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The effect of erbium oxide in physical and structural properties of zinc tellurite glass system

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ABSTRACT

In this research, the melt-quenching method was used to synthesize a series of zinc tellurite glass systems doped with erbium oxide with the chemical composition of $[(TeO_2)_{0.7}\,(ZnO)_{0.3}]_{1-x}\,(Er_2O_3)_x$ at different molar fraction, x = 0, 0.01, 0.02, 0.03, 0.04 and 0.05. X-ray diffraction (XRD), Fourier Transform Infrared (FTIR) spectroscopy, density, molar volume, elastic and optical measurements were used to characterize the prepared glass samples. At room temperature, the result of the XRD, FTIR, density, elastic and optical properties were all recorded. An amorphous nature of glass samples is proven by the XRD spectra. The analysis of FTIR spectra shows the presence of functional vibration of tellurite network. It is observed that the density of the glass system increase with the molar fraction of Er_2O_3. The value of molar volume is found to be directly proportional to the density. Thus, the increment in the density value causes the increment of the molar volume due to the increase of erbium concentration. This in turn results in the creation of excess free volume due to the difference of atomic radius between erbium and tellurite. On the other hand, ultrasonic velocity was used to determine the elastic moduli of the glass systems. The elastic moduli such as longitudinal modulus, shear modulus, bulk modulus and Young's modulus give a fluctuating trend against the concentration of Er_2O_3. The increase of the elastic moduli is due to the mix former effect. In contrast, the decrease of the elastic moduli is due to the breakdown of Er_2O_3 in the zinc tellurite glass system which weakens the glass structure of the ternary tellurite system. The optical properties of the prepared glasses were determined by UV–vis analysis. The optical absorption was recorded at room temperature in the wavelength ranging from 220 nm to 800 nm. The optical absorption spectra reveal that fundamental absorption edge shifts to higher wavelength as the content of erbium oxide increase. The values of direct and indirect band gap have been calculated and are observed to decrease with the increase content of erbium oxide. However, the Urbach energy, refractive index, molar refraction and electronic polarizability are shown to be increased with an addition content of erbium oxides.

1. Introduction

Glasses have some unique properties such as high hardness and high transparency at room temperature, along with sufficient strength and excellent corrosion resistance. Due to their potential applications in various engineering and technological fields, the study of the properties of glasses is one of a great significance. Glassy materials have acknowledged advantages, such as physical isotropy, the absence of grain boundaries and practical to be used for optical applications [1].

Tellurium oxide, TeO_2 is known as a conditional glass former which needs a modifier ion to form the glassy state easily. It is also known for its significant properties such as high refractive index, low phonon maxima, low melting point and high dielectric constant [2]. As a result, tellurite glasses start to gain a wide scientific and technological interest [3]. Besides that, tellurite glasses possess encouraging properties such as good mechanical strength, good chemical durability and excellent transmission in the visible and infrared wavelength regions [4].

Nowadays, the most important concern in rare earth doped glasses is to define the dopant effect to the host materials. In addition, tellurite glass systems which contain rare earth oxide or transition metals are considered as the latest type of non-crystalline solid or amorphous which have many functions with a huge field of composition, frequencies, and temperatures. Elastic properties of materials are directly related to the interatomic potential and provide information on the structure of solids which is generally described by two independent elastic constants, C11 and C44. These two parameters, C11 and C44 are referred as the longitudinal and shear sound velocities respectively which are interrelated with the density of glass. Other elastic constant

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such as Poisson's ratio, Young's modulus, and bulk modulus can also be obtained from the two aforementioned parameters [5]. Due to their superior properties such as good solubility for rare earth ions, low cost, high thermal stability and easy preparation, tellurite glasses are considered as the best host materials to be doped with rare earth ions for fiber optic and laser applications [6].

In addition, zinc tellurite glass doped with rare earth ions are fabricated and characterized due to its own interest which can preserve continuity. This erbium zinc tellurite glass is beneficial especially in the field of communication where they are applicable for remote chemical sensors, glass fibers, optical amplifiers and medically used as solid state lasers [7]. Although several researches have been done on fabrication and characterization of zinc tellurite doped with erbium oxide, the elastic and optical properties of the glass system have never been reported. Thus, through this research, a glass system with the chemical composition of $[(TeO_2)_{0.7}\ (ZnO)_{0.3}]_{1-x}\ (Er_2O_3)_x$ at different molar fraction, x = 0, 0.01, 0.02, 0.03, 0.04 and 0.05 were investigated and characterized in terms of structural and physical properties; and the effect of doping erbium ion on elastic and optical properties of zinc tellurite glasses then was determined.

2. Materials and methods

A series of zinc tellurite glass systems were produced from oxide powders of TeO_2, ZnO, and Er_2O_3 as raw materials using the conventional melt-quenching technique. Different values of a molar fraction, x = 0, 0.01, 0.02, 0.03, 0.04 and 0.05 were used to fabricate the glass systems. All required amounts of the raw material were mixed together.

An electronic weighing balance machine was used to weigh the mixture of all the chemical powders with an accuracy of ± 0.0001 g. The amount of chemical elements added in each composition of the glass samples are recorded in Table 1. The entire chemical with a weight of 11 g were mixed thoroughly and transferred to alumina crucible. The alumina crucible, glass rod, and spatula were firstly cleaned by using acetone and distilled water to remove impurities. Next, the mixture was consistently stirred for about 30 min to produce a homogenous mixture.

The homogenous mixture in the alumina crucible was placed in the first furnace, to be preheated at a temperature of 400 °C, and kept at this temperature for 1 h in order to get rid of the water content in the mixture which will affect the final result. After 1 h, the crucible was then moved to the second furnace for 2 h at 900 °C. The mixture in the crucible was melted in this furnace. A stainless steel cylindrical shape split was used to mould the raw material which had been polished earlier in order to prevent the material from reacting with impurities. The stainless steel mould was also previously preheated at 400 °C in order to avoid thermal shock as a result of the temperature difference between the molten mixture and the mould.

The molten mixture that had been poured into the mould was annealed at 400 °C for 2 h. The purpose of the annealing process is to get rid of the formation of air bubbles, reduce thermal stress and enhance the mechanical stress. The furnace was then switched off and the glass sample was allowed to cool down in the furnace at room temperature. The glass samples were taken out from the furnace and kept in the bottle with silica gel to absorb any moisture.

Table 2
Uncertainties for each measurement in this work.

Measurement	Uncertainties
X-ray diffraction (XRD)	$2\theta^{<}1.5\%$
Fourier Transform Infrared (FTIR)	± 10 cm^{-1}
Density	± 0.001 g/cm^3
Ultrasonic velocities	± 5 m/s
UV–vis spectrophotometer	± 0.3 nm

Table 2 shows the uncertainties of the devices being used for each measurement in this work.

The surfaces of the glass samples were polished by using SiC abrasive of grade 800, 1000, 1200, 2400 and 4000 in ascending order until a parallel, flat and smooth surface of the glass systems were obtained. A vernier caliper was used to measure the thickness of glass sample to determine the thickness suitability for elasticity measurement which is approximately 5.0 mm. On top of that, another prepared glass sample was measured around 2.3 mm in order to achieve excellent optical measurement. Some parts of the glass samples were ground into powder by using the plunger. Then, the samples were sent for structural and physical analysis.

3. Results and discussions

Fig. 1 shows the graph of XRD diffraction patterns of the prepared glass sample at different concentration of erbium oxide. The XRD analysis is implemented with an uncertainty of $2\theta^{<}1.5\%$. From the figure, a broad hump is observed at lower scattering without the existence of sharp discrete peaks which indicating the presence of short-range structural order in the glass samples [8]. The absence of sharp, strongly diffracted beams that is resembled as sharp peaks in the X-ray diffraction pattern proves that there are no well-defined planes in the structure of the materials [9].

Fig. 2 shows the graph of FTIR spectra while Table 3 shows the assignment of infrared transmission bands of the prepared glass sample at different concentration of erbium oxide respectively. This analysis is elucidated with an uncertainty of ± 10 cm^{-1}. From the figure, it can be seen that there is only one absorption band for the glass samples at 601–623 cm^{-1}. The assignment of infrared transmission bands of erbium zinc tellurite glasses is recorded in Table 3.

Stretching vibrations of TeO_4 (trigonal bipyramid) group exert smaller frequency position than TeO_3 (trigonal pyramid) group. The first group of the band formed around 600–650 cm^{-1} corresponds to TeO_4 and the second group of band observed around 650–700 cm^{-1} corresponds to the TeO_3. The changes in the composition of the glass network rely on the band shift of these groups. The presence of TeO_4 group in all tellurite containing glass system has been proven by the appearance of absorption band at 601–623 cm^{-1}. The absorption band of ZnO does not appear in the spectra, indicating that zinc lattice is completely broken down.

Density can be defined as a measurement of compactness in a material or substance. Density is measured closely towards the uncertainty of ± 0.001 g/cm^3. Table 4 shows the values of density and molar volume with respect to different concentration of erbium oxide. The

Table 1
The amounts of each chemical used.

Molar fraction, x	Weight of TeO_2 (± 0.0001 g)	Weight of ZnO (± 0.0001 g)	Weight of Er_2O_3 (± 0.0001 g)	Total weight (g)
0.00	9.0273	1.9727	0.0000	11
0.01	8.7781	1.9183	0.3036	11
0.02	8.5377	1.8657	0.5966	11
0.03	8.3055	1.8150	0.8795	11
0.04	8.0812	1.7660	1.1529	11
0.05	7.8643	1.7186	1.4172	11