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Prism method of studying the refractive index for zinc borate sodium glass doped neodymium oxide

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This work presents the elasto optic effect and some optical properties of a glass system with a chemical composition (15+x)Na_2O-(43-x)B_2O_3-40ZnO-2Nd_2O_3 (where $x = 0$, 5 and 10), which has been prepared using the melt quenching method. Density and refractive index were measured. Molar mass, permittivity, molar refraction, reflectance, phase velocity, Brewster angle, polarizability, electric susceptibility and elasto optic coefficient were estimated. X-ray diffraction analysis conformed that amorphous nature of the prepared glass were found. The density and molar volume was followed the normal behavior of glass system for the three samples. The effects of Na_2O content on the glass system were causing effect of the estimated values with changing of the boron network of BO3 and the BO4. The theoretical results that used in this research paper are good agreement to be followed for any expecting results to any oxide glass materials. Clausius-Mossotti is an excellent method for calculating the optical behaviors like reflectance, phase velocity, Brewster angle, polarizability, electric susceptibility or any related optical properties for any oxide glass materials.

Key words: Prism, glass, Refractive index, Borate glass.

Introduction

Nowadays, the non-crystalline and crystalline solid researches for creating smart materials due to their applications in photonics and nuclear has increased [1-6]. The idea of protective materials from nuclear radiation finds increasing interest due to the expansion of using the nuclear technology [7-17]. The fabrication of zinc borate glass is very attractive to many scientists because of its low melting point, which can be easily shaped and mold. The main peculiar properties for this type of glass are low thermal expansion coefficient, electrical resistance and chemical stability [18].The researcher focused on doping this type of glass by rare earth elements for optical applications [19-23]. The elasto optic coefficient due to stress and the change of refractive index due this stress are very important to be considered for any fabricator or optical designers, such as optical fiber, photonic glass and laser rods [24]. This change of refractive index can cause damage to the optical systems such as high power laser [25]. The consideration that was done by Clausius-Mossotti as a model for refractive index changes, where very successive for calculating the elasto optic coefficient noncubic crystals and glasses [25-27]. The studying of this type of effect was studied in both modeling and measurement, because it is very important in high power solid state lasers [28-33]. The present article deals with the effect of Na_2O addition of elasto optic coefficient by using Clausius-Mossotti as a model, and the using of prism method for measurement the refractive index.

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Experimental

Sample preparation

Neodymium doped Borate glass system with a chemical composition (15+x)Na_2O-(43-x)B_2O_3-40ZnO-2Nd_2O_3 (where $x = 0$, 5 and 10) was prepared by conventional melting method in a porcelain crucible by heating up to 1150 °C. The well mixed powders were preheated at 600 °C for 1.5 h to release gases, and then heated up to 1150 °C for 1 hr with clockwise shaking to ensure high homogeneity. The casting glass were quenched and annealing at 370, 350 and 350 °C respectively for 1 hr holding time, and the furnace was switched off to reach the room temperature.

The casting glass was quenched and annealing in stainless steel mould. The final glass prism as shown in Fig. 1 the prisms were subjected to annealing at 370, 350 and 350 °C respectively for 1 h holding time, and the furnace was switched off to reach the room temperature. The prisms were polished for refractive index measurements by using fine abrasive materials.

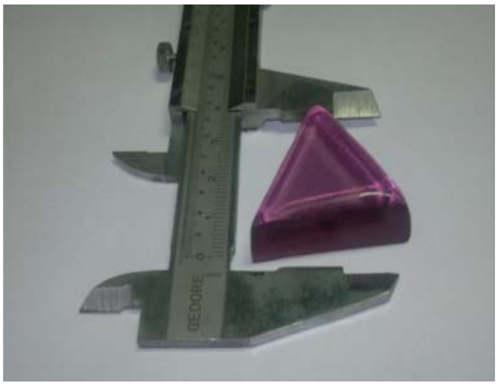

Fig. 1. A prism with 40 mm × 40 mm × 40 mm with 60 ° for all corners.

Characterization

The X-ray powder diffraction (XRD) technique was used for glass samples. The measurement was obtained by using Bruker AXS D8 Advance XRD diffractometer. The results observed no peaks were indicating crystalline nature of the prepared samples.

The densities of glass samples were determined at room temperature by Archimedes method using a liquid toluene as immersing liquid [34]. The molar volume V was calculated using the relation below [35]:

$$V = \frac{M_{glass}}{\rho_{glass}} \quad [\mathrm{cm}^3] \tag{1}$$

The refractive index was measured at room temperature, using glass prism with 40 × 40 × 40 mm 60 °; Spectrometer was used for measuring the prism samples by using Sodium-vapor lamp with wavelength about 589 nm, the calculating of the refractive index by using the relation below [36]:

$$n = \frac{\sin\left(\frac{A+D}{2}\right)}{sin\left(\frac{A}{2}\right)} \tag{2}$$

Where A = 60 ° and D calculating by two different angles.

Result and Discussion

Fig. 2 shows the XRD patterns of the formed zinc borate glass with the composition (15+x)Na_2O-(43-x) B_2O_3-40ZnO-2Nd_2O_3 (where x = 0, 5 and 10) synthesized by melting method preheated at 600 ºC for 1.5 hr and then annealed at 1150 ºC for 1 hr. It can be seen that the amorphous structure has observed for all sample.

The density and molar volume of the 2% neodymium doped sodium zinc borate glass with different Na content were measured. The results were given in Fig. 2 and Table 1. Obviously, the density was decreased as the molar volume was increased with increasing Na^+ ion. The discontinuity of the density and molar volume were attributed to borate structural units, which consist of the bands, the first band was imputed to the B-O stretching of trigonal BO_3 units, the Na_2O was acting as a modifier and producing BO_4^{-1} tetrahedra, and non-bridging oxygen atoms in the network of borate [10, 37]. The second structural, which is the band center, this band was related the B-O stretching of BO_3 units, the modifier was also breaked the network of the units [38]. The third structural band was assigned to the B-O stretching of BO_4^{-1} tetrahedra, and non- bridging oxygen atoms in the network of borate. Furthermore, the modifier was caused the similar effect [39].

The variation of density with Na_2O concentration can be explained by assuming that the structural changes of the boron glass network coordination. The network glass of B_2O_3 made a triangle arrangement in boroxyl rings which consist of three oxygen atoms as a part of the ring and the other three oxygen atoms outside the ring [40]. These are randomly interconnected through loose $[BO_{3/2}]^0$ units [41]. Because of the additions that modifying the glass network such as Na_2O. The three coordinated boron $[BO_{3/2}]^0$ units are converted to four coordinated boron tetrahedral $[BO_{4/2}]$, and this network dimensionality and connectivity increases, this would lead to efficient packing and compactness in the structure [40]. In addition to the values of molar volume V_M which

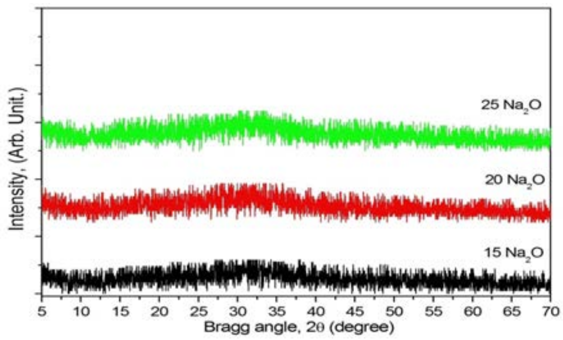

Fig. 2. XRD analysis of glass samples at x = (0, 5, 10 and 15).

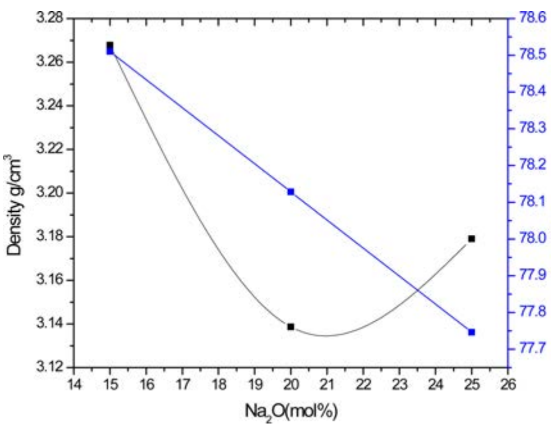

Fig. 3. Molar mass, densities as a function of Na_2O mol. % for B_2O_3-Na_2O-ZnO- Nd_2O_3 glasses.

Table 1. The measured density (ρ) and molar volume (V_M), of B_2O_3-Na_2O-ZnO- Nd_2O_3 glasses system.

x mol %	Na_2O mol. %	ρ (gm cm^{-3})	V_M (cm^3)
0	15	3.268	24.025
5	20	3.139	24.892
10	25	3.179	24.456

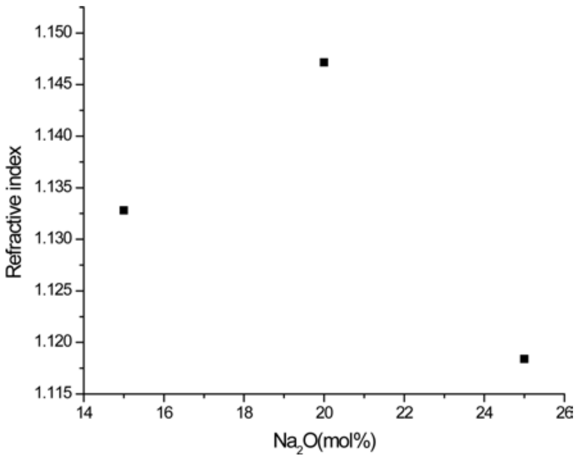

Fig. 4. Refractive index vs. Na_2O mol.% for B_2O_3-Na_2O-ZnO-Nd_2O_3 glasses.

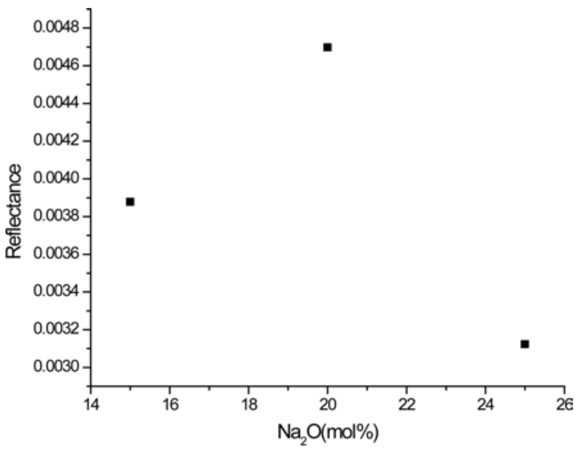

Fig. 5. Reflectance vs. Na_2O mol.% for B_2O_3-Na_2O-ZnO-Nd_2O_3 glasses.

shows opposite trend. Otherwise, the glass system follows the normal behavior of density ρ and molar volume V_M.

To know the physical properties of the glasses, the calculated values of density (ρ) and refractive index along with other physical parameters such as reflectance, molar refraction, permittivity, polarizability, elasto optic coefficient, electric susceptibility, Brewster's angle and speed of light of the medium were calculated using conventional formulae. Fig. 3 shows the variation of refractive index as a function of Na_2O concentration.

The reflectance as shown in Fig. 4 can be calculated by the using the following equation [41]:

$$R=\frac{(n-1)^2}{(n+1)^2} \tag{3}$$

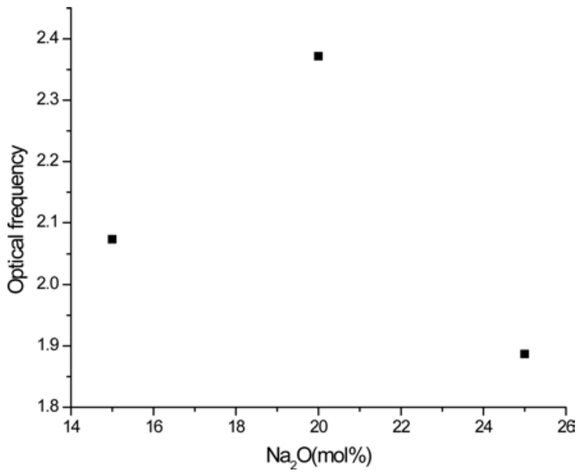

Fig. 6. Molar refraction vs. Na_2O mol.% for B_2O_3-Na_2O-ZnO-Nd_2O_3 glasses.

The molar refraction as shown in Fig. 5 can be calculated by using the following equation [42-43]:

$$O_f=\frac{M}{\rho}\frac{n^2-1}{n^2-2} \tag{4}$$

Where M is the molecular weight and ρ is the density

The permittivity, polarizability [44] and elasto optic coefficient as shown in Figs. 6,7,8 were calculated by the following equations [45]:

$$\varepsilon=n^2 \tag{5}$$

$$\gamma=\frac{3}{4\pi N}\frac{\varepsilon-1}{\varepsilon+2} \tag{6}$$

$$p\approx\frac{(1-B)(1+2B)}{3} \tag{7}$$

$$B=\frac{1}{\varepsilon} \tag{8}$$

The electric susceptibility as shown in Fig. 9 was

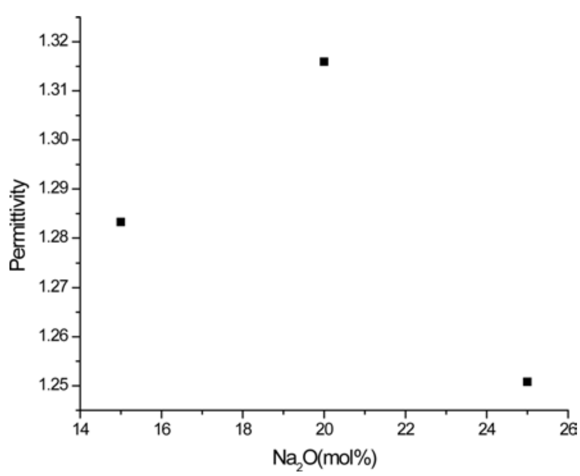

Fig. 7. Permittivity vs. Na_2O mol.% for B_2O_3-Na_2O-ZnO-Nd_2O_3 glasses.

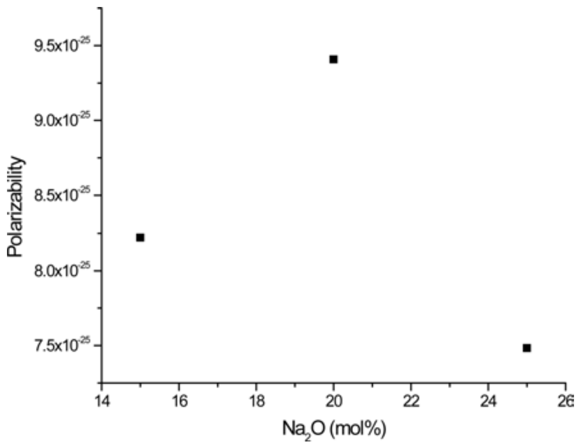

Fig. 8. Polarizability vs. Na_2O mol.% for B_2O_3-Na_2O-ZnO- Nd_2O_3 glasses.

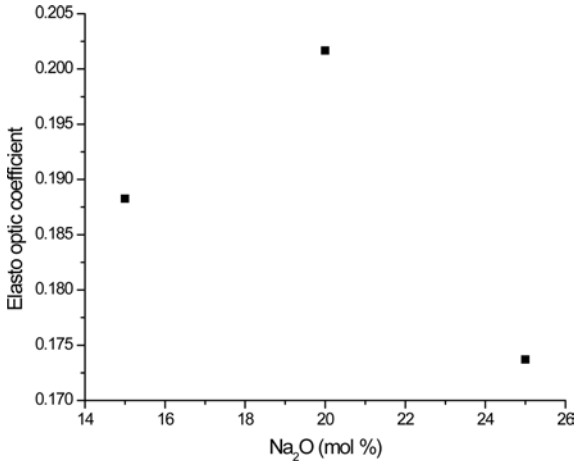

Fig. 9. Elasto optic coefficient vs. Na_2O mol.% for B_2O_3-Na_2O-ZnO- Nd_2O_3 glasses.

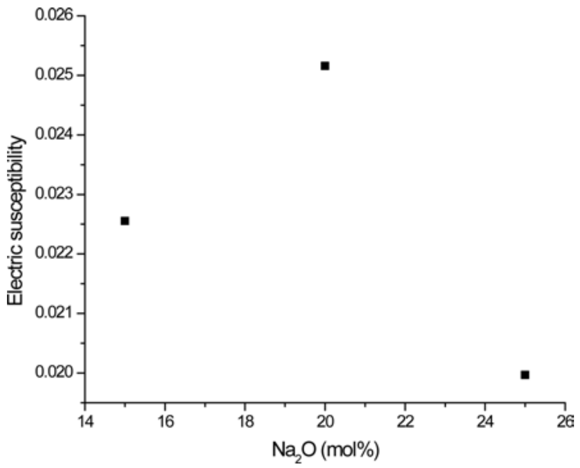

Fig. 10: Electric susceptibility vs. Na_2O mol.% for B_2O_3-Na_2O-ZnO- Nd_2O_3 glasses

calculated by the following equation [44]:

$$\chi = \frac{(\varepsilon - 1)}{4\pi} \tag{9}$$

The Brewster's angle as shown in Figs.10 was

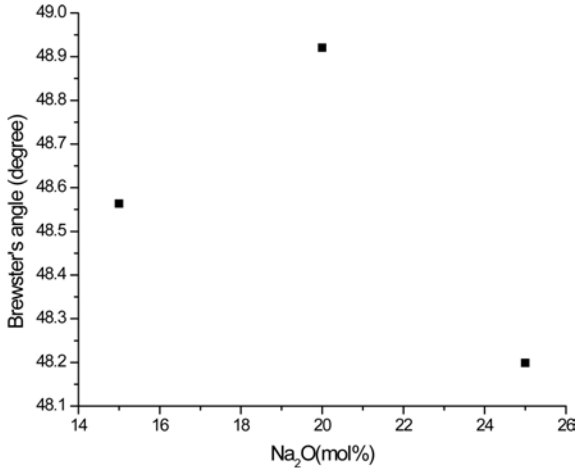

Fig. 11. The Brewster's angle vs. Na_2O mol.% for B_2O_3-Na_2O-ZnO- Nd_2O_3 glasses.

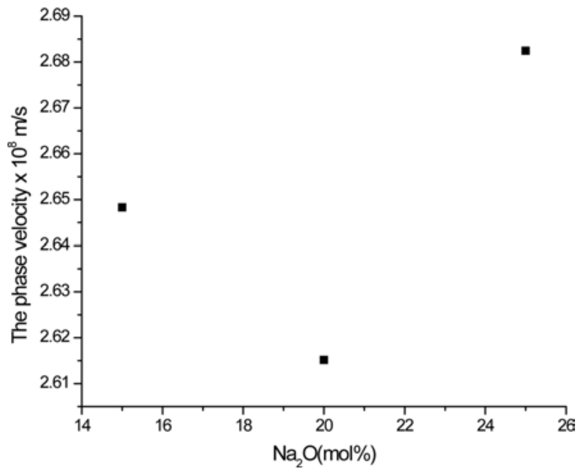

Fig. 12. The speed of light of the medium vs. Na_2O mol.% for B_2O_3-Na_2O-ZnO-Nd_2O_3 glasses.

calculated by the following equation [46]:

$$\text{Brewster's angle} = \arctan\left(\frac{n_2}{n_1}\right) \tag{10}$$

Where $n_1 = 1$ for air

The speed of light of the medium as shown in Fig. 11 was calculated by the following equation [47]:

$$v = \frac{c}{n} \tag{11}$$

Where c the speed of light in the vacuum 3×10^8, v is the speed of light in the medium and n the refractive index

Conclusions

A successive method was used to measure the refractive index by the prism. The spectroscopic calculation of different parameters for the glass by Clausius-Mossotti method was done. The effect of sodium oxide contents was observed with increasing or decreasing to some parameters. However, the discontinuity of the results due to the boron oxide structure changing from BO_3 to BO_4. The material is very interested because its applications in lasing medium.

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