Research Article

Studying the Effect of ZnO on Physical and Elastic Properties of $(\text{ZnO})_x(\text{P}_2\text{O}_5)_{1-x}$ Glasses Using Nondestructive Ultrasonic Method

Khamirul Amin Matori,^{1,2} Mohd Hafiz Mohd Zaid,¹ Hock Jin Quah,³ Sidek Hj. Abdul Aziz,¹ Zaidan Abdul Wahab,¹ and Mohd Sabri Mohd Ghazali⁴

¹Department of Physics, Faculty of Science, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

²Materials Synthesis and Characterization Laboratory, Institute of Advanced Technology, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

³Materials Processing and Technology Laboratory, Institute of Advanced Technology, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

⁴School of Fundamental Sciences, Universiti Malaysia Terengganu, 21030 Kuala Terengganu, Terengganu, Malaysia

Correspondence should be addressed to Khamirul Amin Matori; khamirul@upm.edu.my

Received 23 September 2014; Revised 15 December 2014; Accepted 16 December 2014

Academic Editor: Baibiao Huang

Copyright © 2015 Khamirul Amin Matori et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Binary zinc phosphate glass system with composition of $(\text{ZnO})_x(\text{P}_2\text{O}_5)_{1-x}$, ($x = 0.1, 0.2, 0.3, 0.4, 0.5$ and 0.6 mol%) was successfully prepared using a conventional melt-quenching method. Composition dependence of physical properties and elastic properties in the $(\text{ZnO})_x(\text{P}_2\text{O}_5)_{1-x}$ were discussed in association with the effects of adding zinc oxide (ZnO) as a modifier. The addition of ZnO modifier was expected to produce substantial changes on physical properties of the phosphate glasses. An increase in density values of the phosphate glasses was observed. Elastic moduli were studied by measuring ultrasonic longitudinal and shear velocities (V_l and V_t) of the glasses at room. Longitudinal modulus, shear modulus, bulk modulus, Young's modulus, Poisson's ratio, and Debye temperature (θ_D) were derived from both data of velocities and respective density of all of the samples. Findings from present work showed dependence of density and elastic moduli of each ZnO- P_2O_5 series on glass composition.

1. Introduction

Phosphate glasses have been extensively studied due to their interesting properties, such as high thermal expansion coefficient, high gain density, low melting point, low refractive index, low dispersive and transparency ability in a wide spectral range (from UV to IR), as well as potential applications in many industrial fields, which made the phosphate glass suitable for the fabrication of optical fibers, sensor, and laser technologies (laser host glasses) [1–5]. However, the poor chemical durability and high hygroscopic and volatile nature limited the phosphate glasses from replacing the conventional glasses in a wide range of technological applications [6–9]. Many researchers reported that properties of the glasses in terms of chemical durability and physical, structural, and

elastic properties can be improved by the addition of metal oxides, such as ZnO, PbO, Al_2O_3 , TiO_2 , and Bi_2O_3 [10–13]. Thus, the phosphate glasses with addition of heavy metal oxide have been found to be used in broad range of applications, such as photonic, bone regeneration and hermetic sealing technology.

In a phosphate glass, phosphorus always stands in a tetrahedral coordination. It is trustworthy from previous works that addition of glass former and/or glass modifier in the phosphate glass will increase density of the glass produced. This has been proven by the addition of lead oxide (PbO) by Matori et al. [13], ferum oxide (Fe_2O_3) by Sidek et al. [14], samarium oxide (Sm_2O_3) by Brassington et al. [15], vanadium oxide (V_2O_5) by Mierzejewski et al. [16], and phosphate glass by Farley and Saunders [17]. Further investigation by other

researchers that had studied binary lead phosphate glasses showed an increase in the density and molar volume as PbO was added to the phosphate network system. The addition of PbO and a decrease in the P_2O_5 concentration in the glass network would cause the densities to increase. This indicated that the Pb^{2+} might act as a network modifier, which altered structure of the glass by reducing nonbridging oxygens (NBOs) in the network and causing the structure to become more compact [13]. Sidek et al. on the other hand studied the effects of ZnO addition on thermal properties of tellurite glass. Experimental results showed an increase in density and thermal expansion coefficient as more ZnO content was being added to the tellurite glass network with a decrease in glass transition, Debye temperature, and softening temperature. The decrease was believed to be related to a change in coordination number of the glass network and destruction of the network structure by the formation of some NBOs atoms [18]. In addition, Kim et al. studied the effects of ZnO addition on photoluminescence of the phosphate glass [19]. It was disclosed that the zinc phosphate glasses were chemically durable with a processing temperatures below 400°C. Hence, zinc phosphate glasses have been used as nuclear waste hosts due to their high chemical durability and low processing temperature [20]. Le Saout et al. characterized the structure of $(PbO)_x(ZnO)_{0.6-x}(P_2O_5)_{0.4}$ system using ^{31}P NMR, Raman, and infrared spectroscopies. The investigations revealed no significant change in the average chain length composed of PO_4 tetrahedral units with the substitution of Zn for Pb cation [21].

In this study, ZnO is added to the phosphate glass network as a glass modifier to improve chemical durability of the glass. The resulting zinc phosphate glasses would be interesting for study since the glass phase can be formed over a wide range of concentrations. Moreover, the ZnO can enter the glass network, both as network modifier and as a network former [22, 23]. It was also suggested that a dramatic improvement in chemical durability of the phosphate glasses was associated with the formation of P–O–Zn bond after the addition of ZnO into the phosphate network [24]. In order to further investigate the effects of ZnO addition into the phosphate glass system, physical and elastic properties of the zinc phosphate glass network are of concern in this work. A short-term significance of this work is to establish a baseline for the elastic properties of the phosphate glass with the addition of ZnO into the glass network.

2. Experimental Details

Glass batch of $(ZnO)_x(P_2O_5)_{1-x}$ binary zinc phosphate (where $x = 0.1, 0.2, 0.3, 0.4, 0.5$, and 0.6 mol%) was prepared using conventional melt-quenching method. All the glass samples were prepared from commercial powders by mixing specific weights of the batches using zinc oxide, ZnO (99.99%, Assay, Alfa Aesar, Ward Hill, MA, USA), and phosphorus pentoxide (P_2O_5) (97.00%, Technical grade, Alfa Aesar, Ward Hill, MA, USA) weighed in appropriate quantities according to the mol% of the composition in glass samples. The mixture was ground using an agate mortar to obtain good homogeneity.

The mixture was then placed into an alumina crucible and heated at 1100°C in a box furnace for an hour. The molten mixture was then quickly poured into a stainless steel mould at room temperature. The glass samples were annealed at 350°C (T_g of zinc phosphate glass in the range of 280°C to 370°C) for an hour before the furnace was switched off in order to remove the thermal strain [23]. The glass samples were allowed to cool down in situ at room temperature for a day. Later, the glass samples were cut (dimensions of ~ 10 mm $\times$ 20 mm) by using an Isomet Low Speed Saw machine (Buehler) and polished using fine sand paper to obtain flat, parallel end faces that were suitable for ultrasonic measurements.

Density measurement was performed using the Archimedes method with acetone as the buoyant liquid:

$$\rho = \left(\frac{W_a}{(W_a - W_b)} \right) \rho_b, \quad (1)$$

where W_a is the glass sample weight in air, W_b is the glass sample weight in acetone, and ρ_b is the density of acetone. All of the glass samples' weights were measured with a digital balance (± 0.0001 g accuracy). The molar volume was calculated using the relation of $V_m = M/\rho$, where M is the molar weight and ρ is the density of glass. Ultrasonic measurements were performed at room-temperature by pulse superposition technique using an Ultrasonic Data Acquisition System (Matec 8020, Matec Instruments, USA) at 10 MHz via x -cut and y -cut quartz transducers with a burnt honey used as a bonding material between the glass samples and the transducers. By measuring thickness of the glass sample (d), the longitudinal (V_l) and transverse (V_t) wave velocities can be measured and calculated using the relation $V = 2d/t$. The absolute accuracy in the measurement of the velocity is ± 5 ms $^{-1}$, and the relative error is $\pm 0.1\%$.

In an amorphous solid, elastic strain produced by small stress can be described by two independent elastic constants, C_{11} and C_{44} . Elastic moduli were calculated using the following standard relations [17]:

$$\begin{aligned} \text{Longitudinal modulus } C_{11} &= L = \rho V_l^2, \\ \text{Shear modulus } C_{44} &= G = \rho V_t^2, \\ \text{Bulk modulus } K &= L - \left(\frac{4}{3} \right) G, \\ \text{Young's modulus } E &= (1 + \sigma) 2G, \\ \text{Poisson's ratio } \sigma &= \frac{(L - 2G)}{2(L - G)}, \\ \text{Debye temperature } \theta_D &= \frac{h}{k} \left[\frac{3\rho n N}{4\pi M} \right] \left(\frac{1}{3} \right) V_m. \end{aligned} \quad (2)$$

3. Results and Discussion

The prepared zinc phosphate $((ZnO)_x(P_2O_5)_{1-x})$ glasses were subjected to ultrasonic measurements at room temperature. Table 1 presents the value of density (ρ), molar volume (V_m),

TABLE 1: The values of density, molar volume, sound velocities, elastic moduli, Poisson's ratio, and Debye temperature.

Glass sample (x)	ρ (kg m ⁻³)	V_m (cm ³ mol ⁻¹)	V_l (m/s)	V_t (m/s)	C_{11} (GPa)	C_{44} (GPa)	K (GPa)	E (GPa)	σ	θ_D (K)
0.1	2420	56.2	3887	2406	36.6	14.0	17.9	33.3	0.189	257
0.2	2590	50.1	3986	2424	41.2	15.2	20.9	36.8	0.207	265
0.3	2745	45.1	4087	2446	45.8	16.4	24.0	40.1	0.221	276
0.4	2937	40.1	4158	2462	50.8	17.8	27.0	43.8	0.230	283
0.5	3105	36.0	4275	2486	56.7	19.2	31.2	47.8	0.245	293
0.6	3281	32.2	4376	2506	62.8	20.6	35.4	51.8	0.256	303

FIGURE 1: Variation of density versus ZnO mol%.

FIGURE 2: Variation of molar volume versus ZnO mol%.

sound velocities (both longitudinal (V_l) and transverse (V_t)), the calculated elastic constants (C_{11} and C_{44}), bulk modulus (K), Young's modulus (E), Poisson's ratio (σ), and Debye temperature (θ_D) for the investigated samples. When a higher mol% of ZnO was added to the phosphate glass system, an increase in the density (ρ) of the glass system from 2420 kg m⁻³ to 3281 kg m⁻³ was observed (Figure 1). The values of the density measurement are near to other researches [19, 21]. This was due to the reduction of P₂O₅ concentration in the glass network, whereby the Zn²⁺ would act as a network modifier, to reduce the number of nonbridging oxygens (NBOs) in the glass structure and a more compact glass was formed. The possible reactions in the glass network can be represented as follows:

The additional oxygen sharing and charge balance requirements are met by the conversion of P=O in [POO_{3/2}] units to form P-O in [PO_{4/2}]⁺ units. Therefore, continuous titration of P=O bonds was needed in order for the Zn to be incorporated into the glass network and formed P-O-Zn linkages [23].

Figure 2 shows that the molar volume of the glasses is decreased as the content of ZnO is increased. Generally, an opposite trend for the density and molar volume of the investigated samples were observed in this work, which was

in agreement with previous reported results [25, 26]. A decrease in molar volume of the (ZnO)_x(P₂O₅)_{1-x} glasses from 56.2 cm³ mol⁻¹ to 32.2 cm³ mol⁻¹ was observed due to the substitution of phosphorus by zinc. Since the radius of Zn²⁺ (0.074 nm) was greater than P⁵⁺ (0.038 nm), the addition of ZnO into the glass system has caused an increase in the bond length or inter-atomic spacing between the atoms, whereby the glass network will expand and form more pores.

Zn²⁺ ions might enter the glass network interstitially to break the P-O-P bonds that might lead to the formation of ionic bonds between the Zn²⁺ and single bonded oxygen atoms. So if one assumed that the only effect of adding Zn cations was to break down the network bonds P-O-P, then the decrease in the molar volume with ZnO content would be expected for the entire vitreous range of the studied glass system. Therefore, the compactness of the glass will increase and reduce NBO's, which increased the rigidity of the glasses [27].

The longitudinal (V_l) and shear ultrasonic (V_t) velocities in binary zinc phosphate glass systems with different mole fractions of ZnO content are depicted in Figure 3. The changes of glass structure were depending on the propagation of both longitudinal and shear wave velocities in the bulk samples. Hence, filling of Zn²⁺ ions into the phosphate glass network would result in the glass structure being more compact and rigid. As a result, both velocities V_l and V_t were increased from 3887 m s⁻¹ to 4376 m s⁻¹ and 2406 m s⁻¹ to 2506 m s⁻¹, respectively. It can be seen that the values of V_l are higher than V_t . The increase of ultrasonic velocities with the

FIGURE 3: Variation of sound velocity versus ZnO mol%.

FIGURE 5: Variation of Poisson's ratio versus ZnO mol%.

FIGURE 4: Variation of elastic moduli versus ZnO mol%.

FIGURE 6: Variation of Debye temperature versus ZnO mol%.

increase of ZnO concentration has been observed, indicating that ZnO plays a dominant role in the velocities. The increase in ultrasonic velocity of the studied glass revealed the fact that the addition of ZnO to the phosphate glass would cause a swift movement of the ultrasonic wave inside the network of the glass structure. Due to this factor, the ultrasonic velocity of the glasses would increase as the ZnO content was increased. In this $(\text{ZnO})_x(\text{P}_2\text{O}_5)_{1-x}$ glass system, ZnO functioned as a network modifier. The ZnO would modify the glass structure, making a glass harder.

The independent elastic constants for isotropic solids and glasses are longitudinal modulus (C_{11}) and shear modulus (C_{44}), where calculation for other elastic constants and Poisson's ratio depend on the density and both the velocities values. Young's modulus (E) determined from the sound velocity was defined as a ratio of the linear stress over the linear strain [27], whereby this Young's modulus was related to the bond strength of the materials. The bulk modulus (K) was defined as the changing in volume when a force is acted upon it at all directions [28].

Figure 4 shows the variation of elastic moduli: C_{11} , C_{44} , K , and E versus mol% of ZnO. The values of elastic moduli were showing an increasing trend with the increase of ZnO content. The attainment of a higher value of C_{11} than C_{44} indicated that the $(\text{ZnO})_x(\text{P}_2\text{O}_5)_{1-x}$ glasses were able to

withstand a higher longitudinal stress than transverse stress. The increase in C_{44} and K was due to the changing in the coordination number with an increasing in the ZnO content. A comparison between K and E ($K < E$) indicated that the samples were more tolerant to the stress from one direction than the stress from all directions. Since the addition of ZnO would increase the rigidity of glass structure, the velocity and elastic moduli would also increase.

The obtained Poisson's ratio from the elastic moduli is shown in Figure 5. Poisson's ratio obtained from the glasses was affected by the crosslink density of the glass structure. An increase in Poisson's ratio from 0.189 to 0.256 as a function of ZnO content suggested that an equal amount of stress was applied throughout the whole range of the glass composition and the lateral strain was gradually leveled out [29]. In addition, the observation made in Poisson's ratio supported that there were changes in cross link densities. A continuous increase in the Debye temperature was observed as more ZnO was added to the glass system (Figure 6). This was an indication that the obtained Debye temperature from the ultrasonic velocity data was sensitive towards the amount of ZnO content in glass system, whereby the packing structure of the glass became more compact due to the reduction of NBO's as the ZnO content was being increased.

4. Conclusion

As a conclusion, a series of binary $(\text{ZnO})_x(\text{P}_2\text{O}_5)_{1-x}$ zinc phosphate glass systems have been successfully prepared and characterized. Based on the results, it showed that the densities increased when ZnO content was added to the phosphate glass systems, while a molar volume was decreased. The increase in density was also probably caused by a change in crosslink density and coordination number of Zn^{2+} ions. The addition of ZnO and a decrease of the P_2O_5 concentration in the glass network caused the densities to increase, indicating that the Zn^{2+} had served as a network modifier and altered structure of the glass by reducing NBOs in the network, and thus the structure turned out to be more compact. The decrease in the molar volume might be attributed to a decrease in the bond length or interatomic spacing between the atoms. The velocities (V_l and V_t), elastic moduli (C_{11} , C_{44} , K , E), Poisson's ratio, and Debye temperature showed a gradual increasing trend as ZnO was being added to the phosphate glass network. The dramatic increase in ultrasonic velocity and elastic moduli was suggested to be caused by the increase in rigidity and change in coordination number as a result of the decrease in the NBO's, as revealed by density measurement.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

The researchers gratefully acknowledge the financial support for this study from the Malaysian Ministry of Higher Education (MOHE) through the Fundamental Research Grant Scheme. The author (Hock Jin Quah) would like to acknowledge the financial support provided by Universiti Putra Malaysia (UPM) under UPM Post-Doctoral Fellowship Scheme.

References

- [1] A. Schülzgen, L. Li, X. Zhu, V. L. Temyanko, and N. Peyghambarian, "Microstructured active phosphate glass fibers for fiber lasers," *Journal of Lightwave Technology*, vol. 27, no. 11, pp. 1734–1740, 2009.
- [2] G. Le Saoût, Y. Vaills, and Y. Luspín, "Effects of thermal history on mechanical properties of $(\text{PbO})_x(\text{ZnO})(0.6-x)(\text{P}_2\text{O}_5)_{0.4}$ glasses using Brillouin scattering," *Solid State Communications*, vol. 123, no. 1-2, pp. 49–54, 2002.
- [3] M. A. Karakassides, A. Saranti, and I. Koutselas, "Preparation and structural study of binary phosphate glasses with high calcium and/or magnesium content," *Journal of Non-Crystalline Solids*, vol. 347, no. 1-3, pp. 69–79, 2004.
- [4] K. V. Shah, M. Goswami, R. Kumar, S. Manikandan, V. K. Shrikhande, and G. P. Kothiyal, "Preparation of mixed alkali multicomponent phosphate glasses and some studies on their thermomechanical and optical properties," *Physics and Chemistry of Glasses*, vol. 46, no. 3, pp. 274–278, 2005.
- [5] P. Jozwiak and J. E. Garbacz, "Mixed electronic-ionic conductivity in the glasses of the $\text{Li}_2\text{O}-\text{V}_2\text{O}_5-\text{P}_2\text{O}_5$ system," *Solid State Ionics*, vol. 176, no. 25–28, pp. 2163–2166, 2005.
- [6] L. Koudelka, J. Jiráček, P. Mošner, L. Montagne, and G. Palavit, "Study of lithium-zinc borophosphate glasses," *Journal of Materials Science*, vol. 41, no. 14, pp. 4636–4642, 2006.
- [7] B. Eraiah and S. G. Bhat, "Optical properties of samarium doped zinc-phosphate glasses," *Journal of Physics and Chemistry of Solids*, vol. 68, no. 4, pp. 581–585, 2007.
- [8] R. Praveena, V. Venkatramu, P. Babu, and C. K. Jayasankar, "Fluorescence spectroscopy of Sm^{3+} ions in $\text{P}_2\text{O}_5-\text{PbO}-\text{Nb}_2\text{O}_5$ glasses," *Physica B*, vol. 403, no. 19-20, pp. 3527–3534, 2008.
- [9] A. Musinu, G. Piccaluga, and G. Pinna, "Structural properties of lead-iron phosphate glasses by X-ray diffraction," *Journal of Non-Crystalline Solids*, vol. 122, no. 1, pp. 52–58, 1990.
- [10] T. Minami and J. D. Mackenzie, "Thermal expansion and chemical durability of phosphate glasses," *Journal of the American Ceramic Society*, vol. 60, no. 5-6, pp. 232–235, 1977.
- [11] H. S. Liu, T. S. Chin, and S. W. Yung, "FTIR and XPS studies of low-melting $\text{PbO}-\text{ZnO}-\text{P}_2\text{O}_5$ glasses," *Materials Chemistry and Physics*, vol. 50, no. 1, pp. 1–10, 1997.
- [12] R. K. Brow, L. Kovacic, and R. E. Loehman, "Novel glass sealing technologies," *Ceramic Transition*, vol. 70, pp. 177–187, 1996.
- [13] K. A. Matori, M. H. M. Zaid, S. H. A. Aziz, H. M. Kamari, and Z. A. Wahab, "Study of the elastic properties of $(\text{PbO})_x(\text{P}_2\text{O}_5)_{1-x}$ lead phosphate glass using an ultrasonic technique," *Journal of Non-Crystalline Solids*, vol. 361, no. 1, pp. 78–81, 2013.
- [14] H. A. A. Sidek, S. Rosmawati, B. Z. Azmi, and A. H. Shaari, "Effect of ZnO on the thermal properties of tellurite glass," *Advances in Condensed Matter Physics*, vol. 2013, Article ID 783207, 6 pages, 2013.
- [15] M. P. Brassington, A. J. Miller, J. Pelzl, and G. A. Saunders, "Third order elastic constants and vibrational anharmonicity of a semiconducting iron phosphate glass," *Journal of Non-Crystalline Solids*, vol. 44, no. 1, pp. 157–169, 1981.
- [16] A. Mierzejewski, G. A. Saunders, H. A. A. Sidek, and B. Bridge, "Vibrational properties of samarium phosphate glasses," *Journal of Non-Crystalline Solids*, vol. 104, no. 2-3, pp. 323–332, 1988.
- [17] J. M. Farley and G. A. Saunders, "Elastic properties of semiconducting phosphate glasses," *Physica Status Solidi*, vol. 28, no. 1, pp. 199–203, 1975.
- [18] M. M. Umair and A. K. Yahya, "Elastic and structural changes of $x\text{Na}_2\text{O}-(35-x)\text{V}_2\text{O}_5-65\text{TeO}_2$ glass system with increasing sodium," *Materials Chemistry and Physics*, vol. 142, no. 2-3, pp. 549–555, 2013.
- [19] Y. S. Kim, K. H. Lee, T. H. Kim, Y. J. Jung, and B. K. Ryu, "Effect of ZnO addition on the photoluminescence of a novel phosphate glass," *Journal of the Korean Physical Society*, vol. 53, no. 1, pp. 232–235, 2008.
- [20] H. A. S. Al-Shamiri and A. S. Eid, "Optical and ultrasonic properties of chromium oxide in sodium zinc phosphate glass," *Photonics and Optoelectronics*, vol. 1, pp. 1–8, 2012.
- [21] G. Le Saoût, F. Fayon, C. Bessada, P. Simon, A. Blin, and Y. Vaills, "A multispectroscopic study of $\text{PbO}_x\text{ZnO}_{0.6-x}(\text{P}_2\text{O}_5)_{0.4}$ glasses," *Journal of Non-Crystalline Solids*, vol. 293–295, no. 1, pp. 657–662, 2001.
- [22] H. S. Liu and T. S. Chin, "The new zinc barium metaphosphate glasses. $(50-x)\text{BaO}-x\text{ZnO}-50\text{P}_2\text{O}_5$ with," *Physics and Chemistry of Glasses*, vol. 38, pp. 123–131, 1997.
- [23] K. A. Matori, M. H. M. Zaid, H. A. A. Sidek, M. K. Halimah, Z. A. Wahab, and M. G. M. Sabri, "Influence of ZnO on the

- ultrasonic velocity and elastic moduli of soda lime silicate glasses,” *International Journal of Physical Sciences*, vol. 5, no. 14, pp. 2212–2216, 2010.
- [24] P. Pascuta, M. Bosca, G. Borodi, and E. Culea, “Thermal, structural and magnetic properties of some zinc phosphate glasses doped with manganese ions,” *Journal of Alloys and Compounds*, vol. 509, no. 11, pp. 4314–4319, 2011.
- [25] Z. Pawlak, P. K. D. V. Yarlagadda, R. Frost, and D. Hargreaves, “The mechanical characteristics of phosphate glasses,” *Journal of Achievements in Materials and Manufacturing Engineering*, vol. 37, pp. 458–465, 2009.
- [26] R. El-Mallawany, “Longitudinal elastic constants of tellurite glasses,” *Journal of Applied Physics*, vol. 73, no. 10, pp. 4878–4880, 1993.
- [27] Y. B. Saddeek, “Ultrasonic properties of Gd^{+3} doped tellurovanadate glasses,” *Materials Chemistry and Physics*, vol. 91, pp. 146–153, 2005.
- [28] M. H. M. Zaid, K. A. Matori, L. C. Wah et al., “Elastic moduli prediction and correlation in soda lime silicate glasses containing ZnO,” *International Journal of Physical Sciences*, vol. 6, no. 6, pp. 1404–1410, 2011.
- [29] H. A. A. Sidek, S. P. Chow, Z. A. Talib, and S. A. Halim, “Formation and elastic behavior of lead-magnesium chlorophosphate glasses,” *Turkish Journal of Physics*, vol. 28, no. 1, pp. 65–72, 2004.