonlinearity can be aquired. The decrease in the nonlinear refractive index at 5 atomic percent of Bi is described by means of RSA. The high value of RSA at Bi= 5 atomic percent as compared to other composition of Bi, reduces the possibility of positive nonlinear refractive index [35]. Accordingly, n_2 decreases at Bi = 5 atomic percent. The enhancement in n_2 upto Bi = 4 atomic percent of the studied thin films has been explained using several parameters including lone pair electrons, linear refractive index, optical band gap and number of heteropolar bonds in the studied system. The total number of lone pair electrons has a positive effect on n_2 [36]. In the studied thin films, Se & Te possess two lone pair electron (LPE) and Bi possess one

LPE. As Bi content is added in Se-Te, the total number of electronic lone pairs is increased and hence n_2 increases upto Bi= 4 atomic percent. The evolution of n_2 on the basis of number of electronic lone pair for Ge-Sb-S-Se system has been stated by L. Petit et al. [37]. Also, its comparable with Harbold *et al.* [38] that stated n_2 rely on the electronic lone pair concentration and composition as well as structure of the glass correlated with the band gap energy.

There are various physical parameters that independently contribute to optical nonlinearities of the materials. One of them is metallization criterion that is evaluated using static refractive index *(n_0)* and optical band gap(E_g) by the following relations:

$$M = 1 - \frac{(n_0^2-1)}{(n_0^2+2)} \quad (6)$$

$$M = \left(\frac{E_g}{20}\right)^{1/2} \quad (7)$$

Fig 4 and Fig 5 represents the variation of n_2 of the examined thin films with metallization criterion $(1-(n_0^2-1)/(n_0^2+2))$ and $\left(E_g/20\right)^{1/2}$, also n_2 increases with decrease of M upto Bi =4 atomic percent while for Bi=5 atomic percent, the value of n_2 is found to be negative i.e minimum. The value of metallization criterion of the investigated system lies in the range of 0.3-0.35 on the basis of refractive index and 0.25-0.27 on the basis of E_g (tabulated in Table 1.) These values of M are a good basis for expecting new nonlinear optical material for nonlinear optics. Briefly, the nonlinear refractive index increases with decrease of energy gap which is further linked with decrease of mettalicty.

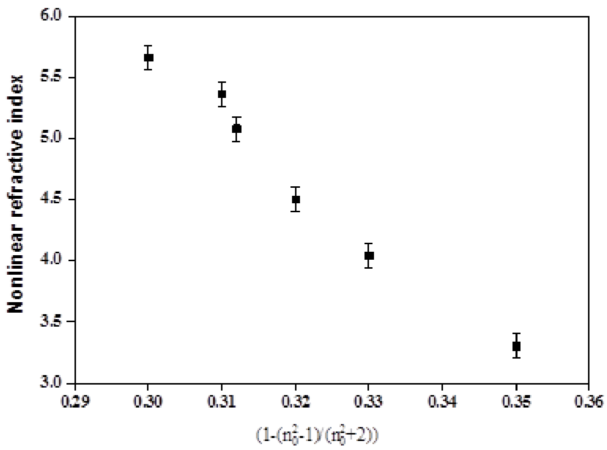

Fig. 4. Nonlinear refractive index n_2 as a function of metallization criterion $(1-(n_0^2-1)/n_0^2+2)$.

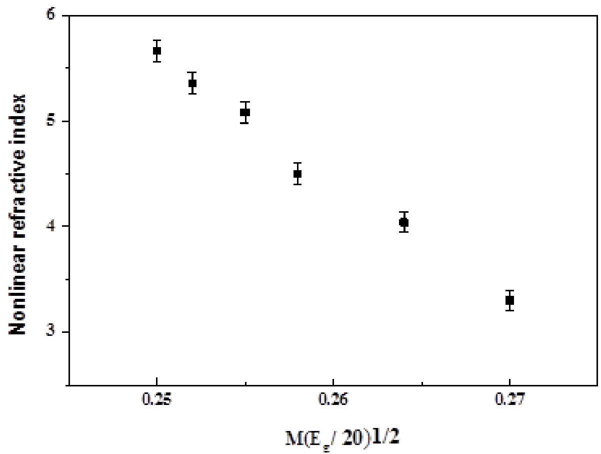

Fig. 5. Nonlinear refractive index n_2 as a function of metallization criterion $\left(E_g/20\right)^{1/2}$.

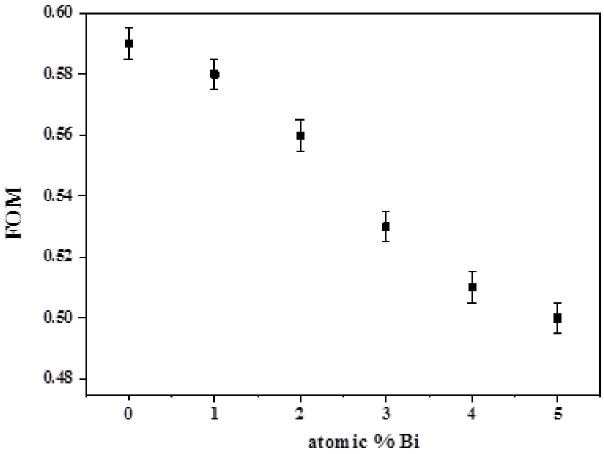

Fig. 6. The graph between FOM and atomic percent of Bi in $Se_{85}Te_{15}Bi_x$ thin films.

Table 1. Values of n_2, β_2, metallization criterion M on the basis of static refractive index(n_0) and on the basis of band gap (E_g), for ternary $Se_{85-x}Te_{15}Bi_x$ (x = 0, 1, 2, 3, 4, 5) thin films at 800 nm.

X	n_2 x 10^{-13} (cm^2/W)	β_2 x 10^{-8} (cm/W)	M $1-\frac{(n_0^2-1)}{(n_0^2+2)}$	M $\left(\frac{E_g}{20}\right)^{1/2}$
0	3.3	0.7	0.345	0.271
1	4.04	0.86	0.326	0.262
2	4.5	1	0.319	0.258
3	5.08	1.2	0.314	0.255
4	5.36	1.31	0.308	0.259
5	-5.66	1.39	0.302	0.25

Usually, the free carrier effects influence the nonlinear optical properties of samples in picosecond pulse duration and longer. In the present experimental study, a femtosecond laser is employed for the analysis of nonlinear study. Consequently, the free carrier effect is insignificant . Although the laser irradiated thin films may be affected by the local heating but the laser repetition rate in our study is in LHz which is much smaller than MHz. Accordingly, the possibility of thermal nonlinearity in the prepared samples is negligible and the third order optical nonlinearity are initiated from electronic contribution. Also, chalcogenide glasses are structural flexibility and sensitive to light induced changes. Furthermore, the chalcogen elements are two folds coordinated and attain nonbonding lone pair electrons. As lone pair electrons have highest energy, therefore lies above the valence band. Accordingly, the nonbonding electrons are prefertially excited with the help of laser,which allows amorphous chalcogenide thin films to show a fast response time (within 200 fs).

The nonlinear refractive index of the same composition has already calculated using different theoretical methods which are studied by researchers [39]. The theoretically calculated n_2 by Fournier & Snitzer, Modified Boiling and Tichy &Ticha approach were compared with experimentally calculated values of the investigated samples. It is valuable to note that the obtained n_2 of studied thin films measured by Z-scan technique is found to be in good agreement with the Fournier & Snitzer relation. Consequently, in Fournier & Snitzer relation the percentage error is minimum. These determined n_2 values of the examined thin films is compared with n_2 of As_2Se_3 and $Ge_{10}As_{10}Se_{80}$ compositions calculated by nonlinear imaging technique (NIT), mach-zehnder interferometric (MZT) and Z-scan technique, were 2-4 times higher [40]. n_2 values considered thin films were compared with n_2 of $Zn_2S_{28}Se_{70}$ chalcogenide glass [41] evaluated using Z-scan and degenerate four wave mixing (DFWM) method is formulated in Table 2.

Comparative studies of n_2 prepared alloys with other chalcogenide alloys are shown in Table 2. The n_2 of the examined alloys are also compared with pure silica [42](Table 3). It has been observed from the Table 3 that n_2 for our samples acquire significantly large n_2 of the order of 2.44 - 5030000 times higher compared to other chalcogenide thin films and pure silica. The higher values of n_2 of our samples makes this system valuable for optical application like night vision objects [43].

Table 2. Comparison of n_2 of $Se_{85-x}Te_{15}Bi_x$ (x = 4) chalcogenide thin film with n_2 of As_2Se_3, $Ge_{10}As_{10}Se_{80}$, $Zn_2S_{28}Se_{70}$, $80GeS_2$ (20 x) Ga_2S_3 xSb_2S_3(x=20) and pure silica.

Other Composition	***n_2 cm^2/W***	**Comparison** ***$n_2/n_{2\ other}$***	**Technique**
As_2Se_3	1.30×10^{-13}	4.12	NIT [40]
As_2Se_3	1.40×10^{-13}	3.83	MZT [40]
As_2Se_3	1.80×10^{-13}	2.98	Z-scan [40]
$Ge_{10}As_{10}Se_{80}$	1.50×10^{-13}	3.57	NIT [40]
$Ge_{10}As_{10}Se_{80}$	1.20×10^{-13}	4.47	MZT [40]
$Ge_{10}As_{10}Se_{80}$	2.20×10^{-13}	2.44	Z-scan [40]
$Zn_2S_{28}Se_{70}$	1.67×10^{-12}	3.21	Z-scan [41]
$Zn_2S_{28}Se_{70}$	1.07×10^{-19}	5030000	DFWM [41]
$80GeS_2$ (20 x) Ga_2S_3 xSb_2S_3 x=20	5.68×10^{-14}	9.44	Z-scan [42]
Pure silica	2.70×10^{-16}	1990	Z-scan [42]

Table 3. Values of Re $\chi^{(3)}$, Im $\chi^{(3)}$, absolute value of third order susceptibility, second hyperpolarizability, coupling factor and figure of merit (FOM) for ternary $Se_{85-x}Te_{15}Bi_x$ (x = 0, 1, 2, 3, 4, 5) thin films at 800 nm.

X	***Re $\chi^{(3)}$* x *10^{-15} (esu)***	***Im $\chi^{(3)}$* x *10^{-15} (esu)***	***$\chi^{(3)}$* x *10^{-15} (esu)***	***$Re[\gamma] X 10^{-40}$***	***ρ***	**|FOM|**
0	0.6	7.5	7.51	2.79	12.5	0.59
1	0.72	9.8	9.86	2.68	13.6	0.58
2	0.84	11.86	11.89	2.82	14.1	0.56
3	0.9	14.8	14.91	2.79	16.4	0.53
4	1.06	16.4	16.51	3.04	15.5	0.51
5	-1.14	17.86	17.89	-2.96	15.7	0.5

n_2 and β_2 values were calculated and helps to find out the real and imaginary part of $\chi^{(3)}$ given by the equation:

$$\text{Re}\chi^{(3)} = \frac{10^{-4}\epsilon_0 c^2 n_0^2 n_2}{\pi} \tag{8}$$

$$\text{Im}\chi^{(3)} = \frac{10^{-2}\epsilon_0 c^2 n_0^2 \beta_2 \lambda}{4\pi^2} \tag{9}$$

where n_0 is static refractive index that has been taken from [44], ε_0 is permittivity of free space and c represents velocity of light.

The absolute value of $\chi^{(3)}$ was evaluated by the equation:

$$\chi^{(3)} = \sqrt{\left(\chi_R^{(3)}\right)^2 + \left(\chi_I^{(3)}\right)^2} \tag{10}$$

The calculated values of $\chi_R^{(3)}$ and $\chi_I^{(3)}$ and absolute value of $\chi^{(3)}$ are shown in Table 3. Table 3 shows that $\chi_R^{(3)}$ increases upto Bi = 4 atomic percent and for Bi= 5 atomic percent, $\chi_R^{(3)}$ is negative. The behavior of $\chi_R^{(3)}$ has been explained by means of RSA. At Bi =5 atomic percent, the high value of RSA changes the positive value of n_2 into negative value [35]. Since $\chi_R^{(3)}$ is directly related with n_2, accordingly, $\chi_R^{(3)}$ is negative for Bi=5 atomic percent. However, the value of $\chi_I^{(3)}$ is found increased Bi content from 0 to 5 atomic percent. Also, cacluated value of $\chi_I^{(3)}$ is higher than $\chi_R^{(3)}$. As a result, the absorption effect can be considered strong as compared to refraction effect. Hence, the absolute value of $\chi^{(3)}$ increases with increased Bi. The higher value of absolute $\chi^{(3)}$ makes the studied thin films as an ideal material for nonlinear optics.

The nonlinear induced polarization per molecule is ascribed by means of second hyperpolarizability (γ) is correlated with the real part of $\chi^{(3)}$ by [45]

$$Re[\gamma] = \frac{Re[\chi^{(3)}]}{Nf^4} \tag{11}$$

Here N represents the number of molecules per unit volume and f is the local field correction factor stated by Lorenz is

$$f = \frac{(n_0^2+2)}{3} \tag{12}$$

The calculated value of second order hyperpolarizability is lies in the range of 2.79 X 10^{-40} to -2.96 X 10^{-40} esu.

Imaginary part and real part ratio of third order nonlinear optical susceptibility gives the value of coupling factor ρ via; the relation:

$$\rho = \frac{Im\chi^{(3)}}{Re\chi^{(3)}} \tag{13}$$

The calculated value of coupling factor is lie in the range of 12.5 to -15.7. This is because of the impact of two photon absorption change that is more effective in comparison to nonlinear refraction and electronic origin of nonlinearity [45].

Various figures-of-merit have been recommended for the evaluation of optical devices which use n_2 and β_2. Linear absorption coefficient (α_0) and n_2 helps to study figure of merit by the relation: $n_2/(\tau\alpha_0)$, where τ represents response time [46]. Figure of merit (FOM) is calculated so that the materials can be used for optical switching devices [47].

At 800 nm, the figure of merit for the examined samples is computed with the help of n_2 and β_2 via; the relation.

$$|\mathrm{FOM}| = \frac{n_2}{\beta_2\lambda} \tag{14}$$

The obtained values of FOM decreases with addition of Bi as shown in Table 3. The value of FOM is found to be less than 1 for all the composition. All optical switching devices used nonlinear optical materials with FOM<1. Accordingly, this glass system is a beneficial material for all optical switch devices. The FOM for $As_{40}Se_{60}$ and $Ge_{20}As_{40}Se_{40}$ chalcogenide glasses has been studied by Quemard *et al.* [48] at 1064 nm and 1430 nm. The obtained result of FOM for the systems is found to be greater than 1 at 1064 nm and less than 1 at 1430 nm. The FOM versus Bi content for the studied thin film is shown in Figure 6.

4. Conclusion

n_2 and β_2 of ternary $Se_{85-x}Te_{15}Bi_x$ thin films have been determined using Z-scan method (800 nm). It is observed that the appearance of peak after the valley upto Bi=4 atomic percent indicates the self-focusing effect. While for Bi=5 atomic percent, the nonlinear refractive index is negative. The negative behavior of n_2 has been described by means of RSA. n_2 increases upto Bi=4 atomic percent as Bi content increases while for Bi=5 atomic percent, n_2 is minimum. The enhancement of n_2 is described by several parameters like linear refractive index, optical band gap, number of heteropolar bonds and total number of electronic lone pairs of the atoms involved. n_2 behaviour is described using parameters like metallization criterion, free carrier effects etc. Experimentally determined n_2 values are in accordance with calculated values of Fournier and Snitzer.

The experimentally determined n_2 is compared with n_2 of other chalcogenide alloys measured by NIT, MZT, DFWM and Z-scan method. The higher values of n_2 of studied composition make this system advantageous for night vision devices. The increasing behavior of β_2 with Bi content can be explained using E_g. The value of $\chi^{(3)}$ increases with addition of Bi content. FOM values are less than 1 for all the composition. Accordingly, this glassy system is a beneficial material for all optical switching devices.

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