Measurement 116 (2018) 314–317

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Effect of Bi_2O_3 addition on the ultrasonic properties of pentaternary borate glasses

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ARTICLE INFO

Keywords:
Ultrasonic velocities
Elastic moduli
Crosslink density
Microhardness and Debye temperature

ABSTRACT

The effects of addition of Bi_2O_3 to borate glasses in a series of (75-x) B_2O_3-xBi_2O_3-10Na_2O-10CaO-5Al_2O_3 have been studied through the ultrasonic properties of the glasses. The ultrasonic wave velocities (longitudinal, V_L and shear, V_S) were measured at 4 MHz using ultrasonic pulse echo method. Longitudinal *L*, shear *G*, bulk *K*, Yong's *E* moduli, Poisson's ratio *σ*, Microhardness (H), softening temperature (T_s) and Debye temperature (θ_D) were measured. Quantitative analysis of the experimental data has been carried based on the bond compression and Makishima-Mackenzie models.

1. Introduction

Mechanical properties by using ultrasonic techniques of solid materials have gained considerable interest due to their applications in science and technology. Elastic moduli, Debye temperature, Poisson's ratio and microhardness measurements are useful for understanding the coordination changes in materials [1–5]. Bulk modulus – volume relation has been studied to explain the coordination changes in glass network [1–3]. Debye temperature and Poisson's ratio data give excellent information about cross-link density [4,5].

Borate glasses doped with another glass forming oxide have wide applications in the field of electronic industry due to their higher conductivity, thermal resistivity and other related properties [6,7]. Structural and coordination changes in bismuth-borate glasses have already been studied and investigated [8]. Optical properties of borate glasses and the effect of addition of CuO, PbO, SrO and Y_2O_3 have been measured and discussed [9–12]. Previously, FTIR, UV spectra, optical energy band gap, Urbach's energy and refractive index have been measured on a series of (75-x) B_2O_3-xBi_2O_3-10Na_2O-10CaO-5Al_2O_3 glasses [13].

The present study is to report the effect of addition of Bi_2O_3 on the ultrasonic wave velocities of (75-x) B_2O_3-xBi_2O_3-10Na_2O-10CaO-5Al_2O_3 glasses. Also, to calculate the experimental longitudinal *L*, shear *G*, bulk *K*, Yong's *E* moduli, Poisson's ratio *σ*, Microhardness H, softening temperature T_s and Debye temperature θ_D. The experimental results will be interpreted according to Makishima-Mackenzie and bond compressional models.

2. Experimental procedures

Borate glass series in the form (75-x)B_2O_3-xBi_2O_3-10Na_2O-10CaO-5Al_2O_3(where x = 0, 5, 10,15, 20 and 25 mol.%) were prepared using reagent grade H_3BO_3, Na_2CO_3, $CaCO_3$ Al_2O_3 and Bi_2O_3 as starting materials as mentioned in the first part of this study [13] with amorphous state confirmation. Glass density was determined by using Automatic Gas Pycnometers for true density, Ultrapyc 1200e, and apparatus with helium gas and the molar volume V_M (cm^3) was calculated by using the next equation,

$$V_M = M_g/\rho \quad (1)$$

where M_g is the molecular weight of the glass and ρ is the density of the glass.

The ultrasonic velocities measurements were performed at 4 MHz for both shear and longitudinal transducers at room temperature (22 ± 2 °C) using pulse echo technique as explained before [14–20]. The time difference between the first two echoes (t_1 and t_2) was used to calculate the ultrasonic velocities (v_L and v_S) using Eq. (2).

$$v = \frac{2x}{t_2 - t_1} \quad (2)$$

where x = thickness of the sample. The ultrasoic velocities were repeated five times with accuracies V_L ± 9 m/s and V_S ± 11 m/s.

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https://doi.org/10.1016/j.measurement.2017.11.028
Received 22 June 2017; Received in revised form 13 October 2017; Accepted 13 November 2017
Available online 14 November 2017

Table 1
Glass composition, density ρ, molar volume V_M, Longitudinal velocity V_L, Shear velocity V_S, bulk modulus (B), Young's moduli (E), Poission's ratio (σ), Micro Hardness (H), Deby's temperature (θ_D) and softening temperature (T_s) of the (75-x)B_2O_3-xBi_2O_3-10Na_2O-10CaO-5Al_2O_3 Glasses.

Bi_2O_3 (mol.%)	Density (kg/m^3)	V_M (cm^3/mol.)	Long. velocity (m/s)	Shear velocity (m/s)	L (GPa)	G (GPa)	B (GPa)	E (GPa)	σ	H (GPa)	ΘD (K)	Ts (K)
0	2244.85	31.06	5687	3110	72.6	21.7	43.6	55.9	0.287	3.09	459.13	577.6
5	2939.19	30.27	5220	2853	80.1	23.9	48.2	61.6	0.287	3.40	425.29	616.2
10	3571.11	30.44	4884	2669	85.2	25.4	51.2	65.5	0.287	3.61	398.41	653.3
15	4218.66	30.11	4587	2492	88.8	26.2	53.9	67.6	0.291	3.65	374.23	668.6
20	4503.10	32.90	4434	2444	88.5	26.9	52.7	68.9	0.282	3.91	356.53	738.6
25	5028.75	33.40	4089	2281	84.1	26.2	49.2	66.7	0.274	3.94	331.21	726.6

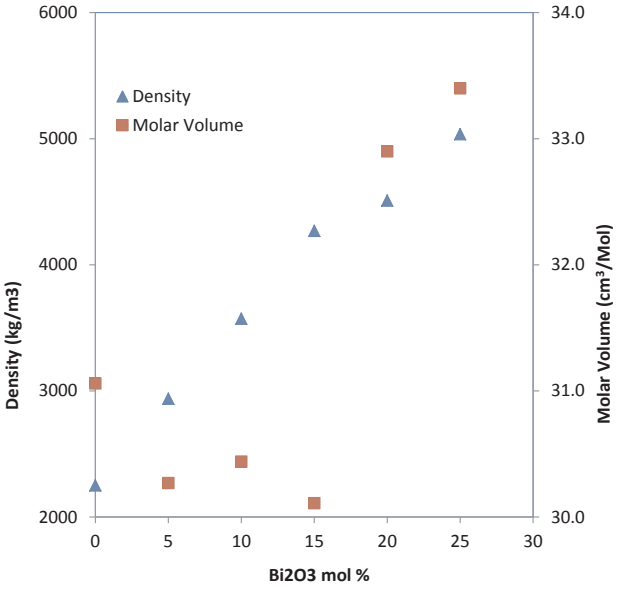

Fig. 1. Variation of density and molar volume with Bi_2O_3 mol.%.

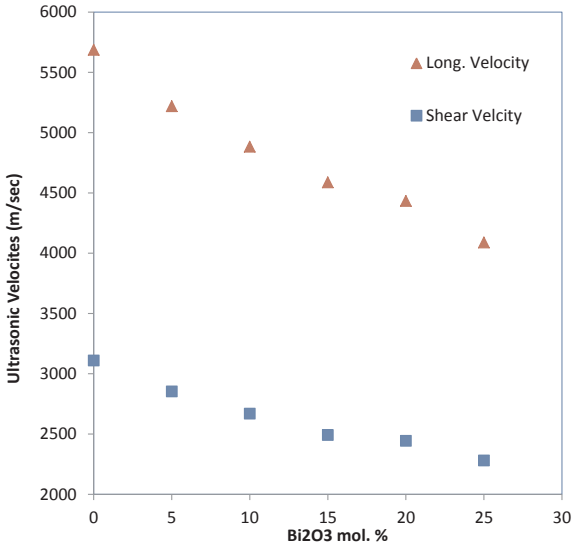

Fig. 2. Variation of longitudinal and shear ultrasonic velocities with Bi_2O_3 mol.%.

3. Results and discussion

Density ρ and molar volume V_m, values of the present (75-x) B_2O_3-xBi_2O_3-10Na_2O-10CaO-5Al_2O_3 glasses have been collected in Table 1 and represented in Fig. 1 for different of Bi_2O_3 mol.%. A change of the behavior of the density at 15 mol.% could be attributed due to structural changes. Previously [13], density of the glass samples increased from 2245 to 5029 kg/m^3 for increasing Bi_2O_3 mol.%, it was less than that for (100-x) B_2O_3-xBi_2O_3 (where x = 30, 40, 50, 60 mol.%) [9] and it was correlated as well with B_2O_3-xBi_2O_3 glasses doped with Al_2O_3 [21].

Longitudinal V_L, shear V_S, velocities, bulk modulus (K), Young's moduli, Poission's ratio, Deby's temperature, (θ_D), softening temperature and Micro Hardness (H) of the (75-x)B_2O_3-xBi_2O_3-10Na_2O-10CaO-5Al_2O_3 glasses have been collected in Table 1. Fig. 2 shows both V_L and V_S ultrasonic velocities. The measured data of the ultrasonic velocities are found to be decreased from 5687 m/s to 4089 m/s for V_L and from 3110 m/s to 2281 m/s for V_S which reveal the sensitive dependence on the glass composition. Longitudinal *L*, shear *G*, bulk *K*, Yong's *E* moduli, and Poisson's ratio *σ* have been calculated by using the next relations [22]:

$$L = \rho V_L^2 \tag{3}$$

$$G = \rho V_S^2 \tag{4}$$

$$B = \rho\left(V_L^2 - \frac{4}{3}V_S^2\right) \tag{5}$$

$$E = \frac{\rho V_S^2(3V_L^2 - 4V_S^2)}{V_L^2 - V_S^2} \tag{6}$$

$$\sigma = \frac{V_L^2 - 2V_S^2}{2(V_L^2 - V_S^2)} \tag{7}$$

Elastic moduli of (75-x)B_2O_3-xBi_2O_3-10Na_2O-10CaO-5Al_2O_3 glasses have been collected in Table 1 and represented in Fig. 3. Table 1 shows that elastic moduli gradually increase and show a maxima at x = 15 mol.% then a notable decrease have be observed while Bi_2O_3 increases to 25 mol.%. Borate glasses doped with Bi_2O_3 have shown the formation of BO_4 units [11,21,23–26]. Thus, the increase in the elastic moduli as Bi_2O_3 increases from 0 to 15 mol.% might due to the presence of BO_4

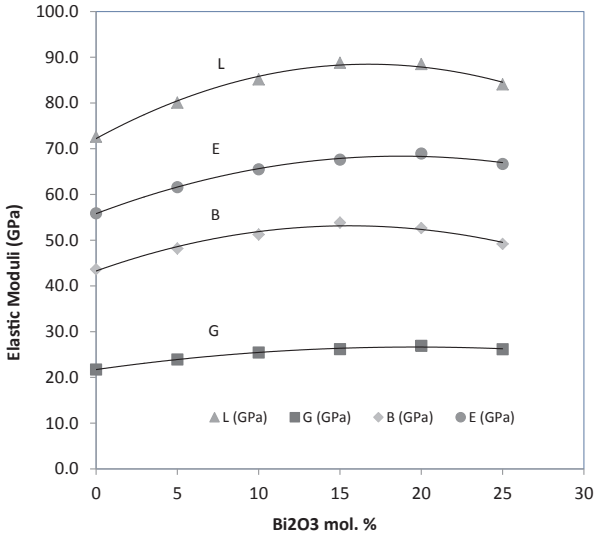

Fig. 3. Variation of elastic moduli with Bi_2O_3 mol.%.