UNIVERSITI PUTRA MALAYSIA

ELASTIC, OPTICAL AND THERMAL PROPERTIES OF ZINC-LEAD TELLURITE GLASS SYSTEMS

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By

SALAH HASSAN ALMOKHTAR ALAZOUMI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

August 2018

DEDICATION

This work is dedicated to my late parents Hassan and Iftaimah. May Allah forgive their shortcoming and wrongs.

Abstract of a thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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August 2018

Chairman : Professor Sidek Abdul Aziz, PhD
Faculty : Science

This thesis presents the comprehensive study on elastic, optical and thermal properties of tellurite glasses, binary lead tellurite (PbO-TeO_2) and ternary zinc lead tellurite (PbO-ZnO-TeO_2) glass systems prepared using the conventional melt-quenching technique. The physical, structural, elastic, optical and thermal properties of the glasses were investigated using ultrasonic technique, X-ray diffraction (XRD), scanning electron microscopy and energy dispersive X-ray spectroscopy (SEM/EDX), differential scanning calorimetry (DSC), UV-Visible spectroscopy (UV-Vis) and Fourier transform infrared (FTIR) spectroscopy.

Density (ρ), molar volume (V_m), oxygen packing density (OPD), refractive index, band gap energy (E_g), average cross-link density (n_c), the number of bonds per unit volume (n_b) and Poisson's ratio (σ) values were calculated from the characterizations data obtained for the interpretation of physical, structural and optical properties of the glass system under study. The density measurements were carried out under ambient condition using densitometer (Model: MD- 300S Densimeter) which works on the basis of Archimedes principle. Ultrasonic pulse-echo technique carried out at room temperature, and resonating frequency of 5 MHz was used for the determination of the ultrasonic velocities (longitudinal and shear). Elastic (longitudinal, shear, bulk and Young's) moduli, Poisson's ratio, Debye temperature, and a softening temperature of all glass samples have been calculated using the measured ultrasonic velocities and densities. Experimental values of elastic moduli were compared with calculated values of elastic moduli using bond compression model, Makishima-Mackenzie model, and Rocherulle's model.

The profiles of the EDX analysis showed the presence of all the mentioned elements in the prepared glass system. It is observed from the result obtained that the use of alumina crucible induces a partial dissolution of Al_2O_3 in the melt that modifies the original composition. The prepared glass samples were homogeneous, lime green color and became more transparent as PbO increases. The XRD pattern confirmed the amorphous nature of the two glass systems. The FTIR spectra for the binary glass system showed a decrease in non-bridging oxygen (NBO) concentration with PbO introduction, which later then increased as more PbO was added to the system. Addition of more ZnO in the ternary system showed a pattern of increasing and decreasing NBO concentration in the glass network.

An addition of PbO content in the binary leads to the increase in the density, while molar volume decreased in the tellurite glass system. The density of ternary glass system decrease, and molar volume decreased with the increase of ZnO concentration in the (PbO-ZnO-TeO_2) glass system. The elastic moduli of the glasses were found to be composition dependent; the elastic moduli values decreased (from L = 63.41 to 53.55 GPa, G = 21.78 to 16.42 GPa, K = 34.37 to 31.65 GPa, E = 53.94 to 41.99 GPa) for binary tellurite system with increase of PbO concentration and increased (from L = 47.09 to 50.61 GPa, G = 21.78 to 16.42 GPa, K = 27.01 to 28.01 GPa, E = 38.09 to 42.30 GPa) in the case of ternary system increase in ZnO concentration. With the increase in the PbO in the binary system, the microhardness and Debye temperature decreased as the elastic moduli, while the Poisson ratio increased. In the case of the ternary system, increase in the ZnO content increased the microhardness and Debye temperature and decreased the Poisson ratio. The refractive index of the TeO_2-PbO glasses fall in the range of 2.39 to 2.50 for increasing mole fraction of PbO content. The refractive indices for ternary glass system show a varying between 2.504 – 2.580. Thermal analysis of the glasses was realized regarding glass transition temperature (T_g), crystallization temperature (T_c), and glass stability against crystallization (ΔT). The values of T_g, T_c, ΔT and Tm fall in the range of 380 to 311 ºC, 379 to 425 ºC, 45 to 67 and 469 to 534 ºC respectively for the binary glass system and 291 to 300 ºC, 389 to 459 ºC, 89 – 166 ºC and 534 490 ºC respectively for the ternary glass system.

The two glass systems were observed to be amorphous, with good mechanical strength (on the bases of their elastic properties), thermal stability as well as high refractive index. The high refractive index value index as well as high optical transparency (In the case of ZnO incorporated) for the two series of glasses gives the ternary glass system good potential for optical fiber applications.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

SIFAT ELASTIK, OPTIK DAN TERMA BAGI SISTEM KACA ZINK-PLUMBUM TELLURITE

Oleh

SALAH HASSAN ALMOKHTAR ALAZOUMI

Ogos 2018

Pengerusi : Profesor Sidek Abdul Aziz, PhD
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Tesis ini menerangkan tentang kajian secara komprehensif terhadap sifat elastik, optikal dan terma system kaca tellurite, plumbum tellurite binari (PbO-TeO_2) dan zink plumbum tellurite ternari (PbO-ZnO-TeO_2) menggunakan teknik lindapan leburan konvensional. Sifat fizikal, struktural, elastik, optikal dan terma bagi kaca ini di kaji dengan menggunakan teknik ultrasonik, pembelauan sinar-X (XRD), mikroskop transmisi elektron dan spektroskopi serakan tenaga sinar-X (SEM/EDX), kalorimetri pengimbasan pembezaan (DSC), spektroskopi sinar ultra ungu-cahaya Nampak (UV-Vis) dan spektroskopi infra merah pembezaan Fourier (FTIR).

Ketumpatan (ρ), isipadu molar (V_m), isipadu kepadatan oksigen (OPD), indeks refraktif, tenaga jurang jalur (E_g), ketumpatan purata taut-silang (n_c), bilangan ikatan per unit isipadu (n_b) dan nilai nisbah Poisson (σ) dikira dari data yang diperolehi dari sifat fizikal, struktural dan optikal bagi system gelas yang dikaji. Pengukuran ketumpatan diperolehi menggunakan densitometer (Model: MD- 300S Densimeter) berdasarkan kepada prinsip Archimedes. Teknik gema-denyut ultrasonic dijalankan pada suhu bilik menggunakan frekuensi beresonan 5 MHz untuk menentukan halaju ultrasonik (longitud dan ricih). Elastik (longitus, ricih, pukal dan Young) moduli, nisbah Poisson, suhu Debye dan suhu pelembutan bagi semua sampel kaca dikira menggunakan halaju dan ketumpatan ultrasonik. Nilai eksperimen bagi modulus elastik dibandingkan dengan modulus elastik menggunakan model pemampatan ikatan, model Makishima-Mackenzie dan Model Rocherulle.

Analisis EDX menunjukkan kehadiran semua elemen yang digunakan untuk penghasilan sistem kaca. Hasil dari pemerhatian yang menggunakan krusibel alumina telah mengaruh pelarutan sebahagian dari Al_2O_3 dalam leburan yang telah

mengubah komposisi asal. Sampel kaca adalah homogen, berwarna hijau muda dan menjadi semakin lut-sinar apabila PbO meningkat. Graf XRD mengesahkan sifat amorfus bagi sistem dua kaca. Spectrum FTIR bagi sistem kaca binari menunjukkan pengurangan oksigen bukan penitian (NBO) dengan kehadiran PbO, yang akhirnya meningkat apabila semakin banyak PbO ditambah kedalam sistem. Penambahan lebih banyak ZnO dalam sistem ternari menunjukkan pola penambahan dan pengurangan NBO dalam rangkaian kaca.

Penambahan kandungan PbO ke dalam plumbum binari meningkatkan ketumpatan dan mengurangkan isipadu molar sistem kaca tellurite. Ketumpatan sistem kaca ternari menurun sementara isipadu molar mengurang dengan penambahan ZnO dalam sistem kaca (PbO-ZnO-TeO_2). Modulus elastik bagi kaca didapati bergantung kepada komposisi; nilai modulus elastik berkurang (julat L = 63.41 ke 53.55 GPa, G = 21.78 ke 16.42 GPa, K = 34.37 ke 31.65 GPa, E = 53.94 ke 41.99 GPa) bagi sistem kaca tellurite binari dengan meningkatnya kepekatan PbO dan meningkat (julat L = 47.09 ke 50.61 GPa, G = 21.78 ke 16.42 GPa, K = 27.01 ke 28.01 GPa, E = 38.09 ke 42.30 GPa) dalam sistem ternari meningkat dalam kepekatan ZnO. Dengan peningkatan PbO dalam sistem binari, mikrokekerasan dan suhu Debye menurun seperti modulus elastik dan nisbah Poisson meningkat. Dalam sistem ternari, peningkatan kadungan ZnO meningkatkan mikrokekerasan dan suhu Debye dan menurunkan nisbah Poisson. Analisis terma kaca dapat mengenalpasti suhu peralihan kaca (T_g), suhu penghabluran (T_c), dan kestabilan kaca terhadap penghabluran (ΔT). Indeks refraktif bagi kaca TeO_2-PbO didapati meningkat bagi pecahan mol PbO. Indeks refraktif bagi sistem kaca ternari adalah diantara 2.504 – 2.580. Indeks biasan bagi kaca TeO_2-PbO berada dalam julat antara 2.39 ke 2.50 apabila pecahan mol PbO meningkat. Manakala indeks biasan bagi sistem kaca ternari menunjukkan nilai berbeza antara 2.504 – 2.580. Analisis terma bagi kaca menunjukkan nilai suhu peralihan kaca (T_g), suhu penghabluran (T_c), dan kestabilan kaca melawan penghabluran (ΔT). Nilai T_g, T_c, ΔT and T_m berada dalam julat 380 ke 311 ºC, 379 ke 425 ºC, 45 ke 67 ºC dan 469 to 534 ºC bagi sistem kaca binari dan 291 ke 300 ºC, 389 ke 459 ºC, 89 ke 166 ºC dan 534 ke 490 ºC bagi sistem kaca ternari.

Pemerhatian ke atas kedua-dua sistem kaca tersebut menunjukkan ia adalah amorfus, dengan kekuatan mekanikal (berdasarkan sifat elastik), kestabilan terma yang baik dan juga indek biasan yang tinggi. Nilai indek biasan yang tinggi dan juga kelutsinaran optikal yang tinggi (dalam kes penambahan ZnO) bagi dua siri kaca menunjukkan sistem kaca ternari mempunyai potensi yang baik bagi kegunaan fiber optik.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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Declaration by graduate student

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LIST OF ABBREVIATIONS AND SYMBOLS

XRD	X-Ray diffraction
FTIR	Fourier transform infrared
UV-Vis	Ultraviolet-Visible
SEM	Scanning electron microscopy
EDX	Energy dispersive X-ray spectroscopy
OPD	Oxygen packing density
BO	Bridging oxygen non
NBO	Non-bridging oxygen
DSC	Differential scanning calorimetry
DTA	Differential thermal analysis
IR	Infrared
TeO_2	Tellurium oxide
PbO	Lead oxide
ZnO	Zinc oxide
Al_2O_3	Aluminum oxide
P	Density
V_m	Molar volume
V_L	Longitudinal velocity
V_S	Shear velocity
U_m	Mean ultrasonic velocity
E	Young's modulus
K	Bulk modulus
L	Longitudinal modulus
G	Shear modulus

θ_D	Debye temperature
D	Fractal bond connectivity
Z	Acoustic impedance
α_P	Thermal expansion coefficient
H	Microhardness
Σ	poisson's ratio
T_g	Glass transition temperature
T_s	Softening temperature
T_C	Crystallization temperature
ΔT	Glass stability
T_m	Melting temperature
K_g	Hruby's parameter
K_B	Boltzmann's constant
h	Plank's constant
$\bar{F}$	Average stretching force constant
n_b	Number of network bond per unit volume
n_f	Number of network bonds per glass formula unit
F	Calculated stretching force constant
n_c	Number of cross-link per cation in oxide
N_c	Number of cation per glass formula unit
η	Total number of cations per glass formula unit
L	External ring diameter
V_t	Packing density
G_t	Dissociation energy
λ	Wavelength
A	Absorption

E_{opt}	Energy band gap
t	Sample thickness
n	Refractive index
R_m	Molar refractive index
M	Metallization criterion
ε	Dielectric constant
ε_{op}	Optical dielectric constant
R_L	Reflection loss
T	Transmission coefficient
α_m	Molar polarizability
R_p	Polaron radius

CHAPTER 1

INTRODUCTION

1.1 Research background

The physical and chemical properties of glass constituents have a strong influence the elastic and structural properties of a glass system (Arulmozhi and Sheelarani, 2011). Since the strength of non-crystalline solid materials is always proportional with their elastic modulus, the strength of the materials can be estimated indirectly by studying their elastic properties (Zaid et al., 2011). The elastic constant of glassy materials provides information about a material's structure since elastic constants, interatomic forces, and potentials are directly related to electric constants (Zhou et al., 2014; Sidek et al., 2013; Bootjomchai et al., 2014; El-Aal and Afifi, 2009). The microstructural feature, network former, and behaviour of a modifier are influenced by acoustical parameters (Halimah et al., 2010; Sidek et al., 2014; El-Moneim, 2016). Of late, ultrasonic technique has become a very important tool in the evaluation of the acoustical parameters of glasses, such as elastic modulus, microhardness, Poisson's ratio, ultrasonic attenuation coefficient, and Debye temperature (Abd El-Moneim, 2014; Abd El-Moneim, 2012). Bridge et al. proposed that the longitudinal and shear velocities of ultrasonic waves and glass elastic constants can be evaluated using semi-empirical relations and theories (Bridge et al.,1983). Elastic modulus is computed using three structural parameters, i.e. number of bonds per unit volume, average stretching force constant, and average crosslink density per glass formula unit. Attempts have been made to estimate the Poisson ratio and elastic modulus of glasses from the unit volume dissociation energy and packing density of constituent chemical oxides of a glass network (Makishima and Mackenzie, 1973; Makishima and Mackenzie, 1975; Rocherulle et al., 1989; Abd El-Moneim and Alenezy, 2016).

Researchers have been giving more attention to TeO_2 in comparison other oxide glasses by virtue of their promising potential and quality in the high UV to IR transmission range, high refractive index, low phonon energy, high transmissivity of infrared radiation, and superior thermal stability and chemical durability (Wang et al., 2009; Stambouli et al., 2012). The prospect of using tellurite-based glasses in the fields of technology and science is very promising due to the excellent transparency of their visible and infrared regions, low melting temperature, high refractive index (~2), high dielectric constant, and high electrical conductivity (El-mallawany, 2002; Suehara et al., 1995; Villegas and Navarro, 2007; Kaur et al., 2010). Even though research in this field has been very successful, there are still some problems which need to be solved with regard to the strong up-conversion luminescence and low tensile strength of tellurite glasses. These problems have adverse effect on the performance of tellurite glass devices in many practical applications (Halimah et al., 2010). Some of the identified drawbacks can be eliminated by adding heavy metal oxides to the matrix of the glasses (Kaky et al., 2017). Researchers have been investigating the effects of incorporating heavy metal oxide such as PbO in tellurite glasses due to their ability to increase the density of tellurite glasses as well as improve their thermal and optical properties with regard to polarizability and thermal stability (Kaur et al., 2010). Tellurite glasses which have been incorporated with heavy metal oxides have shown promising properties in various optical applications. Studies have been done to understand the physical properties of various composition of tellurite glasses (Uma et al., 2018; Da Silva et al., 2018; Sun et al., 2018; Merzliakov et al., 2018; Rao et al., 2018; El-Mallawany et al., 2017; Moawad et al., 2004; Hager et al., 2011; Hager et al., 2010; El-Zaidia et al., 1985; Hussain et al., 2009; El-Mallawany, 2000; Mirgorodsky et al., 2012; Elkholy and El-Mallawany, 1995; Bouchaour et al., 2005).

The addition of ZnO to lead tellurite glass matrix have been shown to alter the physical and elastic properties of the glasses. Another area of study that is quite interesting is the use of multiple glass modifier, i.e. PbO and ZnO, to impart distinct properties to the network of tellurite glasses. Hence, the present work seeks to elucidate the structural and elastic properties of ternary zinc lead tellurite glasses modified with varying concentrations of ZnO, and to compare the values of theoretical elastic properties with the experimentally measured data of the investigated glasses.

1.2 Tellurite glass application

Various research have been carried out to explore the benefits of using tellurite glasses in different applications. Tellurite glasses have a high refractive index, low processing temperature, wide range of transmission (35 – 500 cm), high corrosion resistance, and good glass stability (El-Mallawany, 1998). They are also among the oxide glass formers which have the lowest vibrational energy (about 780 cm^{-1}). The high refractive index of tellurite glasses increase their local field correction at the rare-earth ion site, which in consequence improve their radiative transition rate (Lousteau et al., 2012).

When mixed with an appropriate amount of GeO_2, tellurite glasses exhibits photo-induced phenomena which result in improved photo-structural of the refractive index (Pereira et al., 2017). This makes them a good solid electrolyte by virtue of the high ionic conductivity of the glasses. The addition GeO_2 to a tellurite glass network has been observed to improve its fiber-drawing ability, thereby making it a good optical fiber option in communication technology (Gouraud et al., 2015). When combined with Sb_2O_3, tellurite glasses exhibits high polarizability, which in turn improve their refractive index. These glasses have a promising potential in various 3-D photonics applications, such as specific devices for nonlinear optics (Ultrafast power limiters and optical switches) (Pereira et al., 2016). Tellurite glasses doped with Er^{3+}, Nd^{3+}, Ho^{3+} or other rare earth ions have been found to be excellent materials for application in high performance fiber amplifiers, fiber lasers, wavelength converting devices, and planar waveguide (Yousef, 2013; Linganna et al., 2016; Yanmin et al., 2015).

1.3 Problem statement

In the past several years many studies have been carried out in the fields of glass science and technology in the effort to find solutions or to improve the utilization of glass materials in domestic, scientific, industrial and technological applications (Dousti et al., 2015). Tellurite glasses are very important in many fields, such as in the mechanical, electrical, optical, and medical industries (Annapoorani et al., 2015; Umar et al., 2017). Researchers have investigated the physical, structural, elastic, thermal, mechanical, morphological, and optical properties of tellurite glasses, in addition to other properties, to find ways of fulfilling the specific requirements in various application (Gouraud et al., 2015).

Ma and co-authors fabricated Er^{3+}/Ho^{3+} co-doped fluoro-tellurite glasses and investigated their utilization in laser applications (Ma et al., 2013). Another recent investigation incorporated rice husk in borotellurite glasses doped with erbium to determine the physical, structural and optical properties of the glasses for possible application in the erbium doped fiber amplifier (EDFA) technology (Umar et al., 2017). Many research which aim to improve the optical, elastic, and thermal characteristics of various tellurite glasses through the addition of different chemicals have been carried out. These include the work of Kaky et al., (2017) which explore the thermal, structural and optical absorption characteristics of tellurite rich glasses doped with heavy metal oxides. Awshah et al. (2017) studied the effect of Neodymium NPs on the elastic properties of zinc-tellurite glasses.

Several investigations have been done on tellurite glasses incorporated with varying amounts of either PbO or ZnO or both. Silva et al., (2001) studied the structural characteristics of a binary system lead tellurite. The glasses were analyzed using DSC, Raman spectroscopy, and XRD analysis. In 2010, Eraiah reported the results of a study on the optical properties of samarium doped lead-tellurite glasses. (Yousef et al., 2016) studied the optical and elastic characteristics of tellurite glasses, $75TeO_2$-$10Nb_2O_5$-10ZnO-5PbO, doped with Er^{3+}, while (Sidek et al., 2013) investigated the thermal properties of a binary zinc tellurite glasses. (Veeraiah, 1997) reported the results of a study of the elastic properties of ZnF_2 -PbO-TeO_2 glass doped with varying amounts of rare earth. Tagiara and other partners examined the structural and thermal characteristics of a binary zinc tellurite glass (Tagiara et al., 2017). (Munoz et al., 2009) analyzed the characteristics of ternary tellurite glasses incorporated with tungsten and lead using XRD, FTIR, DTA and UV-V.

Plenty of attention has been given to heavy metal oxides, for instance PbO doping, in recent years by virtue of their effects on the structural (density), optical, mechanical and thermal characteristics of tellurite glasses. Not many research have investigated the physical, structural, elastic, and optical characteristics of the binary lead tellurite (PbO-TeO_2) and ternary zinc lead tellurite (PbO-ZnO-TeO_2) glass systems, which means that there is a dearth of information on these types of glasses.

1.4 Research objectives

The present study aims to:

1. Examine how the incorporation of lead affect the structural, elastic, optical, and thermal characteristics of binary tellurite glass.
2. Examine how the incorporation of ZnO affect the structural, elastic, optical, and thermal characteristics of binary lead tellurite glass.
3. Elucidate the elastic modulus of tellurite glass system, compute the elastic modulus using the Makishima-Mackenzie, bond compression, and Rocherulle models, and correlate them with the experimental values.

1.5 Scope of the study

The scope of the study is as follow:

1) A series of precursor glass were prepared based on the stoichiometric equation of binary PbO-TeO_2 and ternary PbO-TeO_2-ZnO glasses using the melt-quenching technique.
2) The physical, structural, elastic, optical, and thermal characteristics of the glasses were analyzed using ultrasonic technique, XRD, EDX/SEM, FTIR, DSC, and UV-Vis.
3) The elastic constants of the glass systems were predicted, and the microhardness, acoustic impedance, thermal expansion coefficient, softening temperature, and Debye temperature were computed by employing the experimental data.
4) The Makishima-Mackenzie theory, bond compression model, and Rocherulle model were used to compare the experimental values of the elastic modulus of the glasses with the theoretically determined values.
5) DSC spectroscopy was used to determine the glass transition (T_g) and crystallization (T_c) temperatures.
6) The coefficient of absorption, optical band gap energy, Urbach energy, refractive index, molar refractive index, and polarizability of the glasses were obtained using absorption spectra.

1.6 Importance of the study

Unlike conventional silicate, phosphate and borate glasses, tellurite glasses have higher electronic polarizability due to the high polarizability of the Te^{4+} ions and the lone electrons pair in the valence shell which is highly polarizable (Ersundu and Ersundu, 2016). TeO_2 based glasses with high transparency visible region have been reported to have high refractive index and are good candidates for EDFA, and laser and high speed optical switches (Pereira et al., 2016).

Many fields of science and technology, particularly the fields of optical fiber amplifiers, and bulk and waveguide lasers, are giving increasing attention to tellurite glasses doped with rare earth ions.

Rare earth doped tellurite glasses are currently used in infrared optical devices and visible optical devices; for instance, white light emitting diode (w-LED) are frequently used in automobile headlights and backlight (Annapurna et al., 2016).

The incorporation of heavy metal oxide, such as lead or bismuth, in glasses are the best alternative in the glass structure of rare earth doped hosts. Heavy metal oxide glasses are used to fabricate optical fibers in order to impart the fibres with very good environmental stability and lower optical loss in comparison to the use of fluorides. This makes them more suitable for use in short distance photonic applications (Poor et al., 2013).

The addition of ZnO to borotellurite glass network have been proven to accord the network with better stability as well as enhanced glass forming ability. Glasses containing PbO and ZnO have been shown to have a high third order nonlinear optical susceptibility and long infrared cut-off, making them suitable for application in photonics as components for infrared transmission (Kundu et al., 2014).

This work attempts to leverage the potentials of tellurium oxide, which has high polarizability, high refractive index, high dielectric constant, low phonon energy, good electrical conductivity, large third order non-linear susceptibility chemical durability and wide band infrared transmittance, and improve its properties by adding PbO and ZnO to accord the glasses with better stability and better glass forming ability. These glasses are expected to have very promising potential in optical fibers and photonic applications.

1.7 Thesis Organization

This thesis comprises five chapters, introduction, literature review, methodology, results and discussion, and conclusion. The thesis is structured as follows:

Chapter 1 gives a description of tellurite glass, i.e. PbO-TeO_2 glass, PbO-TeO_2-ZnO glass; it also presents the problem statements, objectives, scope and importance of the study. The theory of glass as well as previous and current investigation by other researchers are discussed in Chapter 2. Chapter 3 discusses the basic theory of glass formation, theories of elasticity, theories optics and thermal. This chapter also presents a detail description of sample preparation, design of the experiment, and measurement techniques. Chapter 4 presents the results, discussion and analysis of the glasses studied in this work. Finally, Chapter 5 presents the conclusion and suggestion for future research.

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LIST OF PUBLICATIONS

Publications

S. H. Alazoumi, H. A. A. Sidek, M. K. Halimah, K. A. Matori, M. H. M. Zaid, and A. A. Abdulbaset, "Synthesis and elastic properties of ternary ZnO-PbO-TeO_2 glasses," *Chalcogenide Letters*, vol. 14, no. 8, pp. 303–320, 2017.

S. H. Elazoumi, H. A. A. Sidek, Y. S. Rammah, R. El-Mallawany, M. K. Halimah, K. A. Matori, and M. H. M. Zaid, "Effect of PbO on optical properties of tellurite glass," *Results in Physics*, vol. 8, pp. 16–25, 2017.

Salah Hassan Alazoumi, Sidek Abdul Aziz, R. El-Mallawany, Umar Sa'ad Aliyu, Halimah Mohamed Kamari, Mohd Hafiz Mohd Mohd Zaid, Khamirul Amin Matori, "Optical properties of zinc lead tellurite glasses," *Results in Physics*, vol. 9, no. March, pp. 1371–1376, 2018.

Conferences

S.H.Alazoumi, H. A. A. Sidek, M.K. Halimah, K.A. Matori "Synthesis and Elastic Moduli of PbO-TeO_2 System." Fundamental Science Congress, FSC2016, August 9-10, 2016 Universiti Putra Malaysia, 2016.

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