UNIVERSITI PUTRA MALAYSIA

EFFECT OF GAMMA RADIATION ON ELASTIC AND OPTICAL PROPERTIES OF Tm2O3/CeO2-DOPED ZINC BOROTELLURITE GLASS SYSTEM

HASNIMULYATI BINTI LAODING

EFFECT OF GAMMA RADIATION ON ELASTIC AND OPTICAL PROPERTIES OF Tm_2O_3/CeO_2-DOPED ZINC BOROTELLURITE GLASS SYSTEM

By

HASNIMULYATI BINTI LAODING

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

November 2017

This thesis is specially dedicated to my mother, Bungatang Bte Petalimpe,
my lecturers, family and friends.
Thank you for encouraging me to finish this journey.

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

EFFECT OF GAMMA RADIATION ON ELASTIC AND OPTICAL PROPERTIES OF Tm_2O_3/CeO_2-DOPED ZINC BOROTELLURITE GLASS SYSTEM

By

HASNIMULYATI BINTI LAODING

November 2017

Chairman : Associate Professor Halimah Mohamed Kamari, PhD
Faculty : Science

Two series of zinc borotellurite glasses that were doped with thulium and cerium oxide were successfully fabricated using the known melt-quenching technique. The glasses were prepared based on the empirical formula of $\{[(TeO_2)_{0.7}(B_2O_3)_{0.3}]_{0.7}[ZnO]_{0.3}\}_{1-x}\{Tm_2O_3/CeO_2\}_x$ with the concentration of the rare earth oxides were varied from 0.00 to 0.05 mol. The structural, elastic and optical properties of the glass samples were tested using densimeter, Fourier Transform Infrared Spectrometer (FTIR), X-ray diffraction (XRD) analysis, ultrasound technique and UV-Visible Spectrophotometer (UV-VIS). The samples with 1 mol% of dopants were exposed to gamma radiation with dose ranging from 10 to 35 kGy and all the tests were done before and after the radiation process. As the rare earth oxides were added into the glass system, the density of the glass was found to increase from 3.69 to 4.99 g/cm^3. Meanwhile, the molar volume (V_m) of glass decreases rapidly at 0.01 mol of the additional oxide and varies beyond that. The minimum and maximum values for V_m are 25.57 and 31.75 cm^3/mol respectively. In terms of FTIR spectra, the absence of Zn-O, Tm-O and Ce-O bonds implies that these bonds have been broken and these oxides take the role as network modifier by filling up the interstitial spaces inside the glass network. The amorphous nature of the glass is confirmed using XRD analysis. Besides, the elastic moduli and other elastic parameters of the glass under study generally found to increase with the substitution of Tm_2O_3 and CeO_2 while the value of Poisson's ratio lies in the range of 0.2633 to 0.2740. In terms of optical parameters, all of them exhibit some variations as the dopants are added. After the glass samples with 1 mol% of rare earth oxides is radiated with gamma rays, the density for Ce-doped glass found to decrease from 4.600 to 3.576 g/cm^3 whereas for Tm-doped glass, it varies with minimum value of 4.57 g/cm^3 and maximum value of 4.66 g/cm^3. Meanwhile, the molar volume for both glass series is totally opposite to density. The glass samples also maintain their amorphous nature after radiation even though new absorption bands were found to be produce in the FTIR analysis. The elastic moduli for cerium doped glass show a decrement after exposed to gamma rays while in thulium doped glass, they show an

increasing trend. Furthermore, the optical band gaps for both glass series tend to decrease with the increment of radiation dose. In conclusion, the addition of thulium and cerium oxide into zinc borotellurite glass found to alter the glasses' properties differently. In addition, the effects of gamma radiation also are different for both glass series. This research can contribute new knowledge regarding rare-earth doped zinc borotellurite glass and the effect of gamma radiation on them. Besides that, these glasses also have a high potential to be used as gain media in laser devices for medical surgery and as fibre amplifier in radiation-exposed environment.

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

KESAN SINAR GAMA KEPADA SIFAT KENYAL DAN OPTIK SISTEM KACA Tm_2O_3/CeO_2 DIDOP DENGAN ZINK BOROTELURIT

Oleh

HASNIMULYATI BINTI LAODING

November 2017

Pengerusi : Profesor Madya Halimah Mohamed Kamari, PhD
Fakulti : Sains

Dua siri kaca zink borotelurit yang didop dengan tulium dan serium oksida berjaya dihasilkan menggunakan teknik sepuh lindap yang terkenal. Kaca ini disediakan berdasarkan formula empirikal $\{[(TeO_2)_{0.7}(B_2O_3)_{0.3}]_{0.7}[ZnO]_{0.3}\}_{1-x}\{Tm_2O_3/CeO_2\}_x$ dengan kepekatan nadir bumi oksida divariasikan daripada 0.00 hingga 0.05 mol. Sifat struktur, kenyal dan optik sampel kaca diuji menggunakan densimeter, Spektrometer Inframerah Jelmaan Fourier (FTIR), analisis pembelauan sinar-X (XRD), teknik ultrabunyi dan Spektrofotometer UV-nampak (UV-VIS). Selepas itu, sampel dengan 1 mol% dopan didedahkan kepada sinar gama dengan julat dos dari 10 ke 35 kGy dan semua ujian dilakukan sebelum dan selepas proses radiasi. Apabila nadir bumi oksida ini ditambahkan ke dalam sistem kaca, ketumpatan kaca itu didapati meningkat dari 3.69 kepada 4.99 g/cm^3. Sementara itu, isipadu molar kaca (V_m) turun secara mendadak pada 0.01 mol oksida tambahan dan bervariasi selepas itu. Nilai minima dan maksima untuk V_m masing-masing adalah 25.57 dan 31.75 cm^3/mol. Dari segi spektra FTIR, ketidakhadiran ikatan Zn-O, Tm-O dan Ce-O bererti bahawa ikatan-ikatan ini telah terputus dan bahan oksida ini mengambil peranan sebagai pengubah rangkaian dengan memenuhi ruang interstis di dalam rangkaian kaca itu. Sifat amorfus kaca itu dipastikan dengan menggunakan analisis XRD. Selain itu, modulus kenyal dan parameter kenyal yang lain untuk kaca yang dipelajari ini secara umumnya didapati meningkat dengan penggantian Tm_2O_3 dan CeO_2 manakala nilai nisbah Poisson terletak pada julat 0.2633 hingga 0.2740. Dari segi parameter optik, kesemuanya menunjukkan perubahan apabila dopan ditambah. Selepas sampel kaca dengan 1 mol% nadir bumi diradiasi dengan sinar gama, ketumpatan untuk kaca yang didop Ce didapati menurun daripada 4.600 kepada 3.576 g/cm^3 sedangkan untuk kaca yang didop Tm, ianya berubah dengan nilai minima 4.57 g/cm^3 dan nilai maksima 4.66 g/cm^3. Sementara itu, isipadu molar untuk kedua-dua siri kaca adalah bertentangan dengan ketumpatan. Sampel kaca ini juga mengekalkan sifat amorfus mereka selepas radiasi walaupun jalur penyerapan baru ditemui terhasil di dalam analisis FTIR. Modulus-modulus kenyal untuk kaca yang didop dengan serium menunjukkan penurunan selepas didedahkan kepada sinar gama manakala di dalam kaca yang didop dengan tulium, mereka menunjukkan trend

yang meningkat. Tambahan pula, nilai jurang jalur optik bagi kedua-dua siri cenderung untuk menurun dengan kenaikan dos radiasi. Kesimpulannya, penambahan tulium dan serium oksida kepada kaca zink borotelurit telah merubah ciri-ciri kaca tersebut secara berbeza-beza. Selain itu, kesan sinar gama juga berbeza bagi kedua-dua siri kaca tersebut. Kajian ini boleh menyumbang ilmu baharu mengenai kaca zink borotelurit yang didop dengan nadir bumi dan kesan sinar gama kepada kaca-kaca tersebut. Selain itu, kaca-kaca ini juga mempunyai potensi yang tinggi untuk digunakan sebagai media gandaan di dalam peralatan laser untuk pembedahan perubatan dan sebagai amplifier gentian dalam persekitaran yang terdedah pada sinar gama.

ACKNOWLEDGEMENTS

Upon completion of this project, I would like to thank to ALLAH, God the Almighty, Most Gracious and Most Merciful to allow me to finish this successfully. I also would like to express my gratitude to my supervisor and committee, Prof Madya Dr. Halimah Mohamed Kamari, Prof Azmi Zakaria, Prof Abdul Halim Shaari, and Dr. Ishak Mansor for their guidance, help, suggestions and encouragement while I am doing this study.

Special thanks to all my colleagues, former and present, Dr. Muhammad Noorazlan Abdul Azis, Azuraida Amat, Hajer Saad, Dr. Chua Ee Von, Faznny Mohd Fudzi, Ami Hazlin Mohd Nor, Zaitizila Ismail, Nurhayati Mohd Nor, Umar Saad Aliyu, Abdullahi, Abdul Baset, Abdulkarim Mohammad Hamza, Suzliyana Muhamad and Nazirul Nazrin Shahrol Nidzam for guiding me to do the experiments, discussing about the findings and giving advice when I go through the rough time.

A sincere appreciation also to my beloved mother, Bungatang Binti Petalimpe, my family and friends that give me their endless support and prayer.

I would also like to thank the Ministry of Higher Education for funding me with MyPhD scholarship that greatly helps me financially throughout this study.

Last but not least, I would like to give an appreciation to the staff of Faculty of Science, who gave me the permission to use all the machinery and required equipments. Without all the supports I might not be able to finish this project.

THANK YOU.

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:

Halimah Bt Mohamed Kamari, PhD
Associate Porfessor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Azmi Zakaria, PhD
Professor
Faculty of Science
Universiti Putra Malaysia
(Member)

Abdul Halim Shaari, PhD
Professor
Faculty of Science
Universiti Putra Malaysia
(Member)

Ishak Mansor, PhD
Senior Research Officer
Technical Support Section
Malaysian Nuclear Agency
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration By Graduate Student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ________________________ Date: ___________________

Name and Matric No.: Hasnimulyati Binti Laoding (GS40600)

Declaration By Members Of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature:	____________	Signature:	____________
Name of Chairman of Supervisory Committee:	Assoc. Prof. Halimah Bt Mohamed Kamari	Name of Member of Supervisory Committee:	Prof. Azmi Zakaria
Signature:	____________	Signature:	____________
Name of Member of Supervisory Committee:	Prof. Abdul Halim Shaari	Name of Member of Supervisory Committee:	Dr. Ishak Mansor

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

TeO_2	Tellurium oxide
B_2O_3	Boron oxide
ZnO	Zinc oxide
Tm_2O_3	Thulium oxide
CeO_2	Cerium oxide
BOs	Bridging oxygens
NBOs	Non-bridging oxygens
Tm	Thulium
Ce	Cerium
ρ	Density
V_m	Molar volume
V_L	Longitudinal velocity
V_S	Shear velocity
L	Longitudinal modulus
G	Shear modulus
K	Bulk modulus
Y	Young's modulus
σ	Poisson's ratio
H	Microhardness
θ	Debye temperature
Z	Acoustic impedance
T_s	Softening temperature
M	Metallization criterion
E_{opt}	Optical band gap
n	Refractive index
R_m	Molar refraction
α_m	Molar polarizability
$\alpha_O{}^{2-}$	Oxide ion polarizability
Λ	Optical basicity
ɤ	gamma

CHAPTER 1

INTRODUCTION

This chapter deals with the research background and consists of a brief introduction to glass, tellurite glass, and all chemicals that were used in this research. Besides that, other important components of the study were also included, such as the problem statement, objectives of study, significance of study and hypothesis as well as scope and limitations.

1.1 Research background

1.1.1 Definition of glass

The word glass is derived from the Latin term glæsum, referring to a lustrous and transparent material. During early civilizations, the most significant properties attributed to glass are luster or shine, and in particular its durability when being exposed to natural elements (Varshneya, 2013) . It is the oldest man-made material and its invention has enabled man to have a broad daylight in his protected environment (Aben and Claude, 2012).

According to the American Society for Testing Materials (ASTM) in 1945, glass can be defined as "an inorganic product of fusion which was cooled to a rigid condition without crystallizing". However, this definition does not give a full explanation about glass, since several other ways to produce glass were discovered later. These include vapour deposition, sol-gel processing of solutions and neutron irradiation of crystalline materials. Both sol-gel processing and chemical vapour deposition are techniques that would avoid the normal high temperatures applied for glass formation.

Among the common characteristics of glass are, it does not have a long range, periodic atomic arrangement and it shows time-dependent glass transformation behaviour that makes it different when compared to the other types of solid. The absence of long-range order is the property that made glass known as an amorphous solid. From the above statement, glass can be fully defined as an amorphous solid that is completely lacking in long range, periodic atomic structure, and exhibiting a region of glass transformation behaviour (Shelby, 2005).

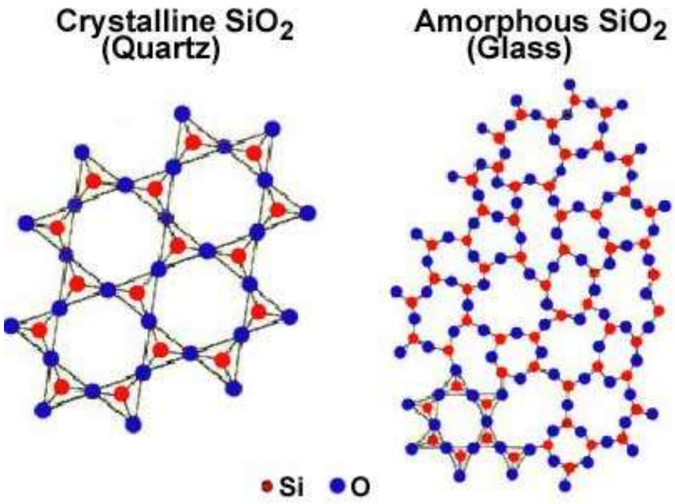

Figure 1.1: Network structure of crystalline and amorphous solid (Mayhugh, 2010)

1.1.2 Tellurite glass (TeO_2)

Tellurium dioxide is a conditional glass former which can form a glass on its own. The term 'conditional' is used as the process to produce the glass is very difficult if the chemical is not added with other chemical compounds. Before 1985, the studies on this type of glass are very scarce and unattractive to international attention (Rivera and Manzani, 2017). However, this situation recently has started to change when the TeO_2 glass was found to possess many unique properties as it was doped with transition metals or rare earth ions. Some advantages of tellurite glass are low melting points, high refractive index, high dielectric constant and good infrared transmission (Halimah et al., 2005a). Besides that, Podmaniczky (1976) and Warner et al., (1972) mentioned that it has low acoustic losses and slow-shear wave propagation velocity. Hence, they suggested that tellurite glass has a potential to be used in laser light modulators.

In terms of rare-earth doped tellurite glass, many researchers suggested that it has a potential to be used in optoelectronic areas. El-Mallawany et al., (2004) stated in their study that Er^{3+} doped tellurite-titanium-tungsten glasses are suitable to be applied as fibre amplifier since a broad emission spectrum can be detected at 1550 nm with a width of 121 nm and decay time 4.5 ms. In addition, the increment of overall upconversion fluorescence and relative increase in the intensity of red emission with respect to green emission make the glass a promising candidate for infrared amplifiers as well as for red and green upconversion emissions. Besides that, Er^{3+} - Yb^{3+} codoped TeO_2-PbF_2 oxyhalide tellurite glasses that was studied by Yang et al., (2014) was found to enhance the performance of amorphous silicon solar cell as they were coupled together.

1.1.3 Borate (B_2O_3)

Borate is also one of the glass formers which can form glass on its own. According to Kotz, (2016), borates are a large number of boron-containing oxyanions that are $(BO_3)^{3-}$ units. These units exist in trigonal planar BO_3 and tetrahedral BO_4 structural units which are connected in linear or cyclic arrangement. Borate can also be studied by obtaining information regarding two elements that are present in it namely boron and oxygen. In the periodic table, boron is the fifth element and categorized as a metalloid. Metalloid properties lie between metals and non-metals. It does not conduct electricity and heat as good as a metal like copper (Cu) but conducts better than non-metal such as sulphur (S) (Adair, 2007). Boron and oxygen in borates form strong covalent bonds and thus make them suitable to be used as a glass former.

Borate glass is known to have high transparency, low melting point, good rare-earth ion solubility and high phonon energy (Maheshvaran et al., 2013). Besides that, several researchers also stated that it has high chemical durability, thermal stability and cost effective properties (Reddy et al., 2015; Nurbaisyatul et al., 2014). These advantages make the glass suitable for various applications such as optical materials, low temperature sealing glasses and electronic devices (Chimalawong et al., 2010; Rejisha et al., 2016; Beckmann et al., 2013). However, borate glass is also known to possess a hygroscopic nature where it can react with atmospheric water. This, in turn, limits the glass applications. In order to overcome this problem, other chemical oxides are added into the glass system such as alkali metal, heavy metal and rare-earth oxides.

1.1.4 Zinc oxide (ZnO)

Zinc oxide is an inorganic compound which is white in colour (powdered form) and insoluble in water. It is widely used as additive in materials such as plastic, glass, lubricants and cement. It is naturally found as mineral zincite which is yellow to red in colour and usually contains a certain amount of manganese (Klingshirn, 2007). Besides that, ZnO can also be synthetically produced via direct, indirect and wet chemical processes (Porter, 1991). In the periodic table, zinc is the first element in group 12 and classified as a transition metal. Some general properties of transition metals are high melting points, good electrical conductivity and have a moderate-to-extreme hardness (Petrucci et al., 2010). In addition, Helmenstine, (2016) stated that transition metal also has low ionization energy, positive oxidation states and exhibits metallic luster. Transition metal ions are used as dopants in glasses mainly due to two reasons; 1) they have defined and sharp energy levels that can serve as structural probes for the dopant environment, and 2) modifications of energy level structure due to dopants insertion may lead to interesting applications, such as new lasers and luminescence materials (Al-Shamiri and Eid, 2012).

Many previous researchers have reported the improvement in the properties of a material when zinc oxide (ZnO) is added into it. Kundu et al., (2014) mentioned that the insertion of ZnO into glass system produces stability and increases the glass forming ability. Furthermore, Azlan et al., (2013) stated that ZnO can reduce the melting point and optical band gap as well as increase the refractive index of glass. On top of that, it can also act both as the network former and network modifier with a certain composition.

1.1.5 Thulium oxide (Tm_2O_3)

Thulium with chemical formula Tm was firstly discovered by Per Teodor Cleve, a Swedish chemist, who separated it from an impure sample of erbia in 1879 (Gagnon, n.d.). It is a pale green colour compound and can also be prepared synthetically by burning thulium metal in air or decomposition of their oxyacid salts such as thulium nitrate. Tm is categorized as a rare-earth element which is found in very small amount in the vast majority of the geological environment (Atwood, 2012). In lanthanide series, thulium is the thirteenth element which is situated between erbium (Er) and ytterbium (Yb). The common oxidation state for Tm is +3 while it is also available in +2. According to Bonnelle and Spector, (2015), thulium is found in the trivalent state in $TmAl_2$, TmS, and Tm_2O_3 while it can exists in both trivalent and divalent states in TmTe and TmSe. A few known uses of Tm and its isotopes are as a radiation source in portable X-ray equipment and dopant in ceramic magnetic materials used in microwave equipment. (Weast and Lide, 1989).

In terms of thulium oxide specifically, it can be used in numerous applications such as X-ray devices, phosphors, atomic reactors and semiconductors (Sidorowicz et al., 2016). Meanwhile, Cho et al., (2000) stated that the insertion of Tm^{3+} into tellurite glass network produces an excellent candidate material for efficient optical fibre amplifiers at 1.47 µm region. Besides that, Tm-doped materials also have drawn much interest due to its ability to produce blue coherent radiation pumped by infrared lasers (Santos et al., 2001). A blue laser is very useful as it can be applied in many fields such as submarine communications and optical data storage (Hanna et al., 1990). Furthermore, lasers containing thulium are also used in surgery, dentistry, atmospheric testing and remote sensing.

1.1.6 Cerium oxide (CeO_2)

Cerium (Ce) is a soft, ductile and malleable metal which is very reactive in air or water ("Cerium," n.d.). It is the second element in lanthanide series and located between lanthanum (La) and Praseodymium (Pr). Among the rare earth elements, Ce is the most abundant and making up 0.0046% of the Earth crust. It was firstly discovered in 1803 by Klaproth, Berzalius and Hisinger. A number of minerals found to contain cerium include allanite (also known as orthite), samarskite, monazite, cerite and bastnasite. Besides that, it can also be produced synthetically by metallothermic reduction techniques such as reducing cerous fluoride with calcium or using electrolysis of molten cerous chloride. These techniques can produce high-purity cerium ("Cerium," 2016). This element is extensively used in the manufacture of pyrophoric alloys for cigarette lighters. Furthermore, it is used in carbon-arc lighting, especially in the motion picture industry and also useful as a catalyst in petroleum refining, metallurgical and nuclear applications.

Nowadays, cerium oxide also called ceria is the most common form of cerium that is widely used in many applications. The main use of CeO_2 is as a polishing compound for glass, replacing rouge as it can polish much faster. Moreover, it is also an important constituent of incandescent gas mantles. The other emerging application is as a hydrocarbon catalyst in the self-cleaning oven where its incorporation into the oven walls can prevent cooking residues collection. In terms of cerium-doped glasses, Singh and Singh, (2011) reported that they are used in various applications such as laser active media, radiation protection of fibre optic materials and scintillation materials.

1.2 Problem statement

Nowadays, numerous studies have been done on the properties of glass and its potential applications. Based on the previous researches, it is widely known that the characteristic of glass can be controlled via the addition of chemical oxides. This is due to the fact that each chemical oxide possesses unique properties which can then alter the glass overall characteristics. The insertion of zinc oxide (ZnO) for example, can decrease tellurite glass density (Kaur et al., 2010; Redman and Chen, 1967) while the incorporation of aluminium oxide (Al_2O_3) causes the elastic moduli of tellurite-based glass to increase (Balaji et al., 2014). Besides that, it is also important to note that this modification is not only dependent on the modifier oxide but also on the overall composition of the glass system.

The doping of glass with rare earth oxides grabs the researchers' attention due to their ability to enhance the optical properties of glass. This is attributed to the existence of 4f electrons in these elements. According to Reddy et al., (2015), the effect of ligand environment on the 4f shell is minimum as rare earth is embedded into a solid matrix. This is caused by 4s and 5p shells which effectively shield the 4f shell. As a result, it is easier for the 4f electrons to be ejected from the atom and produce the optical transitions that do not exist in the other compound. However, some problems arise when the rare earth oxides are added to a high composition, where the glass samples tend to become more fragile and in some cases attain a crystalline nature. Thus, another method was used in the present study to alter the glass properties which is an exposure to gamma radiation. Using this method, it is believed that the glass characteristic can be further modified while at the same time maintain a low percentage of rare earth ions.

Several studies were conducted on borotellurite-based glass by previous researchers. Maheshvaran et al., (2013) mentioned that B_2O_3-TeO_2 glass with the addition of alkali oxide produce glasses with low phonon energy, high refractive index and high optical non-linearity. Besides that, it also stated that borotellurite-based glass is suitable to be used in the fabrication of various new optical devices. Recently, there have been several studies that investigated on zinc borotellurite glass (Eevon et al., 2016; Faznny et al., 2016; Hazlin et al., 2017), but different types of rare earth oxides are used in their study. There is still lack of research that presented on thulium and cerium-doped zinc borotellurite glass system. Moreover, exposing thulium and cerium-doped zinc borotellurite glass to gamma radiation also has not been done by other researchers before. Hence, this study was conducted in order to study the structural, elastic and optical properties of the glass system. Furthermore, the influences of gamma radiation to the properties of the prepared glasses were also studied. All the data are presented in this thesis.

1.3 Objectives of study

This research was conducted based on four clear and concise objectives. The objectives are stated below;

1. To study the effect of Tm_2O_3/CeO_2 on elastic properties of zinc borotellurite glass system.
2. To analyze the effect of Tm_2O_3/CeO_2 on optical properties of zinc borotellurite glass system.
3. To determine the elastic properties of Tm_2O_3/CeO_2 doped zinc borotellurite glass using theoretical approach and compare with the experimental values.
4. To investigate the effect of gamma radiation on elastic and optical properties of Tm_2O_3/CeO_2 doped zinc borotellurite glass.

1.4 Hypotheses

Based on the above objectives, the hypotheses for this study are;

1. The addition of Tm_2O_3 and CeO_2 into glass samples are expected to enhance the elastic properties of the glass by increasing the elastic moduli, microhardness and Debye temperature while decreasing the value of Poisson's ratio. This is because rare earth ion causes the formation of bridging oxygen that will increase the rigidity of the glass samples.
2. These rare earth additions are expected to improve the optical properties of the glass by decreasing the energy band gap while increasing molar polarizability, molar refraction and also refractive index. The advantage of rare earth ion that has 4f electron is the contributing factor to the enhancement of these properties.
3. It is expected that the experimental and theoretical data of elastic properties are in a close range.
4. The exposure to gamma radiation is expected to change the structure, elastic and optical properties of glass samples. Gamma radiation will break the network bond in the structure and lead to the changes in its properties.

1.5 Scope and limitations

The objectives of this study are achieved by following the scope of the study stated below;

1. The preparation of the glasses was done by using melt-quenching technique and based on the stoichiometric equation: $\{[[(TeO_2)_{0.7}(B_2O_3)_{0.3}]_{0.7}(ZnO)_{0.3}]\}_{1-x}\{Tm_2O_3/CeO_2\}_x$. Tm_2O_3 and CeO_2 act as the dopants and vary from 0 to 0.05 mol.
2. The structures of glasses were analyzed using the Fourier Transform Infrared Spectroscopy (FTIR) to study the chemical bonding of the glasses and X-ray Diffraction (XRD) to confirm their amorphous nature.
3. The ultrasonic technique was used to obtain the ultrasonic wave velocity of the glass. Then, the longitudinal and shear velocities were used to determine the elastic properties of the glasses.
4. The optical properties of the glasses were investigated by using UV-VIS Spectrophotometer. Then, the optical parameters were calculated, such as optical band gap, Urbach energy, refractive index, molar and oxide ion polarizability and metallization criterion.
5. The effects of gamma radiation on the glasses were studied by exposing glasses containing 0.01 mol of dopant concentration to Co-60 gamma source with radiation doses ranging from 10 until 35 kGy.

1.6 Significance of study

Nowadays, glass is needed not only for windows and doors but also used as photonic, optical and electronic devices. Some studies about rare earth doped glass were found to enhance the properties of glass, especially in terms of its optical properties. Since then, there was a growing interest among researchers to study about rare earth doped-glass in order to produce glass with better properties.

Gamma radiation was found to be one of the factors that can modify the optical and elastic properties of glass. Thus, the outcome of this study may provide a deeper knowledge about the properties of the new composition of glasses and influence of gamma radiation to them. This research can be a guiding reference for further research on elastic and optical properties of rare earth-doped glass in the educational field and also in industrial applications.

REFERENCES

Aben, H., & Claude G. (2012). *Photoelasticity of Glass*. Berlin: Springer Science and Business Media.

Abdelghany, A. M., Elbatal, F. H., & Elbatal, H. A., (2014). Zinc containing borate glasses and glass-ceramics : Search for biomedical applications. *Processing and Application of Ceramics*, 8(4), 185–193.

Adair, R. (2007). *Boron : Understanding the elements of the periodic table*. New York: The Rosen Publishing Group.

Afifi, H., & Marzouk, S. (2003). Ultrasonic velocity and elastic moduli of heavy metal tellurite glasses. *Materials Chemistry and Physics*, 80(2), 517–523.

Ahmad, F., Aly, E. H., Atef, M., & Elokr, M. M. (2014). Study the influence of zinc oxide addition on cobalt doped alkaline earth borate glasses. *Journal of Alloys and Compounds*, 593, 250–255.

Al-Ani, S. K. J., Hogarth, C. A., & El-Mallawany, R. A. (1985). A study of optical absorption in tellurite and tungsten-tellurite glasses. *Journal of Materials Science*, 20, 661–667.

Ali, A. A. (2009). Optical properties of Sm^{3+}-doped CaF_2 bismuth borate glasses. *Journal of Luminescence*, 129, 1314–1319.

Allred, C. L. (2003). *Effect of Radiation on Silicon and Borosilicate Glass*. (Doctoral dissertation). Massachusetts Institute of Technology.

Al-Mashhadani, A. H., Al-Dafaee, T. A., & Hussain, H. S. (2013). Study the effect of gamma radiation on the some properties of glass and glass-ceramic immobilize nuclear waste. *Iraqi Journal of Physics*, 11(21), 75–83.

Al-Shamiri, H. A. S., & Eid, A. S. (2012). Optical and ultrasonic properties of chromium oxide in sodium zinc phosphate glass. *Photonics and Optoelectronics*, 1(1), 1–8.

Altaf, M., & Chaudhry, M. (2000). Effect of MnO on the optical band gap in MnO-CdO-P_2O_5 glasses. *Journal of the Korean Physical Society*, 36(5), 265–268.

Altaf, M., Chaudhry, M. A., & Zahid, M. (2003). Study of optical band gap of zinc-borate glasses. *Journal of Research (Science)*, 14(2), 253–259.

Arora, M., Baccaro, S., Sharma, G., Singh, D., Thind, K. S., & Singh, D. P. (2009). Radiation effects on $PbO–Al_2O_3–B_2O_3–SiO_2$ glasses by FTIR spectroscopy. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, 267(5), 817–820.

Atwood, D. A. (2012). *The rare earth elements : Fundamentals and Applications*. United Kingdom: John Wiley & Sons.

Ayuni, J. N., Halimah, M. K., Talib, Z. A., Sidek, H. A. A., Daud, W. M., Zaidan, A. W., & Khamirul, A. M. (2011). Optical Properties of Ternary TeO_2-B_2O_3-ZnO

Glass System. *IOP Conference Series: Materials Science and Engineering*, 17(12027), 1-7.

Azianty, S., & Yahya, A. K. (2013). Enhancement of elastic properties by WO_3 partial replacement of TeO_2 in ternary $(80-x)TeO_2–20PbO–xWO_3$ glass system. *Journal of Non-Crystalline Solids*, 378, 234–240.

Azlan, M. N., Halimah, M. K., Shafinas, S. Z., & Daud, W. M. (2013). Effect of erbium nanoparticles on optical properties of zinc borotellurite glass system. *Journal of Nanomaterials*, 2013, 1–9.

Azlan, M. N., Halimah, M. K., Shafinas, S. Z., Daud, W. M., & Sidek, H. A. A. (2014). Influence of erbium concentration on spectroscopic properties of tellurite based glass. *Solid State Science and Technology*, 22(2), 148–156.

Azlan, M. N., Halimah, M. K., Shafinas, S. Z., & Daud, W. M. (2015). Electronic polarizability of zinc borotellurite glass system containing erbium nanoparticles. *Materials Express*, 5(3), 211–218.

Azuraida, A., Halimah, M. K., Azurahanim, C. A. C., & Ishak, M. (2015). Gamma irradiation effect on structural and optical properties of bismuth-boro-tellurite glasses. *International Journal of Chemical,Nuclear, Materials and Metallurgical Engineering*, 9(5), 572–576.

Bahadur, A., Dwivedi, Y., & Rai, S. B. (2013). Optical properties of cerium doped oxyfluoroborate glass. *Spectrochimica Acta - Part A: Molecular and Biomolecular Spectroscopy*, 110, 400–403.

Baizura, N., & Yahya, A. K. (2011). Effects of Nb_2O_5 Replacement by Er_2O_3 on elastic and structural properties of $75TeO_2–(10-x)Nb_2O_5–15ZnO–(x)Er_2O_3$ glass. *Journal of Non-Crystalline Solids*, 357(15), 2810–2815.

Balaji, S., Biswas, K., Sontakke, A. D., Gupta, G., Ghosh, D., & Annapurna, K. (2014). Al_2O_3 influence on structural, elastic, thermal properties of Yb^{3+} doped Ba-La-tellurite glass: evidence of reduction in self-radiation trapping at 1μm emission. *Spectrochimica Acta. Part A, Molecular and Biomolecular Spectroscopy*, 133, 318–325.

Balda, R., Lacha, L. M., Fernandez, J., M.A. Arriandiaga, Fernandez-Navarro, J. M., & D. Munoz-Martin. (2008). Spectroscopic properties of $Tm^{3+}:TeO_2–PbF_2$ glasses. *Optic Express*, 16(16), 11836–11846.

Barbara, L. D., & Christine, M. C. (2015). X-ray powder diffraction (XRD). Retrieved from http://serc.carleton.edu/research_education/geochemsheets/techniques/XRD.html

Basic Physics of Nuclear Medicine/Interaction of Radiation with Matter. (2013). Retrieved from https://en.wikibooks.org/wiki/Basic_Physics_of_Nuclear_Medicine/Interaction_of_Radiation_with_Matter

Beckmann, A. W., Möncke, D., Palles, D., Kamitsos, E. I., & Wondraczek, L. (2013). Structure-property correlations in highly modified Sr, Mn-borate glasses. *Journal of*

Non-Crystalline Solids, 376, 165–174.

Begum, A. N., & Rajendran, V. (2006). Structure and elastic properties of TeO_2-BaF_2 glasses. *Journal of Physics and Chemistry of Solids*, 67(8), 1697–1702.

Berthereau, A., Luyer, Y. L. E., Olazcuaga, R., Flem, G. L. E., Couzi, M., Canioni, L., Ducassee, A., (1994). Nonlinear optical properties of some tellurium (IV) oxide glasses. *Materials Research Bulletin*, 29(9), 933–941.

Beyer, V. H. (1967). Verfeinerung der Kristallstruktur von Tellurit , Gitterkonstanten : *Zeitschrift Fur Kristallographie*, 124, 228–237.

Bishay, A. (1970). Radiation induced color centers in multicomponent glass. *Journal of Non-Crystalline Solids*, *3*, 54–114.

Bonnelle, C., & Spector, N., (2015). *Rare-Earths and Actinides in High Energy Spectroscopy*. New York: Springer.

Boonin, K., Chaemlek, O., Limkitjaroenporn, P., Kim, H., & Kaewkhao, J., (2013). Physical and optical properties of Ce^{3+} doped in bismuth borate glass. *Advanced Materials Research*, 770, 254–257.

Bootjomchai, C. (2015). Comparative studies between theoretical and experimental of elastic properties and irradiation effects of soda lime glasses doped with neodymium oxide. *Radiation Physics and Chemistry*, 110, 96–104.

Brady, G. W. (1956). Structure of tellurium oxide glass. *The Journal of Chemical Physics*, 24(477), 300.

Brady, G. W. (1957). Structure of tellurium oxide glass. *Journal of Chemical Physics*, 27, 300–303.

Bray, P. J. (1985). Structural models for borate glasses. *Journal of Non-Crystalline Solids*, 75(1–3), 29–36.

Brian, C. S. (1995). *Fundamentals of Fourier Transform Infrared Spectroscopy*. Boca Raton: CRC Press.

Bridge, B., & Higazy, A. A. (1986). A model of the compositional dependence of the elastic moduli of polycomponent oxide glasses. *Physics and Chemistry of Glasses*, 27(1), 1–14.

Bridge, B., Patel, N. D., & Waters, D. N. (1983). On the elastic constants and structure of the pure inorganic oxide glasses. *Physica Status Solidi (A)*, 77, 655–668.

Çelikbilek, M., Ersundu, A. E., & Aydin, S. (2013). Preparation and characterization of TeO_2– WO_3–Li_2O glasses. *Journal of Non-Crystalline Solids*, 378, 247–253.

Cerium. (n.d.). Retrieved from www.samaterials.com/137-cerium

Cerium. (2016). Retrieved from periodic.lanl.gov/58.shtml

Chang, K. H., Lee, T. H., & Hwa, L. G. (2003). Structure and elastic properties of iron phosphate glasses. *Chinese Journal of Physics*, 41(4), 414–421.

Chimalawong, P., Kaewkhao, J., & Limsuwan, P. (2010). Effect of Nd^{3+} concentration on the physical and absorption properties of soda-lime-silicate glasses. *Advanced Materials Research*, 93–94(4), 455–458.

Cho, D. H., Choi, Y. G., & Kim, K. H. (2000). Energy transfer from Tm^{3+}:$^{3}F_4$ to Dy^{3+}:$^{6}H_{11/2}$ in oxyfluoride tellurite glasses. *Chemical Physics Letters*, 332(May), 263–266.

Davis, F. A., & Mott, N. F. (1970). Electrical and transparent properties of amorphous semiconductor. *Philosophical Magazine*, 22, 903–920.

Dimitriev, Y., Bart, J. C. J., Ivanova, I., & Dimitrov, V., (1988). Glass formation in the TeO_2- MoO_3-CeO_2, *Zeitschrift für anorganische und allgemeine Chemie*, 562, 175–185.

Dimitrov, V., & Komatsu, T. (1999). Electronic polarizability, optical basicity and non-linear optical properties of oxide glasses. *Journal of Non-Crystalline Solids*, 249(2–3), 160–179.

Dimitrov, V., & Komatsu, T. (2010). An interpretation of optical properties of oxides and oxide glasses in terms of the electronic ion polarizability and average single bond strength. *Journal of the University of Chemical Technology and Metallurgy*, 45(3), 219–250.

Dimitrov, V., & Sakka, S. (1996). Linear and nonlinear optical properties of simple oxides. II. *Journal of Applied Physics*, 79(3), 1741.

Doweidar, H., & Saddeek, Y. B., (2010). Effect of La_2O_3 on the structure of lead borate glasses. *Journal of Non-Crystalline Solids*, 356(28–30), 1452–1457.

Duffy, J. A. (1986). Chemical bonding in the oxides of the elements: A new appraisal. *Journal of Solid State Chemistry*, 62(2), 145–157.

Eevon, C., Halimah, M. K., Azmi, Z., & Azurahanim, C. (2016). Elastic properties of TeO_2-B_2O_3-ZnO-Gd_2O_3 glasses using non-destructive ultrasonic technique. *Chalcogenide Letters*, 13(6), 281–289.

Ehrt, D. (2013). Zinc and manganese borate glasses - Phase separation, crystallisation, photoluminescence and structure. *European Journal of Glass Science and Technology Part B Physics and Chemistry of Glasses*, 54(2), 65–75.

El-Aal, N. S. A., (2001). Elastic properties of γ-radiated borate glasses using pulse echo technique. *Egyptian Journal of Solids*, 24(2), 181–192.

El-Alaily, N. A., & Mohamed, R. M. (2003). Effect of irradiation on some optical properties and density of lithium borate glass. *Material Science and Engineering B*, 98, 193–203.

El-Batal, F. H., El-Kheshen, A. A., & Hamdy, Y. M. (2013). Absorption spectra and bioactivity behavior of gamma irradiated CeO_2-doped bioglasses. *Silicon*, 5(2), 171–181.

El-Deen, L. M. S., Salhi, M. S. A., & Elkholy, M. M. (2008). IR and UV spectral studies for rare earths-doped tellurite glasses. *Journal of Alloys and Compounds*, 465(1–2), 333–339.

Elkhoshkhany, N., Abbas, R., R. El-Mallawany, R., & Fraih, A. J. (2014). Optical properties of quaternary TeO_2–ZnO–Nb_2O_5–Gd_2O_3 glasses. *Ceramics International*, 40, 14477–14481.

El-Malak, N. A. (2002). Ultrasonic studies on irradiated sodium borate glasses. *Materials Chemistry and Physics*, 73, 156–161.

El-Mallawany, R. (1992). Debye temperature of tellurite glasses. *Physica Status Solidi (a)*, 130(1), 103–108.

El-Mallawany, R. (1998). Tellurite glasses Part 1. Elastic properties. *Materials Chemistry and Physics*, 53(2), 93–120.

El-Mallawany, R., (2002). *Tellurite glasses handbook: Physical properties and data*. Boca Raton: CRC Press.

El-Mallawany, R., Abdalla, M. D., & Ahmed, I. A. (2008). New tellurite glass: Optical properties. *Materials Chemistry and Physics*, 109(2–3), 291–296.

El-Mallawany, R., Abousehly, A., Rahamani, A. A., & Yousef, E. (2000). Effect of γ -radiation on the elastic moduli of tricomponent tellurite glasses TeO_2-V_2O_5-Ag_2O. *Journal of Materials Science Letters*, 19, 413–415.

El-Mallawany, R., & Afifi, H. (2013). Elastic moduli and crosslinking of some tellurite glass systems. *Materials Chemistry and Physics*, 143(1), 11–14.

El-Mallawany, R., Elkhoshkhany, N., & Afifi, H. (2006). Ultrasonic studies of $(TeO_2)_{50}$–$(V_2O_5)_{50-x}(TiO_2)_x$ glasses. *Materials Chemistry and Physics*, 95(2–3), 321–327.

El-Mallawany, R., Patra, A., & Friend, C. S. (2004). Study of luminescence properties of Er^{3+}-ions in new tellurite glasses. *Optical Materials*, 26, 267–270.

El-Mallawany, R. A., & Saunders, G. A. (1988). Elastic properties of binary, ternary and quaternary rare earth tellurite glasses. *Journal of Materials Science Letters*, 7, 870–874.

El-Moneim, A. A. (2001). Bond compression bulk modulus and Poisson’s ratio of the polycomponent silicate glasses. *Materials Chemistry and Physics*, 70, 340–343.

Equity, A. O. F. T. (2014). *College physics textbook equity edition volume 2 of 3: Chapters 13-24*. Place of publication not identified: Lulu Com.

Eraiah, B. (2006). Optical properties of samarium doped zinc–tellurite glasses. *Bulletin Material Science*, 29(4), 375–378.

Fares, H., Jlassi, I., Elhouichet, H., & Férid, M. (2014). Investigations of thermal, structural and optical properties of tellurite glass with WO_3 adding. *Journal of Non-Crystalline Solids*, 396–397, 1–7.

Faznny, M. F., Halimah, M. K., & Azlan, M. N. (2016). Effect of lanthanum oxide on optical properties of zinc borotellurite glass system. *Journal of Optoelectronics and Biomedical Materials*, 8(2), 49–59.

Feng, D., & Jin, G. (2005). *Introduction to Condensed Matter Physics*. Singapore:World Scientific Publishing.

Ferlic, K. (2006). The phenomenon of pair production. Retrieved from http://ryuc.info/creativityphysics/energy/pair_production.htm

Gaafar, M. S., El-Aal, N. S. A., Gerges, O. W., & El-Amir, G. (2009a). Elastic properties and structural studies on some zinc-borate glasses derived from ultrasonic, FT-IR and X-ray techniques. *Journal Of Alloys And Compounds*, 475, 535–542.

Gaafar, M. S., El-Batal, F. H., El-Gazery, M., & Mansour, S. A. (2009b). Effect of doping by different transition metals on the acoustical properties of alkali borate glasses. *Acta Pysica Polonica A*, 115(3) 671-678.

Gaafar, M. S., Soliman, L. I., & Marzouk, S. Y. (2009c). Ultrasonic characterization of $Bi_2(Te_{1-x}Se_x)_3$ System. *Archives of Acoustics*, 34(4), 715–725.

Gagnon, S. (n.d.). The element thulium. Retrieved from http://education.jlab.org/itselemental/ele069.html

Gautam, C., Yadav, A. K., & Singh, A. K. (2012). A review on infrared spectroscopy of borate glasses with effects of different additives. *ISRN Ceramics*, 2012(1), 1–17.

Gebavi, H., Milanese, D., Liao, G., Chen, Q., Ferraris, M., Ivanda, M., Taccheo, S. (2009). Spectroscopic investigation and optical characterization of novel highly thulium doped tellurite glasses. *Journal of Non-Crystalline Solids*, 355(9), 548–555.

Gedam, R. S., & Ramteke, D. D. (2013). Influence of CeO_2 addition on the electrical and optical properties of lithium borate glasses. *Journal of Physics and Chemistry of Solids*, 74(10), 1399–1402.

Gowda, V. C. V., & Anavekar, R. V. (2004). Elastic properties and spectroscopic studies of lithium lead borate glasses. *Ionics*, 10(1–2), 103–108.

Gowda, V. C. V., Pasha, K. R. S., Reddy, M. S., & Reddy, C. N. (2012). Optical properties and structural studies on Nd^{3+} doped borate glasses containing heavy metal oxide. *Advanced*, 584, 207–211.

Grebenkemper, J. (2017). Powder X-ray Diffraction. Retrieved from https://chem.libretexts.org/Core/Analytical_Chemistry/Instrumental_Analysis/Diffraction_Scattering_Techniques/Powder_X-ray_Diffraction

Hager, I. Z., El-Mallawany, R., & Bulou, A. (2011). Luminescence spectra and optical properties of TeO_2–WO_3–Li_2O glasses doped with Nd, Sm and Er rare earth ions. *Physica B: Condensed Matter*, 406(4), 972–980.

Hajer, S. S., Halimah, M. K., Azmi, Z., & Azlan, M. N. (2014). Optical properties of zinc-borotellurite doped samarium. *Chalcogenide Letters*, 11(11), 553–566.

Halimah, M. K., Daud, W. M., & Sidek, H. A. A. (2010). Effect of AgI addition on elastic properties of quaternary tellurite glass systems. *Chalcogenide Letters*, 7(11), 613–620.

Halimah, M. K., Daud, W. M., Sidek, H. A. A., Zainal, A. T., Zainul, H., & Jumiah, H., (2005b). Optical properties of borotellurite glasses. *American Journal of Applied Sciences*. Retrieved from http://www.thefreelibrary.com/_/print/PrintArticle.aspx?id=145780430

Halimah, M. K., Sidek, H. A. A., Daud, W. M., Zainul, H., Talib, Z. A., Zaidan, A. W., Mansor, H. (2005a). Ultrasonic study and physical properties of borotellurite glasses. *American Journal of Applied Sciences*, 2(11), 1541–1546.

Hanna, D. C., Percival, R. M., Perry, I. R., Smart, R. G., Townsend, J. E., & Tropper, A. C. (1990). Frequency upconversion in Tm and Yb:Tm-doped silica fibers. *Optics Communications*, 78(2), 187–194.

Hazlin, M. N. A., Halimah, M. K., Mohammad, F. D., & Faznny, M. F. (2017). Optical properties of zinc borotellurite glass doped with trivalent dysprosium ion. *Physica B: Physics of Condensed Matter*, 510, 38–42.

Helmenstine, A. N. (2016). Transition metals. Retrieved from https://www.thoughtco.com/transition-metals-606664

Herzfeld, K. F. (1927). On atomic properties which make an element a metal. *Physical Review*, 2(2), 701.

Hirao, K., Mitsuyu, T., Si, J., & Qiu, J. (2013). *Active Glass for Photonic Devices: Photoinduced Structures and Their Application*. Berlin: Springer-Verlag.

Hughes, E. A. M. (1961). *Physical Chemistry*. London: Pergamon.

Inaba, S., Oda, S., & Morinaga, K. (2003). Heat capacity of oxide glasses at high temperature region. *Journal of Non-Crystalline Solids*, 325, 258–266.

John C. K. (2016). *Chemistry and Chemical Reactivity* (9th ed.). Stamford: Content Technologies, Incorporation.

Jose, R., Suzuki, T., & Ohishi, Y. (2006). Thermal and optical properties of TeO_2-BaO-SrO-Nb_2O_5 based glasses: New broadband Raman gain media. *Journal of Non-Crystalline Solids*, 352(52–54), 5564–5571.

Kaewwiset, W., Kaewkhao, J., & Limsuwan, P. (2010). UV-Visible-NIR study of Er^{3+} doped soda lime silicate glass. *Asian Journal on Energy and Environment*, 11(1), 37–47.

Kajinami, A., Harada, Y., Inoue, S., Deki, S., & Umesaki, N. (1999). The structural analysis of zinc borate glass by laboratory EXAFS and X-ray diffraction measurements. *Proceeding International Conference SRMS-2*, 38, 132–135.

Kamalaker, V., Upender, G., Ramesh, C., & Mouli, V. C. (2012). Raman spectroscopy , thermal and optical properties of TeO_2–ZnO–Nb_2O_5–Nd_2O_3 glasses. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 89, 149–154.

Kannappan, A. N., Thirumaran, S., & Palani, R. (2009). Elastic and mechanical properties of glass specimen by ultrasonic method. *ARPN Journal of Engineering and Applied Sciences*, 4(1), 27–31.

Karthikeyan, P., & Marimuthu, K. (2016). Optical properties of Dy^{3+} doped bismuth boro-tellurite glasses for WLED applications. *AIP Conference Proceedings*, 70009(1731)1-3.

Kaur, A., Khanna, A., Pesquera, C., Gonzalez, F., & Sathe, V. (2010). Preparation and characterization of lead and zinc tellurite glasses. *Journal of Non-Crystalline Solids*, 356(18–19), 864–872.

Khafagy, A. H., El-Adawy, A. A., Higazy, A. A., El-Rabaie, S., & Eid, A. S. (2008). Studies of some mechanical and optical properties of: (70−x)TeO_2+15B_2O_3+15P_2O_5+xLi_2O glasses. *Journal of Non-Crystalline Solids*, 354, 3152–3158.

Kim, S., Yoko, T., & Sakka, S. (1993). Linear and nonlinear optical properties of TeO_2 glass. *Journal of the American Ceramic Society*, 76(10), 2486–2490.

Kindrat, I. I., Padlyak, B. V., Kuklinski, B., & Kulyk, Y. O. (2016). Spectroscopic properties of the Ce-doped borate glasses. *Optical Materials*, 59, 20–27.

Kishi, Y., & Tanabe, S. (2006). Properties of Tm^{3+}-doped germanotellurite glasses for S-band amplifier. *Journal of the American Ceramic Society*, 89(1), 236–240.

Konijnendijk, W. L., & Stevels, J. M. (1975). The structure of borate glasses studied by raman scattering. *Journal of Non-Crystalline Solids*, 18, 307–331.

Kothandan, D., & Kumar, R. J. (2015). Optical properties of rare earth doped borate glasses. *International Journal of ChemTech Research*, 8(6), 310–314.

Kotz, J. C. (2016). *Chemistry and Chemical Reactivity* (9th ed.). Stamford: Content Technologies, Incorporation.

Krogh-Moe, J. (1965). Interpretation of the infrared spectra of boron oxide and alkali borate glasses. *Physics and Chemistry of Glasses*, 6, 46.

Klingshirn, C. F. (2007). ZnO: Material, physics and applications. *ChemPhysChem*, 8(6), 782–803.

Kumar, Y., Hashmi, S. A., & Pandey, G. P. (2011). Lithium ion transport and ion-polymer interaction in PEO based polymer electrolyte plasticized with ionic liquid. *Solid State Ionics*, *201*(1), 73–80.

Kundu, R. S., Dhankhar, S., Punia, R., Nanda, K., & Kishore, N. (2014). Bismuth modified physical, structural and optical properties of mid-IR transparent zinc boro-tellurite glasses. *Journal of Alloys and Compounds*, 587, 66–73.

Laopaiboon, R., Laopaiboon, J., Pencharee, S., Nontachat, S., & Bootjomchai, C. (2016). The effects of gamma irradiation on the elastic properties of soda lime glass doped with cerium oxide. *Journal of Alloys and Compounds*, 666, 292–300.

Leciejewicz, J. (1961). The crystal structure of tellurium dioxide . A redetermination by neutron diffraction. *Zeitschrift Fur Kristallographie*, 116, 345–353.

Maheshvaran, K., Veeran, P. K., & Marimuthu, K. (2013). Structural and optical studies on Eu^{3+} doped boro-tellurite glasses. *Solid State Sciences*, 17, 54–62.

Makishima, A., & Mackenzie, J. D. (1973). Direct calculation of Young's modulus of glass. *Journal of Non-Crystalline Solids*, 12(1), 35–45.

Makishima, A., & Mackenzie, J. D. (1975). Calculation of bulk modulus, shear modulus and Poisson's ratio of glass. *Journal of Non-Crystalline Solids*, 17(2), 147–157.

Martín, A. D. P., García, M. A., Muñoz-Noval, A., Castro, G. R., Pascual, M. J., & Durán, A. (2014). Analysis of the distribution of Tm^{3+} ions in LaF_3 containing transparent glass-ceramics through X-ray absorption spectroscopy. *Journal of Non-Crystalline Solids*, 384, 83–87.

Marzouk, S. Y. (2009). Ultrasonic and infrared measurements of copper-doped sodium phosphate glasses. *Materials Chemistry and Physics*, 114, 188–193.

Mayhugh, J. E. (2010). Fundamentals of general, organic and biological chemistry. Retrieved from http://slideplayer.com/slide/10660252/

McGinley, A. (2000). *Producing sound waves: Discover! Sound*. Dayton: Milliken Publishing Company.

Mhareb, M. H. A., Hashim, S., Ghoshal, S. K., Alajerami, Y. S. M., Saleh, M. A., Maqableh, M. M. A., & Tamchek, N. (2015). Optical and erbium ion concentration correlation in lithium magnesium borate glass. *Optik - International Journal for Light and Electron Optics*, 126(23), 3638-3643.

Milanese, D., Gebavi, H., Lousteau, J., Ferraris, M., Schulzgen, A., Li, L., Peyghambarian, N., Taccheo, S., Auzel, F. (2010). Tm^{3+} and Yb^{3+} co-doped tellurite glasses for short cavity optical fiber lasers: Fabrication and optical characterization. *Journal of Non-Crystalline Solids*, 356(44–49), 2378–2383.

Mustafa, I. S., Halimah, M. K., Yusoff, W. M. D. W, Sidek, H. A. A., & Rahman, A. A. (2013). Structural and optical properties of lead-boro-tellurrite glasses induced by gamma-ray. *International Journal of Molecular Sciences*, 14, 3201–3214.

Neov, S., Gerasimova, I., Kozhukharov, V., & Marinov, M. (1980). The structure of glasses in the TeO_2-P_2O_5 system. *Journal of Materials Science*, 15(5), 1153–1166.

Newman, J. (2010). *Physics of the Life Sciences*. New York: Springer Science & Business Media.

Noranizah, A., Azman, K., Azhan, H., Nurbaisyatul, E. S., & Mardhiah, A. (2014). Spectroscopic properties of rare earth ion doped TeO_2-B_2O_3-PbO Glass. *Jurnal Teknologi (Sciences and Engineering)*, 69(6), 49–52.

Nurbaisyatul, E. S., Azman, K., Azhan, H., Razali, W. A. W., & Noranizah, A. (2014). The structural properties of trivalent rare earth ions (Er^{3+}) doped borotellurite glass. *Jurnal Teknologi*, 2, 97–100.

Ouis, M. A., El-Batal, H. A., Azooz, M. A., & Abdelghany, A. M. (2013). Characterization of WO_3-doped borophosphate glasses by optical , IR and ESR spectroscopic techniques before and after subjecting to gamma irradiation. *Indian Journal of Pure and Applied Physics*, 51(January), 11–17.

Pal, I., Agarwal, A., Sanghi, S., Sanjay, & Aggarwal, M. P. (2013). Spectroscopic and radiative properties of Nd^{3+} ions doped zinc bismuth borate glasses. *Indian Journal of Pure and Applied Physics*, 51(1), 18–25.

Pal, M., Roy, B., & Pal, M. (2011). Structural characterization of borate glasses containing zinc and manganese oxides. *Journal of Modern Physics*, 2011(September), 1062–1066.

Pascuta, P., & Culea, E. (2011). Structural and thermal properties of some zinc borate glasses containing gadolinium ions. *Journal of Material Science: Material Electronics*, 22, 1060–1066.

Pavani, P. G., Sadhana, K., & Mouli, V. C. (2011). Optical, physical and structural studies of boro-zinc tellurite glasses. *Physica B: Physics of Condensed Matter*, 406(6–7), 1242–1247.

Petrucci, R. H., Herring, F. G., Madura, J. D., & Bissonnette, C. (2010). *General Chemistry Principles and Modern Applications* (10th ed.). Canada: Pearson Prentice Hall.

Pisarski, W. A., Goryczka, T., Wodecka-Dus, B., Pło, M., & Pisarska, J. (2005). Structure and properties of rare earth-doped lead borate glasses. *Material Science and Engineering B*, 122, 94–99.

Pisarski, W. A, Pisarska, J., Dominiak-Dzik, G., & Ryba-Romanowski, W. (2004). Visible and infrared spectroscopy of Pr^{3+} and Tm^{3+} ions in lead borate glasses. *Journal of Physics: Condensed Matter*, 16(34), 6171–6184.

Podmaniczky, A. (1976). Some properties of TeO_2 light deflectors with small interaction length. *Optics Communications*, 16(1), 161–165.

Porter, F. (1991). *Zinc handbook : properties, processing, and use in design*. New York: Marcel Dekker, Incorporation.

Prado, M. O., Messi, N. B., Plivelic, T. S., Torriani, I. L., Bevilacqua, A. M., & Arribére, M. A. (2001). The effects of radiation on the density of an aluminoborosilicate glass. *Journal of Non-Crystalline Solids*, 289(1–3), 175–184.

Prajnashree, M., Wagh, A., Raviprakash, Y., Sangeetha, B., & Kamath, S. D. (2013). Characterization of Pr_6O_{11} doped zinc fluoroborate glass. *European Scientific Journal*, 9(18), 83–92.

Pye, L. D., Frechette, V. D., & Kreidl, N. J. (1978). *Borate glasses: Structure, properties, applications*. New York: Plenum Press.

Rada, S., Dehelean, A., & Culea, E. (2011). FTIR and UV–VIS spectroscopy investigations on the structure of the europium–lead–tellurate glasses. *Journal of Non-Crystalline Solids*, 357(16–17), 3070–3073.

Radiation protection. (2012). Retrieved from http://www.arpansa.gov.au/radiation protection/basics/alpha.cfm

Rao, S. L. S., Ramadevudu, G., Shareefuddin, M., Hameed, A., Chary, M. N., & Rao, M. L. (2012). Optical properties of alkaline earth borate glasses. *MultiCraft International Journal of Engineering, Science and Technology*, 4(4), 25–35.

Reddy, C. M., Raju, B. D. P., Sushma, N. J., Dhoble, N. S., & Dhoble, S. J. (2015). A review on optical and photoluminescence studies of RE^{3+} (RE=Sm, Dy, Eu, Tb and Nd) ions doped LCZSFB glasses. *Renewable and Sustainable Energy Reviews*, 51, 566–584.

Redman, M. J., & Chen, J. H. (1967). Zinc tellurite glasses. *Journal of the American Ceramic Society*, 50(10), 523–525.

Rejisha, S. R., Anjana, P. S., & Gopakumar, N. (2016). Effect of cerium(IV) oxide on the optical and dielectric properties of strontium bismuth borate glasses. *Journal of Materials Science: Materials in Electronics*, 27(5), 5475–5482.

Rhein, L. D., Schlossman, M., O Lenick, A., & Somasundaran, P. (2007). *Surfactants in personal care products and decorative cosmetics*. (3rd ed). New York: M. Dekker.

Rivera, V. A. G., & Manzani, D. (2017). *Technological Advances in Tellurite Glasses: Properties, Processing, and Applications*. Switzerland: Springer International Publishing.

Rosmawati, S., Sidek, H. A. A., Zainal, A. T., & Zobir, H. M. (2008). Effect of zinc on the physical properties of tellurite glass. *Journal of Applied Sciences*, 8(10), 1956–1961.

Rouxel, T. (2007). Elastic properties and short-to medium-range order in glasses. *Journal of the American Ceramic Society*, 90(10), 3019–3039.

Ruller, J. A., & Friebele, E. J. (1991). The effect of gamma-irradiation on the density of various types of silica. *Journal of Non-Crystalline Solids*, 136(1–2), 163–172.

Saddeek, Y. B. (2004). Ultrasonic study and physical properties of some borate glasses. *Materials Chemistry and Physics*, 83(August 2003), 222–228.

Saddeek, Y. B. (2005). Elastic properties of Gd^{3+}-doped tellurovanadate glasses using pulse-echo technique. *Materials Chemistry and Physics*, 91, 146–153.

Saddeek, Y. B. (2009). Effect of B_2O_3 on the structure and properties of tungsten–tellurite glasses. *Philosophical Magazine*, 89(1), 41–54.

Saddeek, Y. B. (2012). Correlation between the dimensionality and the constants of elasticity of rare-earth doped borate glasses. *Glass Physics and Chemistry*, 38(4), 373–378.

Saddeek, Y. B., Azooz, M. A., & Kenawy, S. H. (2005). Effect of fly ash on the Li_2O-B_2O_3 system: Structural study by pulse echo technique. *Archives of Acoustics*, 30(3), 357–371.

Saddeek, Y. B., Gaafar, M. S., El-Aal, N. S. A., & El-Latif, L. A. (2009). Structural analysis of some alkali diborate glasses. *Acta Pysica Polonica A*, 116(2), 211–216.

Saddeek, Y. B., & Gaafar, M. S. (2014). Study of rigidity of semiconducting vanadate glasses and its importance in use of coatings. *Bulletin of Materials Science*, 37(3), 661–667.

Saffarini, G., Schmitt, H., Shanak, H., Nowoczin, J., & Müller, J. (2003). Optical band gap in relation to the average coordination number in Ge-S-Bi thin films. *Physica Status Solidi (B) Basic Research*, 239(1), 251–256.

Saffarini, G., Saiter, J. M., & Schmitt, H. (2007). The composition dependence of the optical band gap in Ge-Se-In thin films. *Optical Materials*, *29*, 1143–1147.

Sakida, S., Hayakawa, S., & Yoko, T. (1999a). Part 1. ^{125}Te NMR study of tellurite crystals. *Journal of Non-Crystalline Solids*, 243, 1–12.

Sakida, S., Hayakawa, S., & Yoko, T. (1999b). Part 2. ^{125}Te NMR study of M_2O-TeO_2 (M = Li, Na, K, Rb and Cs) glasses. *Journal of Non-Crystalline Solids*, 243, 13–25.

Santos, P. V. D., Vermelho, M. V. D., Gouveia, E. A., De Araújo, M. T., Gouveia-Neto, A. S., Cassanjes, F. C., Messaddeq, Y. (2001). Efficient energy upconversion emission in Tm^{3+}/Yb^{3+}-codoped TeO_2-based optical glasses excited at 1.064 μm. *Journal of Applied Physics*, 90(12), 6550–6552.

Sazali, E. S., Sahar, M. R., Ghoshal, S. K., Arifin, R., Rohani, M. S., & Awang, A. (2014). Optical properties of gold nanoparticle embedded Er^{3+} doped lead–tellurite glasses. *Journal Of Alloys And Compounds*, 607, 85–90.

Sellappan, P., Sharafat, A., Keryvin, V., Houizot, P., Rouxel, T., Grins, J., & Esmaeilzadeh, S. (2010). Elastic properties and surface damage resistance of nitrogen-rich (Ca,Sr)-Si-O-N glasses. *Journal of Non-Crystalline Solids*, 356(41–42), 2120–2126.

Sestak, J., Quieroz, C. A., & Foller, B. (2011). Some aspects of vitrification, amorphisation and idiosyncratic wet synthesis when considering the degree of nano-crystallinity. In *Selected topics of textile and material science*. Czech Republic: Publishing House of WBU, Plzeň (Pilsen).

Sharma, Y. K., Joshi, R. P., & Goyal, P. (2015). Optical band gap and physical properties of Nd^{3+} doped cadmium borate glasses. *American Journal of Physics and Applications*, 2(6), 162–166.

Shelby, J. E. (2005). *Introduction to Glass Science and Technology*. Cambridge: Royal Society of Chemistry.

Sidek, H. A. A., Rosmawati, S., Talib, Z. A., Halimah, M. K., & Daud, W. M. (2009). Synthesis and optical properties of ZnO-TeO_2 glass system. *American Journal of Applied Sciences*, 6(8), 1489-1494.

Sidkey, M. A., El-Moneim, A. A., & El-Latif, L. A. (1999). Ultrasonic studies on ternary TeO_2-V_2O_5-Sm_2O_3 glasses. *Materials Chemistry and Physics*, 61(February), 103–109.

Sidkey, M. A., & Gaafar, M. S. (2004). Ultrasonic studies on network structure of ternary TeO_2–WO_3–K_2O glass system. *Physica B*, 348(1–4), 46–55.

Sidorowicz, A., Wajler, A., Węglarz, H., Jach, K., Orliński, K., & Olszyna, A. (2016). Thulium oxide nanopowders obtained by precipitation. *International Journal of Applied Ceramic Technology*, 13(2), 302–307.

Silins, A. R. (1995). Defects in glasses. *Radiation Effects and Defects in Solids*, 134(1–4), 7–10.

Singh, G. P., Kaur, S., Kaur, P., & Singh, D. P. P. (2012). Modification in structural and optical properties of ZnO, CeO_2 doped Al_2O_3–PbO–B_2O_3 glasses. *Physica B*, 407, 1250–1255.

Singh, G. P., & Singh, D. P. (2011). Effect of WO_3 on structural and optical properties of CeO_2–PbO–B_2O_3 glasses. *Physica B: Condensed Matter*, 406(3), 640–644.

Singh, G. P., & Singh, D. P. (2012). Modification in structural and optical properties of CeO_2 doped BaO–B_2O_3 glasses. *Journal of Molecular Structure*, 1012, 137–140.

Sreenivasulu, V., Upender, G., Priya, V. V., Mouli, V. C., & Prasad, M. (2014). Raman , DSC , ESR and optical properties of lithium cadmium zinc tellurite glasses. *Physica B: Physics of Condensed Matter*, 454, 60–66.

Srivastava, A. K., & Pyare, R. (2012). Characterization of ZnO substituted 45S5 bioactive glasses and glass - ceramics. *Journal of Materials Science Research*, 1(2), 1–13.

Suib, S. L. (2013). *New and Future Developments in Catalysis: Solar Photocatalysis*.United Kingdom: Elsevier.

Suzuki, C., Kawai, J., Takahashi, M., Vlaicu, A. M., Adachi, H., & Mukoyama, T. (2000). The electronic structure of rare-earth oxides in the creation of the core hole. *Chemical Physics*, 253(1), 27–40.

Tamboli, S. M., Mhaske, S. T., & Kale, D. D. (2004). Crosslinked polyethylene. *Indian Journal of Chemical Technology*, 11(November), 853–864.

Thomas, M. (2013). *Supplementary Cementing Materials in Concrete*. Boca Raton, FL: CRC Press.

Tian, Y., Xu, R., Zhang, L., Hu, L., & Zhang, J. (2010). 1.8μm emission of highly thulium doped fluorophosphate glasses. *Journal of Applied Physics*, 108(8), 0–7.

Tyng, L. Y., Ramli, M. R., Othman, M. B. H., Ramli, R., Ishak, Z. A. M., & Ahmad, Z.

(2012). Effect of crosslink density on the refractive index of a polysiloxane network based on 2,4,6,8-tetramethyl-2,4,6, 8-tetravinylcyclotetrasiloxane. *Polymer International*, 62(3), 382–389.

Umair, M. M., & Yahya, A. K. (2013). Elastic and structural changes of xNa_2O-(35-x)V_2O_5-65TeO_2 glass system with increasing sodium. *Materials Chemistry and Physics*, 142, 549–555.

Upender, G., & Mouli, V. C. (2011). Optical, thermal and electrical properties of ternary TeO_2–WO_3–PbO glasses. *Journal of Molecular Structure*, 1006(1–3), 159–165.

Upender, G., Sameera, C., & Mouli, V. C. (2012). Role of WO_3 on DC conductivity and some optical properties of TeO_2 based glasses. *Materials Research Bulletin*, 47(11), 3764–3769.

Varshneya, A. K.. (1994). *Fundamentals of Inorganic Glasses*. New York: Academic Press, Incorporation.

Varshneya, A. K.. (2013). *Fundamentals of Inorganic Glasses*. San Diego: Elsevier.

Warner, A. W., White, D. L., & Bonner, W. A. (1972). Acousto-optic light deflectors using optical activity in paratellurite. *Journal of Applied Physics*, 43(11), 4489–4495.

Warren, B. E. (1942). The basic principles involved in the glassy state. *Journal of Applied Physics*, 13(10), 602–610.

Weast, R. C., & Lide, D. R. (1989). *CRC Handbook of chemistry and physics : 70th edition 1989-1990*. Boca Raton: CRC Press.

Weber, W. J., Ewing, R. C., Angell, C. A., Arnold, G. W., Delaye, J. M., Hobbs, L. W., & Price, D. L. (1997). Radiation effects in glasses used for immobilization of high-level waste and plutonium disposition. *Journal of Materials Research*, 12(8), 1946–1978.

Wells, A. F. (1975). *Structure of Inorganic Chemistry* (4th ed.). Oxford, UK: Oxford University Press.

Widanarto, W., Sahar, M. R., Ghoshal, S. K., Arifin, R., Rohani, M. S., Hamzah, K., & Jandra, M. (2013). Natural Fe_3O_4 nanoparticles embedded zinc–tellurite glasses: Polarizability and optical properties. *Materials Chemistry and Physics*, 138(1), 174–178.

What is radiation?. (2016). Retrieved from http://world-nuclear.org/nuclear-basics/what-is-radiation.aspx

Xiao, Z., Yan, L., Zhou, B., Zhu, F., Huang, A., Wang, J., & Zhu, Y. (2008). Optical properties of Tm-Er codoped aluminate glasses. *Journal of the Korean Physical Society*, 52(February), 54–57.

Xinjie, F. U., Lixin, S., & Jiacheng, L. I. (2014). Radiation induced color centers in cerium-doped and cerium-free multicomponent silicate glasses. *Journal of Rare Earths*, 32(11), 1037–1042.

Yamauchi, H., Murugan, G. S., & Ohishi, Y. (2005). Optical properties of Er^{3+} and Tm^{3+} ions in a tellurite glass. *Journal of Applied Physics*, 97(43505),1-8.

Yang, F., Liu, C., Wei, D., Chen, Y., Lu, J., & Yang, S. E. (2014). Er^{3+}-Yb^{3+} co-doped TeO_2-PbF_2 oxyhalide tellurite glasses for amorphous silicon solar cells. *Optical Materials*, 36(6), 1040–1043.

Yousef, E., Al-Salami, A. E., Salem, A., & Shaaban, E. R. (2011). Optical and kinetics studies of titanium–zinc–niobium–tellurim oxides glass. *Physica Scripta*, 83(1), 15704.

Yousef, E. S., & Al-Qaisi, B. (2013). UV spectroscopy, refractive indices and elastic properties of the (76-x)TeO_2.9P_2O_5.15ZnO.x$LiNbO_3$. *Solid State Sciences*, 19, 6–11.

Yousef, E. S., El-Adawy, A., El-Khoshkhany, N., & Shaaban, E. R. (2006). Optical and acoustic properties of TeO_2/WO_3 glasses with small amount of additive ZrO_2. *Journal of Physics and Chemistry of Solids*, 67, 1649–1655.

Yu, H. B., Yu, P., Wang, W. H., & Bai, H. Y. (2008). Thulium-based bulk metallic glass. *Applied Physics Letters*, 92(14), 2006–2009.

Zielinska, A. (2011). *Cross-linking and modification of saturated elastomers using function-alized azides*. (Doctoral Dissertation). University of Twente.