Egypt. J. Phy. **Vol. 47,** No.1, pp. 23 - 29 (2019)

Electrical and Optical Properties of Sb_2O_3 B_2O_3 Bi_2O_3 TeO_2 Glass System

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THE OPTICAL and electrical properties of **x**Sb_2O_3 (35-x) B_2O_3 60Bi_2O_3 5TeO_2 glass system (where, x=10, 20, 30) have been studied. It was found that the values of optical energy gap and activation energy of conduction decrease by increasing Sb_2O_3 content for all the studied samples .While as the values of refractive index, real dielectric constant ,molar polarizability ,oxide ion polarizability, optical basicity, third order nonlinear optical susceptibility increase by increasing Sb_2O_3 content. The high values of third order nonlinear optical susceptibility for all the studied samples , were found to be in the range (3.827-8.219) x 10^{-12}esu, which is larger than that of pure silica glass.Finally, it has been suggested that all the studied samples are promising materials for nonlinear optical requests.

Keywords: Density, Molar volume, Optical basicity, Optical and electrical properties.

Introduction

Tellurium oxide glasses have attracted much care because of their optical requests due to their high linear and nonlinear refractive indices and high nonlinear optical susceptibility [1]. The structure, electrical and optical properties of tellurium oxide glasses have been studied by many authors [2-6]. Also, Bismuth oxide glasses have been carried out because of their potential applications in optoelectronics and photonics [7]. Antimony oxide glasses have been given much attention because of their practical applications in nonlinear optical devices [8]. Borate glasses have been attracted attention due to their potential applications in the fields of linear and nonlinear optics and correlated techniques [9]. It was found [10] that the third order nonlinear susceptibility of Sb_2O_3 B_2O_3 glasses increase rapidly by increasing B_2O_3 content. It has been found [11,12] that $TeO_2Bi_2O_3B_2O_3$ glasses have narrow optical energy gap , high refractive index, and high third order nonlinear optical susceptibility. In the present article, the optical and electrical properties of xSb_2O_3 (35-x) B_2O_3 60Bi_2O_3 5TeO_2 glass system (where, x=10, 20, 30) have been studied.

Experimental Details

Proper weights of Sb_2O_3, B_2O_3 , Bi_2O_3 and TeO_2 in accurate molar ratio were mixed to obtain uniform acceptable fine powder and then, placed in a porcelain crucible and heated in an electric furnace whose temperature was elevated in steps to 1100^{0}C for half an hour. Then, the molten samples were rapidly cooled to room temperature by pouring it onto a cooper plate and successively pressing it with another to get glasses. The studied samples have been characterized by the X-ray diffraction (XRD). All the samples reveal non-crystalline nature as no noticeable peak was detected in their (XRD) spectra. The reflection and the transmission of all the samples in the wave length (400-1100nm) were measured using a computerized recording spectrophotometer (type Jasco, V-570). The dc conductivity was measured using a programmable electrometer model Keithley 617) which measure the resistance of the sample directly.

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DOI :10.21608/ejphysics.2018.5425.1012

Results and Discussions

Density and molar volume

The density of the samples was calculated using this equation:

$$d = 0.8635\ [W_a / (W_a - W_b)]$$

where , d is the density of the glass sample, W_a is the weight of the glass sample in air, W_b is the weight of the glass sample in toluene and 0.8635 is the density of toluene. The values of density for all the studied samples are listed in Table 1.

The molar volume = (Total molecular weight)/ (density)

The values of molar volume for all the studied samples are listed in Table 1. It is clear that the values of the density increase because the values of molecular weight increase by increasing Sb_2O_3 content. Also, the values of molar volume increase for all the studied samples. This can be attributed to the Sb_2O_3 ionic radii (0.90 0A) higher than the B_2O_3 ionic radii (0.20 0A) accordingly affected expansion of allowed volume [13].

Optical energy gap

The optical transmission and reflection spectra for all the studied samples are shown in Fig. 1 and 2. The absorption coefficient α was calculated [14] by using the measured values of the reflection (R) and the transmission (T) as follows,

$$\alpha = (1/t)(\ln(1-R)/T)$$

where t is thickness of the sample.

TABLE 1. The values of density, molecular weight and molar volume for all the studied samples.

Sample	Density (g/cm³)	Molar volume (cm³/mol)	Molecular weight (g/mol)
$10Sb_2O_325B_2O_360Bi_2O_35TeO_2$	6.424	52.005	334.081
$20Sb_2O_315B_2O_360Bi_2O_35TeO_2$	6.720	53.016	356.269
$30Sb_2O_35B_2O_360Bi_2O_35TeO_2$	6.989	54.016	378.457

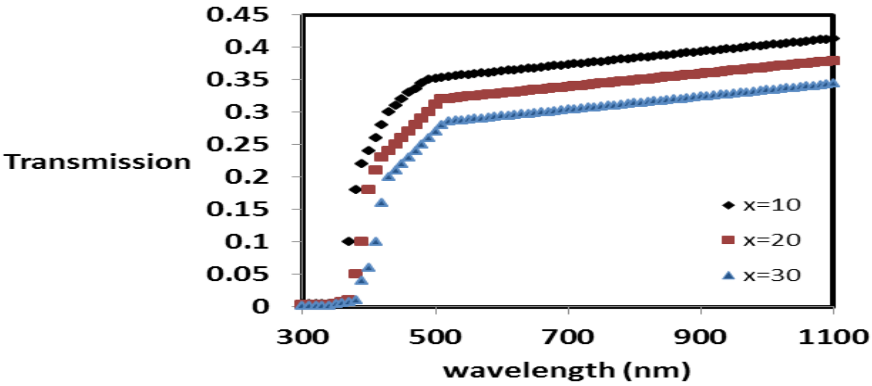

Fig. 1. The optical transmission spectra for all the studied samples.

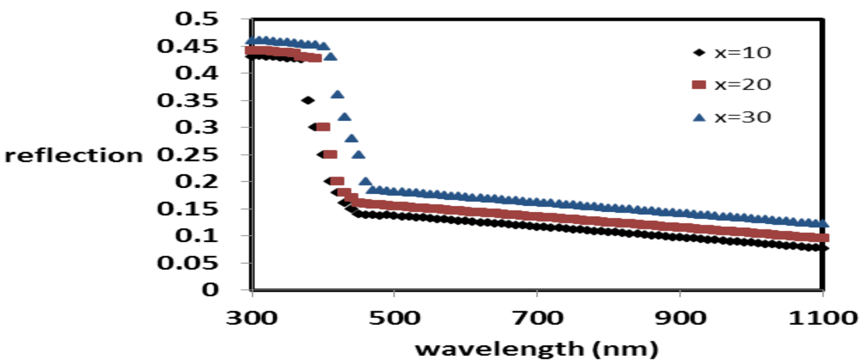

Fig. 2. The optical reflection spectra for all the studied samples.

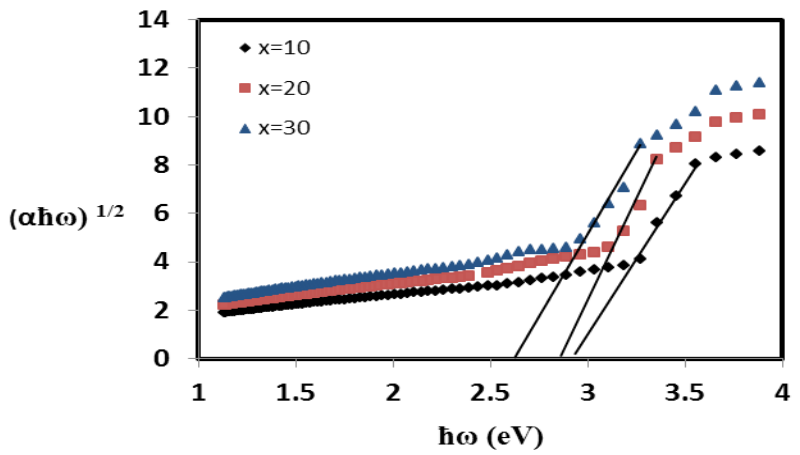

Fig. 3.The relation between (αħω)1/2 and ħω for all the studied samples.

TABLE 2. The values of the optical energy gap, molar refraction molar polarizability for all the studied samples.

Sample	The optical energy gap (eV)	Molar refraction (cm ^{3}/mol)	Molar polarizability (Å^3)
$10Sb_2O_325B_2O_360Bi_2O_35TeO_2$	2.94	29.61	12.72
$20Sb_2O_315B_2O_360Bi_2O_35TeO_2$	2.86	31.71	13.08
$30Sb_2O_35B_2O_360Bi_2O_35TeO_2$	2.62	33.74	13.71

Mott and Davis [15] proposed the following relation between the absorption coefficient α (ω) and the photon energy ħω of the incident radiation, for indirect transitions this relation can be written as follows, ,

$$\alpha\hbar\omega=\beta(\hbar\omega-E_{opt})^2$$

The values of optical energy gap can be determined as the intersection between $(\alpha\hbar\omega)^{1/2}$ and $\hbar\omega$ as shown in Fig. 3. It was found that the values of the optical energy gap which are listed in Table 2 decrease by increasing Sb_2O_3 content for all the studied samples. As a result of the replacement of B_2O_3 with Sb_2O_3, the structural changes take place inside the glass. As Sb_2O_3 in the glass matrix increases, B-O-Bi is replaced with Sb-O-Bi. These structural changes will result in shifting the valence band maximum to higher energies, thus decreasing the band gap of the glass system..

The third order nonlinear susceptibility

The third order nonlinear susceptibility $\chi^{(3)}$ (in e.s.u units) can be calculated from values of the optical energy gap as follows [16],

$$\chi^{(3)}=\frac{(1.4x10^{-11})}{((E_{opt}-1.96)(E_{opt}-1.31)(E_{opt}-0.65))}$$

It was found that the values of third order nonlinear susceptibility which are listed in Table 3 are higher than that of pure silica glass ($2.8x10^{-12}$ e.s.u), which means that all the studied samples are promising materials for nonlinear optical devices. Also, It was noticed that the values of third order nonlinear optical susceptibility increase by increasing Sb_2O_3 content as a result of decreasing the values of optical energy gap for all the studied samples.

The refractive index

The refractive index n can be calculated [17] according to the following equations

$$n = (1+R^{1/2})/(1-R^{1/2})$$

Figure 4 show the dependence of n with wave length λ. It is clear that the refractive index increase by increasing Sb_2O_3 content .The refractive index is related to the polarizability of oxide ions [18].

The polarizability of oxide ions and the optical bacisity

The polarizability of oxide ions can be calculated as follows [13], polarizability of oxide ion =1.67/(1.67-optical basicity) and the optical basicity can be calculated as following [13] ,

$$\text{Optical basicity} = x(Sb_2O_3)\Lambda(Sb_2O_3)+ x(B_2O_3)\Lambda(B_2O_3)+ x(Bi_2O_3)\Lambda(Bi_2O_3) + x(TeO_2)\Lambda(TeO_2)$$

Where x (Sb_2O_3) $x(B_2O_3)$, $x(Bi_2O_3)$and $x(TeO_2)$ are the equivalent fraction of the different oxides. And Λ (Sb_2O_3), $\Lambda(B_2O_3)$, $\Lambda(Bi_2O_3)$ and $\Lambda(TeO_2)$, are the optical basicity values of the constituent oxides. The values of optical basicity and the values of polarizability of oxide ions for all the studied samples are listed in Table 3.

It is clear that, all the studied samples are more basic and more polarized. Also, the increase in refractive index is most likely due to the increase in oxide ion polarizability for all the studied samples.

The real dielectric constant

Also, the real dielectric constant ε' can be calculated [17] using the following equations,

$$\varepsilon' = n^2 - k^2$$

where $k = \alpha\lambda/(4\pi)$ is the extinction coefficient.

Figure 5 shows the dependence of the real dielectric constant with wavelength λ. The optical dielectric constant is related to the polarizability [18] .

The molar polarizability

The molar polarizability (α_m) can be calculated [13] as a function of molar refraction (R_m),

$$\alpha_m = (R_m/2.52)$$

The optical energy gap is related to molar refraction [13].

$$R_m = V_m[1-(E_{opt}/20)^{1/2}]$$

TABLE 3. The values of optical basicity, oxide ion polarizability ,activation energy of conduction and third order nonlinear susceptibility for all the studied samples.

Sample	Optical basicity	Oxide ion polarizability	Activation energy of conduction (eV)	Third order nonlinear susceptibility (esu)
$10Sb_2O_325B_2O_360Bi_2O_35TeO_2$	0.989	2.452	1.25	3.827×10^{-12}
$20Sb_2O_315B_2O_360Bi_2O_35TeO_2$	1.069	2.779	1.19	4.541×10^{-12}
$30Sb_2O_35B_2O_360Bi_2O_35TeO_2$	1.149	3.205	1.10	8.219×10^{-12}

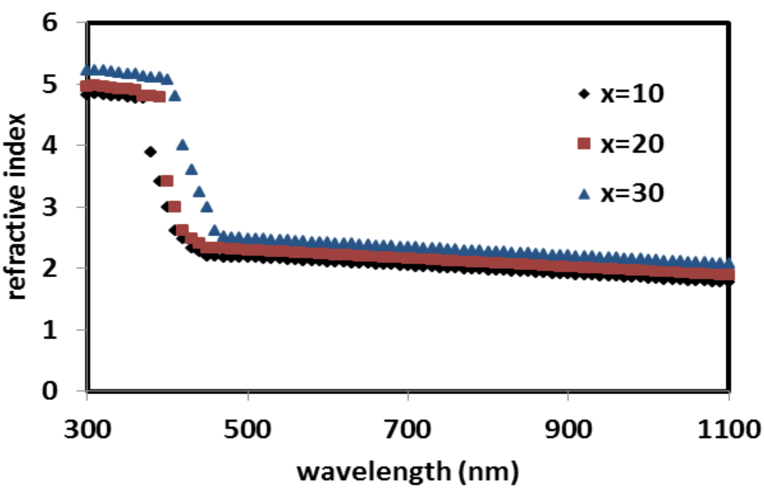

Fig. 4. The refractive index for all the studied samples.

The values of molar refraction and molar polarizability are listed in Table 2. It is clear that the values of the dielectric constant increase as a result of increasing the polarizability of all the studied samples.

dc electrical conductivity

The dc electrical conductivity σ can be calculated [14] as follows,

$$\sigma = \sigma_0 \exp [-\Delta E/K_B T]$$

Where σ_0 is the pre-exponential factor, ΔE is the activation energy of conduction; K_B is the Boltzmann's constant. Figure 6 shows the dc electrical conductivity for all the studied samples. The activation energy of conduction can be calculated from the slope of the straight line. The values of the activation energy of conduction are listed in Table 3. It was found that by increasing Sb_2O_3 content the activation energy of conduction decreased for all the studied samples which agrees with the optical energy gap. The reduction in the activation energy of conduction is most likely due to the replacement of B-O-Bi by Sb-O-Bi.

Conclusions

From the present study of xSb_2O_3 (35-x) B_2O_3 $60Bi_2O_3$ $5TeO_2$ glass system, it was found that both of the values of density and molar volume increase by increasing Sb_2O_3 content. Also the values of optical energy gap and the values of the activation energy of conduction decrease for all the studied samples. While the values of refractive index and optical dielectric constant increase.

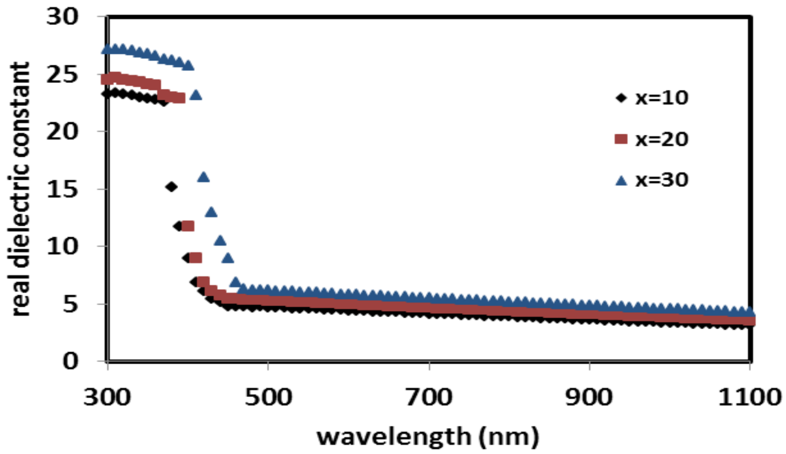

Fig. 5.The relation between the real dielectric constant and wavelength.

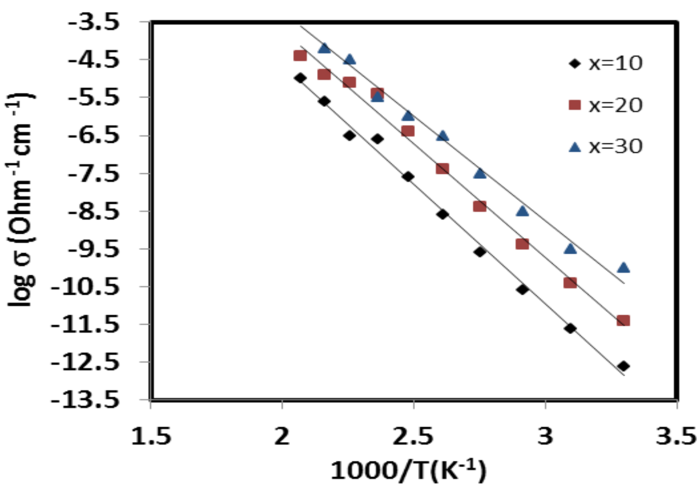

Fig. 6. The dc electrical conductivity for all the studied samples.

The present glasses become more basic and more polarized by increasing Sb_2O_3 content. Finally, it was found that , all the studied glasses which have high refractive index, high optical basicity, high oxide ion polarizability and high third order nonlinear susceptibility are promising materials for nonlinear optical devices.

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(*Received:* 6/10/2018;
accepted: 22/11/2018)

الخواص الكهربية والضوئية للنظام الزجاجى $Sb_2O_3B_2O_3Bi_2O_3TeO_2$

تمت دراسة الخواص البصرية والكهربائية للنظام الزجاجي xSb_2O_3 (35-x) B_2O_3 60 Bi_2O_3 5TeO_2 حيث. $x = 10,20,30$ وجدأن الكثافة تزداد بزيادة محتوى Sb_2O_3 والحجم المولي يتبع نفس الاتجاه. بالإضافة إلى ذلك، وجد أن قيم فجوة الطاقة الضوئية والطاقة التنشيطية للتوصيل تقلب زيادة محتوى. Sb_2O_3 من ناحية أخرى، فإن قيم معامل الانكسار ،الجزءالحقيقي من ثابت العزل الكهربائي،الاستقطاب المولي،الاستقطاب الأيوني للأكسدة،الأساس البصري،الحساسية البصرية غيرالخطية من الدرجة الثالثة تزيد بزيادة محتوى Sb_2O_3 . تم العثورعلى قيم عالية من الحساسية البصرية غيرالخطية من الدرجة الثالثة لجميع العينات المدروسة ،في النطاق (2.827-8.219) $\times 10^{-12}$ ،وهوأكبرمن ذلك من زجاج السيليكا النقي. وأخيرًا،تم اقتراح أن جميع العينات المدروسة هي مواد واعدة للطلبات البصرية غيرالخطية.