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Preface

The Scientific Project Colloquium offers a platform for publishing Diploma Science final year projects (FYP). The objective is to effectively distribute research findings throughout all scientific disciplines. The primary objective of including final year projects into the course curriculum is to encourage students to put their theoretical knowledge into practical applications.

We would like to express our gratitude to our primary establishment, the Faculty of Applied Sciences and Universiti Teknologi MARA, Perak Branch, for their invaluable assistance.

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ELASTIC PROPERTIES OF YTTRIUM TRIOXIDE DOPED NEODYMIUM LEAD BOROTELLURITE GLASS SYSTEM

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Abstract: This paper presents the influence of transition metal such as yttrium trioxide on the elastic properties of a glass system consisting of $(49-x)\text{H}_3\text{BO}_3\text{-}35\text{TeO}_2\text{-}15\text{PbO}\text{-}1.0\text{Nd}_2\text{O}_3\text{-}x\text{Y}_2\text{O}_3$ ($0.0 \leq x \leq 2.5$ mol%). The glass samples were produced by using melt-quenching method and the elastic properties of the glasses were investigated. X-Ray Diffraction was analyzed to confirm the amorphous nature of the glasses. Longitudinal and shear ultrasonic wave velocities of the glass samples were calculated at room temperature. The calculated density and both ultrasonic wave velocities were employed for measuring elastic moduli, poisson's ratio, microhardness, softening temperature, and Debye temperature. The elastic properties of the glass samples were found to be strongly affected by varying concentrations of yttrium trioxide. The role of the yttrium trioxide modifier in the glass system is clearly demonstrated.

Keywords: Elastic, Yttrium, Lead, Borotellurite, Ultrasonic

INTRODUCTION

Borotellurite glasses, composed primarily of boron trioxide (B_2O_3) and tellurium dioxide (TeO_2), are renowned for their unique combination of optical, thermal, and mechanical properties (AlBurihi et al., 2021; Kurtulus et al., 2023). These glasses exhibit high refractive indices, good infrared transmission, and low phonon energy, making them suitable for various optical applications (Gowda et al., 2021). The addition of lead oxide (PbO) further enhances the glass network, improving its thermal stability and density, and contributing to its favourable properties for photonic applications (Devaraja et al., 2020).

The study of rare earth ions doped glass systems with transition metal oxides has attracted the attention of many researchers from all over the world related to their various applications in today's technologies such as in attenuation shielding, window reflection, electronic, thermal and mechanical sensors, and optoelectronic devices. Among all transition metal oxides, yttrium trioxide has attracted the attention of researchers due to its unique properties, such as its extended light absorption, which leads to high absorption efficiency, good chemical stability, and high refractive index (Fayad et al., 2018; Prasad et al., 2020; Siddiq et al., 2023). Studies on oxide glass containing transition metal oxide have been done by Kh.S. Shaaban (2021) and Issa et al. (2020). They reported that the addition of transition metal oxide, such as yttrium trioxide, into glass oxide increased the density, elastic properties, and rigidity of the glass network. Other than that, it also enhances the glass transition temperature and the coefficient of thermal expansion [6]. P. Aryal et al. (2018) stated that yttrium trioxide has excellent visible and infrared transmission with comprehensive band gap semiconductor material, which serves as an efficient active host material for active rare earth ions that increase luminescence and optical properties.

The main objectives of this work are to determine the influence of yttrium trioxide on the elastic properties of lead borotellurite glass system doped with neodymium trioxide by evaluating a variety parameters like molar volume, density, ultrasonic velocities, elastic moduli, Poisson's ratio, microhardness, softening temperature, as well as Debye temperature.

METHODOLOGY

Glass Preparation

The synthesis of Yttrium trioxide doped glasses with various compositions $(49-x)\text{H}_3\text{BO}_3\text{-}35\text{TeO}_2\text{-}15\text{PbO}\text{-}1.0\text{Nd}_2\text{O}_3\text{-}x\text{Y}_2\text{O}_3$ where $x = 0, 0.5, 1.0, 1.5, 2.0$ and 2.5 mol% was achieved by weighing the appropriate amount of chemical reagent grade powders of Y_2O_3 , Nd_2O_3 , H_3BO_3 , TeO_2 and PbO . The weighed batches were mixed for an hour using a milling machine to obtain a satisfactory homogeneity mixture. Then, the mixture was put inside an alumina crucible

and heated at 1000 °C in an electrical furnace for 30 minutes. After that, the glass sample was formed by casting the homogenized molten in a stainless-steel plate that had been pre-heated at 400 °C. Before the furnace was switched off, annealing process was continued for 5 hours at 400 °C in order to remove any residual thermal stress. The glass sample was gradually allowed to reach room temperature. Then, the glass sample was polished using sandpaper on both sides to produce parallel surfaces that were suitable for ultrasonic measurements.

Sample characterization

The density of glass sample was measured based on Archimedes principle using an electronic densimeter model MD-300S with distilled water used as the immersion medium. The glass sample's density was calculated using the formula.

$$\rho = \frac{W_a}{W_a - W_{dw}} \rho_{dw} \quad \text{Equation 1}$$

where ρ is the density, W_a and W_{dw} are the weight of the prepared sample in the air as well as when submerged in distilled water, and ρ_{dw} is the density of distilled water at room temperature. The glass sample was grounded into powder as preparation for X-ray Diffraction testing. The longitudinal wave velocity, V_L , and shear wave velocity, V_s , were measured by using the measuring thickness of the glass sample. From the calculated ultrasonic velocities and density, the elastic moduli, microhardness, Poisson's ratio, Debye temperature, and softening temperature of the glass sample with different concentrations of yttrium trioxide have been determined using the following equation.

Longitudinal modulus:

$$L = \rho V_L^2 \quad \text{Equation 2}$$

Shear modulus:

$$G = \rho V_s^2 \quad \text{Equation 3}$$

Bulk modulus:

$$K = L - \frac{4}{3}G \quad \text{Equation 4}$$

Young's modulus:

$$E = (1 + \sigma)2G \quad \text{Equation 5}$$

Poisson's ratio:

$$\sigma = \left[\frac{(L-2G)}{2(L-G)} \right] \quad \text{Equation 6}$$

The micro hardness, softening temperature and Debye temperature were measured based on the formula.

Microhardness:

$$H = \left[\frac{(1-2)}{6(1+\sigma)} \right] \quad \text{Equation 7}$$

Softening temperature:

$$T_s = \left(\frac{M_w}{c\rho} \right) V_s^2 \quad \text{Equation 8}$$

where

Debye temperature:

$$\theta_D = \frac{h}{k} \left(\frac{9N}{4\pi V} \right)^{1/3} V_m \quad \text{Equation 9}$$

where

$$V_m = \left[\frac{(1/V_L^3) + (2/V_s^3)}{3} \right]^{-1/3} \quad \text{Equation 10}$$

h and k are the Plank's constant and the Boltzmann constant, $\frac{N}{V}$ is the number of vibrating atoms per unit volume and equal to PN_A where P is the number of atoms in the chemical formula, N_A is the number of Avogadro and V_m is the mean ultrasonic wave velocity.

FINDINGS

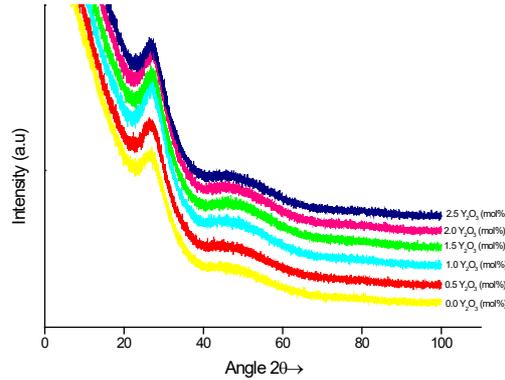
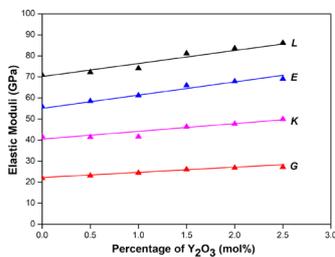


Figure 1. XRD Spectra of The Yttrium Trioxide Doped Neodymium Lead Borotellurite Glasses

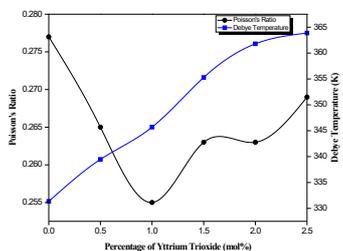
The X-ray diffraction patterns was displayed in Figure 1. From the figure, it can clearly be seen that there are no discrete or continuous sharp crystalline peaks that reveal the amorphous nature of the glass samples [8].

Table 1. Density (ρ), Molar Volume (V_m), Longitudinal Ultrasonic Velocity (V_L), Shear Ultrasonic Velocity (V_s), Elastic Moduli of Yttrium Trioxide Doped Neodymium Lead Borotellurite Glasses

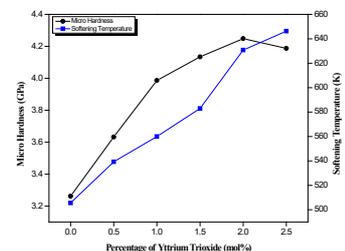
| Mol% Y_2O_3 | ρ (gcm^{-3}) | V_L (ms^{-1}) | V_s (ms^{-1}) | L (GPa) | G (GPa) | K (GPa) | E (GPa) |
|---------------|-----------------------|---------------------|---------------------|-----------|-----------|-----------|-----------|
| 0.0 | 4.771 | 3857 | 2143 | 70.98 | 21.91 | 41.77 | 35.79 |
| 0.5 | 4.756 | 3899 | 2206 | 72.29 | 23.14 | 41.44 | 37.72 |
| 1.0 | 4.870 | 3902 | 2238 | 74.15 | 24.39 | 41.63 | 38.97 |
| 1.5 | 5.045 | 4012 | 2276 | 81.21 | 26.13 | 46.36 | 54.14 |
| 2.0 | 4.839 | 4156 | 2357 | 83.58 | 26.88 | 47.73 | 58.30 |
| 2.5 | 4.814 | 4232 | 2378 | 86.21 | 27.22 | 49.92 | 61.49 |



(a)



(b)



(c)

Figure 2 (a) Elastic Moduli, (b) Poisson's Ratio and Debye Temperature and Microhardness and (c) Softening Temperature of Yttrium Trioxide doped Neodymium Lead Borotellurite Glass

As indicated in Table 1, the results illustrate the variation in density with respect to the mol percent of yttrium trioxide concentration. The density of the prepared glasses was found to increase steeply from 4.756 to 5.045 g/cm³ before it slightly drops to 4.814 g/cm³. The molecular weight of yttrium trioxide is 225.81 g/mol; meanwhile, the molecular weight of H₃BO₃ is 61.83 g/mol. As the heavier compounds replace the lighter compounds, the total molecular weight of the prepared glass will increase. Hence, the density of the glass samples also tends to increase as this parameter is directly proportional to the mass of the glass systems [9]. However, the values of density of the glass samples decrease as the concentration of yttrium trioxide increases, which might be attributed to the fact that an occupation of yttrium trioxide at high concentration in the free space region in the glass network caused the reduction of the glass compactness [10].

The calculated values of V_L and V_S as a function of mol% of yttrium trioxide were tabulated in Table 1. Both values of V_L and V_S of the glass samples show the increment trend from 3857 ms⁻¹ to 4232 ms⁻¹ and 2143 ms⁻¹ to 2378 ms⁻¹, further increasing the yttrium trioxide content. The presence of yttrium trioxide proves that this element acts as a network modifier that modifies the glass network structure in the glass system. The increment trend in ultrasonic velocities might be related to the increase in strengthening and rigidity of the glass network [11]. The involvement of yttrium trioxide in the glass network by breaking up bonds and filling the interstitial position within the vitreous network causes the formation of BO atoms and results in the rigidity of the glass systems increasing [13].

The elastic moduli of the glass samples were listed in Table 1. As shown in Figure 2 (a), the results of elastic moduli of the prepared glass increase as the yttrium trioxide increases from 0 mol% up to 2.5 mol%. The increase in the elastic moduli indicates the increase in the compaction and rigidity of the glass samples [14] and may be related to the increment in the glass density.

Table 2. Poisson's Ratio (σ), Microhardness (H), Softening Temperature (T_s) and Debye Temperature (θ_D)

| Mol% Y ₂ O ₃ | σ | H (GPa) | T_s (K) | θ_D (K) |
|------------------------------------|----------|-----------|-----------|----------------|
| 0.0 | 0.277 | 3.262 | 505.55 | 331.35 |
| 0.5 | 0.265 | 3.632 | 539.28 | 339.47 |
| 1.0 | 0.255 | 3.986 | 560.01 | 345.69 |
| 1.5 | 0.263 | 4.134 | 582.99 | 355.30 |
| 2.0 | 0.263 | 4.248 | 630.77 | 361.79 |
| 2.5 | 0.269 | 4.187 | 646.23 | 363.87 |

The variation values of Poisson's ratio of the samples with different mol percent of yttrium trioxide are listed in Table 2 as well as plotted in Figure 2 (b). These results indicate that the Poisson's ratio of the glass samples initially decreased from 0.277 to 0.255 before it started to increase to 0.269. The decrease in Poisson's ratio might be due to the increase in the crosslink density and rigidity of the glass samples [15]. Meanwhile, an increase in the results of Poisson's ratio might be attributed to the formation of NBO atoms as more yttrium trioxide content is introduced in the glass samples, which weakens the structure of the prepared glass network (Tafida et al., 2020).

Debye temperature is defined as an important parameter of solids, which indicates the temperature at which nearly all modes of vibration are excited (Laopaiboon et al., 2016). The values of the Debye temperature are listed in Table 2. As presented in Figure 2 (b), the Debye temperature of the glass samples show the increment trend from 331.35 K to 363.87 K with an addition in the concentration of yttrium trioxide. These results indicate an increase in ultrasonic velocities and an increase in the rigidity of the glass samples, which is attributed to the increase in the number of atoms in the chemical formula of the glass network (Ezhil Pavai et al., 2019).

Microhardness is defined as the resistance of a material to permanent indentation or penetration (Chinnamat et al., 2017). Variations of the microhardness as a function of dopants are tabulated in Table 2. As presented in Figure 2 (c), the values of micro-hardness are found to increase from 3.262 GPa up to 4.248 GPa as the concentration of yttrium trioxide increases up to 2.0 mol% before it starts to decrease at concentration 2.5 mol% to 4.187 GPa. An increase in the packing density of an atom might cause an increase in the microhardness. This is due to the fact that a material with higher packing density has high rigidity (Sidek Ab. Aziz, 2011). Therefore, it is more difficult to eliminate free volume inside the glass structure (Palani & Selvarasi, 2017). The decrease in microhardness might be related to the fact that the addition of yttrium trioxide at higher concentrations will cause the expansion of the glass network by creating more NBO atoms, thus becoming less rigid (Halimah et al., 2017).

Softening temperature is the variation of temperature from viscous flow to plastic flow in a material, which is used to determine the temperature stability of the glass samples (Umar et al., 2020). As listed in Table 2 and plotted in Figure

2 (c), the values of softening temperature increase from 505.55 K to 646.23 K as the concentration of yttrium trioxide increases from 0 mol% up to 2.5 mol%. This trend of results implies an increase in rigidity of the glass network (Umar et al., 2020).

CONCLUSIONS

The addition of yttrium trioxide into the neodymium lead borotellurite glass system shows a marked effect on the elastic and physical properties. The amorphous nature of these glasses is confirmed by XRD analysis. The density of the prepared glasses vary as the yttrium trioxide increases from 0 to 2.5 mol%. This indicated the modifier behavior of yttrium trioxide in the prepared glasses. The enhancement in both ultrasonic wave velocities of the glass systems reveals the fact that the inclusion of yttrium trioxide content to the neodymium lead borotellurite glass causes an easy movement for both ultrasonic wave velocities inside the glass network and hence the tendency of both ultrasonic velocities to enhance as the concentration of yttrium trioxide increases. From elastic moduli, Poisson's ratio, Debye temperatures, microhardness, and softening temperature results, it is shows that an enhancement in rigidity of the glass structure and strengthening in the bonding of the prepared glass structure.

COMPLIANCE OF ETHICAL STANDARDS

Not applicable.

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Tarikh : 20 Januari 2023

Prof. Madya Dr. Nur Hisham Ibrahim
Rektor
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Sekian, terima kasih.

“BERKHIDMAT UNTUK NEGARA”

Saya yang menjalankan amanah,

Setuju.

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