PHYSICAL, OPTICAL AND THERMAL PROPERTIES OF ERBIUM-DOPED BOROTELLURITE SILICATE GLASS SYSTEM INCORPORATED WITH SILVER OXIDE

ABDULKARIM MUHAMMAD HAMZA

FS 2019 44

PHYSICAL, OPTICAL AND THERMAL PROPERTIES OF ERBIUM-DOPED BOROTELLURITE SILICATE GLASS SYSTEM INCORPORATED WITH SILVER OXIDE

By

ABDULKARIM MUHAMMAD HAMZA

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

August 2019

DEDICATION

This thesis is dedicated to

my mother; Hajiya Khadijah Abdulkarim Hamza
my father; Alhaji Abdulkarim Hamza Musa II
my step mother; Hajiya Fatima Abdulkarim Hamza and Hauwa Abdulkarim Hamza
my lovely wife; Hauwa Muhammad Aliyu
my daughter; Halimah (Mu'aminah) Muhammad Hamza

my brothers and sisters
my generous and supportive supervisor
my helpful lecturers, lab mates, friends and all the members of staff of the Faculty of Science

I also dedicate this thesis to the poor Nigerians who are suffering in the hands of bad and corrupt leaders

Thank you all for your support and understanding
May God Almighty bless and ease your ways

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

PHYSICAL, OPTICAL AND THERMAL PROPERTIES OF ERBIUM-DOPED BOROTELLURITE SILICATE GLASS SYSTEM INCORPORATED WITH SILVER OXIDE

By

ABDULKARIM MUHAMMAD HAMZA

August 2019

Chairman : Professor Halimah Mohamed Kamari, PhD
Faculty : Science

Four series of rare earth doped borotellurite silicate glass were prepared by melt quenching method. The first and second series are a quaternary erbium oxide and erbium oxide nanoparticles doped glass with chemical composition $\{[(TeO_2)_{0.8} (B_2O_3)_{0.2}]_{0.8} (SiO_2)_{0.2}\}_{1-y} (RE)_y$, y= 0.01, 0.02, 0.03, 0.04, 0.05 molar fraction and RE = Er_2O_3 /Er_2O_3 NPs, while the third and fourth series are a multicomposition $[\{[(TeO_2)_{0.8} (B_2O_3)_{0.2}]_{0.8} (SiO_2)_{0.2}\}_{0.99} (Ag_2O)_{0.01}]_{1-y} (RE)_y$ where y = 0.01, 0.02, 0.03, 0.04, 0.05 molar fraction. This research proposes to extract silica from the rice husk and use it to synthesize a series of selected chemical composition of borotellurite silicate glasses doped with different concentration of Er_2O_3, Er_2O_3 nanoparticles (NPs) and doped with Ag_2O in order to study their effects on the physical, structural, optical and thermal properties. Addition of Ag_2O into the glass composition modifies the optical properties of the glass system. This will go a long way in turning waste into wealth. A novel type of glasses containing rare earth ions and silver ions has recently emerged and already attracted significant attention, the reason for such interest lies in the efficient enhancement of the fluorescent properties in rare earth doped glasses when appropriate silver ions is introduced to it. Results of X-ray diffraction (XRD) confirmed the amorphous nature of the glass. The X-ray fluorescence (XRF) verified the achievement of 98.6% of silicate from rice husk. Fourier transform infrared (FTIR) has revealed the basic structural units such as TeO_4, TeO_3, BO_4, BO_3, Si-O-Si and O-Si-O in the glass system. The presence of erbium nanoparticles in the second and fourth series was verified from transmission emission microscopy (TEM) and the size of the nanoparticles were recorded within the range of 25 – 28 nm and 41 – 50 nm. The differential scanning calorimetry (DSC) measurements indicate a good thermal stability of borotellurite silicate glasses with the values of $T_s > 100$ °C, and the transition temperature, T_g in all the glass series are found to increase from 437 to 511 °C, 447 to 498°C, 452 to 482 °C and 469 to 495 °C with the increasing dopants concentrations in all the four glass series. The four glass series have a Hruby parameter

(H_r) in the range of 0.32 – 0.51, 0.20 – 0.37, 0.55 – 0.64 and 0.47 – 0.64 greater than 0.4 which verified that the glasses were easily formed with moderate quenching rate. The reduced glass transition (T_{rg}) are also within the range of $1/2 - 3/2$. The DSC profiles show an improvement of thermal stability of the glasses with addition of Ag_2O to 273 °C. The theoretical complications in understanding the structures and properties of amorphous solids are amplified by the lack of precise experimental information. Absorption spectrum from near infrared to visible light was obtained and the Judd–Ofelt (J–O) intensity parameters $(\Omega_\lambda, \lambda = 2,4,6)$ were calculated. The calculated values of the parameters fall within the range of (4.178 to 6.507) × 10^{-20}cm^2, (1.384 to 2.143) × 10^{-20}cm^2 and (0.893 to 2.451) × 10^{-20}cm^2 for Ω_2, Ω_4 and Ω_6 respectively. Also, the J-O parameter of Ω_2 decreases from 5.366 × 10^{-20} cm^2 to 4.529 × 10^{-20} cm^2 and Ω_6 from 1.349 × 10^{-20} cm^2 to 1.212 × 10^{-20} cm^2 with increasing Er^{3+} NPs/Ag concentration.

Spontaneous emission probabilities of some important transitions, branching ratio, and radiative lifetimes of some excited states of Er^{3+} and Er^{3+} NPs are predicted using J–O intensity parameters. The branching ratio β for $^4I_{15/2}$-$^2H_{11/2}$, and $^4I_{15/2}$-$^4F_{9/2}$ transitions are within the range 65 – 95% indicating that there is a possibility for red and green emissions. The glass samples with 0.01 Er and 0.01 Er NPs for the two glass series exhibits the smallest value of τ which are 0.025 and 0.204 ms respectively corresponding to $^2H_{11/2} \rightarrow {^4I_{15/2}}$ transition. Absorption cross-section, calculated emission cross-section and gain, were evaluated using the McCumber theory for $^4I_{13/2} \rightarrow {^4I_{15/2}}$ Er^{3+} transition. A schematic energy level diagram is proposed in this work. The full width at half maximum (FWHM), the gain band width (GBW) and figure of merit (FOM) for $^4I_{13/2} \rightarrow {^4I_{15/2}}$ transitions of the glasses have also been studied and reported. All the glass samples show a positive gain above 50% population inversion and the samples exhibit a flat gain bandwidth in the range of 1400 - 1700 nm, which covers the S band (1460 - 1530 nm) and C band (1530 - 1565 nm) in the optical communication window. The gain-bandwidth and gain cross-section profile suggest that these glasses could be found as more promising materials for broadband amplification of both S and C-band signals. The large values of thermal stability of the glass unveils that these glasses are stable against devitrification and are suitable for potential application in fiber drawing. The spectroscopic quality factors in the range of 0.79 – 1.87 and 0.29 – 0.43 for Er_2O_3 and Er_2O_3 NPs doped glasses and 0.48-0.79 and 0.80-0.89 for the glasses incorporated with silver oxide obtained from the Judd-Ofelt parameters suggest the fact that the glasses are suitable for solid state laser application.

The optimum concentration of dopants is achieved is achieved at 0.03 molar fraction as shown in the PL analysis of all the sample glasses. Beyond that concentration, the PL intensity begins to drop with increasing dopant concentration. In view of that, the glasses with 0.03 molar fraction are considered suitable for solid state laser application.

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

SIFAT FIZIKAL, OPTIKAL DAN TERMA SISTEM KACA ERBIUM TERDOP DENGAN BOROTELURIT SILIKA DITAMBAHKAN DENGAN ARGENTUM OKSIDA

Oleh

ABDULKARIM MUHAMMAD HAMZA

Ogos 2019

Pengerusi : Profesor Halimah Mohamed Kamari, PhD
Fakulti : Sains

Empat siri nadir bumi borotelurit kaca didopkan dengan bio-silika telah disediakan dengan kaedah sepuh lindap. Siri pertama dan kedua ialah kaca yang didop erbium oksida dan nanopartikel erbium oksida dengan kandungan komposisi kimia $[[(TeO_2)_{0.8} (B_2O_3)_{0.2}]_{0.8} (SiO_2)_{0.2}\}_{1-y} (RE)_y$, y = 0.01, 0.03, 0.04, 0.05 pecahan molar dan RE = Er_2O_3 / Er_2O_3 NPs, manakala siri ketiga dan keempat ialah komposisi pelbagai jenis kaca $[\{[(TeO_2)_{0.8} (B_2O_3)_{0.2}]_{0.8} (SiO_2)_{0.2}\}_{0.99} (Ag_2O)_{0.01}]_{1-y}$ di mana y = 0.01, 0.02, 0.03, 0.04, 0.05 pecahan molar. Penyelidikan ini telah mencadangkan untuk mengeluarkan silika daripada sekam padi dan menggunakannya untuk mensintesis satu siri komposisi kimia terpilih bagi kaca borotelurit silika yang telah didopkan dengan Ag_2O serta Er_2O_3, Er_2O_3 NPs dengan kepekatan yang berbeza untuk mengkaji kesan mereka terhadap sifat fizikal, struktur, optik dan terma terhadap sistem kaca tersebut. Penambahan Ag_2O ke dalam komposisi kaca mengubah sifat optik pada sistem kaca. Ini akan membantu untuk menukarkan bahan buangan kepada bahan berguna dalam jangka masa yang panjang. Sejenis kaca baharu yang mengandungi ion nadir bumi dan ion perak telah muncul kebelakangan ini serta sudah pun menarik perhatian yang ketara, sebab disebalik perhatian sedemikian terletak pada peningkatan kecekapan sifat pendarfluor dalam kaca yang telah didop nadir bumi apabila ion perak yang sesuai telah diperkenalkan kepadanya. Hasil daripada penyinaran sinar-x (XRD) mengesahkan sifat amorfus kaca yang telah dihasilkan. Pendarfluor X-ray (XRF) mengesahkan pencapaian sehingga 98.6 % silika daripada sekam padi. Transformasi Fourier inframerah (FTIR) telah mendedahkan unit struktur asas sistem kaca seperti TeO_4, TeO_3, BO_4, BO_3, Si-O-Si and O-Si-O. Kehadiran nanopartikel erbium dalam siri kedua dan keempat telah diverifikasi daripada TEM dan saiz nanopartikel dicatatkan dalam lingkungan 25 - 28 nm dan 41 - 50 nm. Pengukuran kalorimetri pengimbang perbezaan (DSC) menunjukkan kestabilan terma yang baik daripada kaca silika dengan nilai T_s> 100 ^oC, dan suhu peralihan, T_g dalam semua siri kaca didapati meningkat dari 437 ke 511^oC, 447 ke 498^oC, 452 ke 482^oC dan 469 ke 495^oC dengan

peningkatan kepekatan dopan. Empat siri kaca mempunyai parameter Hruby dalam julat 0.32 – 0.51, 0.20 – 0.37, 0.55 – 0.64 dan 0.47 – 0.64 yang lebih besar daripada 0.4 yang telah mengesahkan bahawa kaca mudah dibentuk dengan kadar pendinginan sederhana. Peralihan kaca berkurang (T_{rg}) juga dalam julat $1/2 - 3/2$. Profil DSC menunjukkan peningkatan kestabilan terma kaca dengan penambahan Ag_2O hingga 273 ^oC. Komplikasi teori dalam memahami struktur dan sifat pepejal amorfus telah diperbesarkan dengan kekurangan maklumat eksperimen yang tepat. Spektrum penyerapan daripada inframerah berhampiran cahaya nampak telah diperoleh dan parameter intensiti Judd-Ofelt (J-O) ($\Omega_\lambda, \lambda = 2,4,6$) telah dikira. Nilai-nilai yang dikira dari parameter tersebut berada dalam lingkungan (4.178 hingga 6.507) × $10^{-20}cm^2$, (1.384 hingga 2.143) × $10^{-20}cm^2$ dan (0.893 hingga 2.451) × $10^{-20}cm^2$ untuk Ω_2, Ω_4 serta Ω_6. Sebagai tambahan, Ω_2 parameter J-O menurun daripada 5.366 × 10^{-20} cm^2 kepada 4.529 × 10^{-20} cm^2 dan Ω_6 daripada 1.349 × 10^{-20} cm^2 kepada 1.212 × 10^{-20} cm^2 dengan peningkatan kepekatan Er^{3+} NP/Ag. Kebarangkalian pancaran spontan pada beberapa peralihan penting, nisbah cawangan, dan jangka hayat radiasi pada beberapa paras yang teruja pada Er^{3+} dan Er^{3+} NPs telah diramalkan menggunakan parameter intensiti J-O. Nisbah cawangan β untuk peralihan $^4I_{15/2}$-$^2H_{11/2}$, and $^4I_{15/2}$-$^4F_{9/2}$ berada dalam lingkungan 65 - 95% yang menunjukkan kemungkinan terdapatnya pancaran merah dan hijau. Sampel kaca yang mempunyai 0.01 Er dan 0.01 Er NPs bagi kedua-dua siri kaca mempamerkan nilai τ terkecil iaitu 0.025 dan 0.204 ms masing-masing yang bersamaan dengan peralihan $^2H_{11/2} \rightarrow {}^4I_{15/2}$. Keratan silang penyerapan, pengiraan keratan rentas pancaran dan perolehan telah dinilai menggunakan teori McCumber untuk peralihan $^4I_{13/2} \rightarrow {}^4I_{15/2}$ Er^{3+}. Rajah paras tenaga skematik juga telah dicadangkan. Lebar penuh pada separuh maksimum (FWHM), lebar jalur peroleh (GBW) dan angka merit (FOM) untuk $^4I_{13/2} \rightarrow {}^4I_{15/2}$ peralihan kaca juga telah dikaji dan dilaporkan. Semua sampel kaca menunjukkan perolehan positif atas 50% penyongsangan populasi dan sampel memperlihatkan lebar jalur perolehan rata dalam julat 1400 - 1700 nm, yang meliputi jalur S (1460 - 1530 nm) dan jalur C (1530 - 1565 nm) dalam tetingkap komunikasi optik. Perolehan jalur lebar dan perolehan profil keratan rentas menunjukkan bahawa kaca ini berpotensi sebagai bahan penguatan jalur lebar bagi kedua-dua isyarat jalur S dan C. Nilai besar kestabilan terma kaca mengungkapkan bahawa kaca ini stabil terhadap penyusunan dan sesuai untuk aplikasi potensi dalam lukisan serat. Faktor-faktor kualiti spektroskopi dalam lingkungan 0.79 – 1.87 dan 0.29 – 0.43 bagi kaca yang didopkan Er_2O_3 dan Er_2O_3 NPs manakala 0.48-0.79 dan 0.80-0.89 bagi kaca yang telah digabungkan dengan argentum oksida yang diperoleh daripada parameter Judd-Ofelt mencadangkan fakta bahawa kaca yang telah dikaji sesuai untuk aplikasi laser keadaan pepejal.

ACKNOWLEDGEMENTS

Glory be to Allah, the most magnificent, the most merciful. May the blessings of Allah be on to the sealed of Prophets Muhammad (S. A. W).

This thesis would not have been possible without the inspiration and supports of a number of wonderful individuals – my thanks and appreciation to all of them for being part of this journey and making this thesis possible.

First and foremost, I would like to express my heartfelt thanks to my supervisor Prof Dr. Halimah Mohamed Kamari, Dr Farah Muhammad Diana and Dr Chan Kar Tim for all the support and encouragement they gave me during the research and while writing the thesis. Much of this thesis would not have been possible if it were not for their input and vigilant editing.

I would like to thank all the professors I had the privilege to work with and learn from during my time at Universiti Putra Malaysia.

I'm also thankful to Dr Brain Walsh of National Aeronautics and Space Administration USA who provided me with all the necessary materials and information needed for Judd-Ofelt analysis.

Finally, I would like to acknowledge my family and friends who supported me during my time here. First and foremost, I would like to thank my Dad, Mom and step mothers for their unconditional love and support. Last but not the least, I am so thankful to my wife, sisters and brothers, who always stood by my side and gave me complete support throughout my stay at Universiti Putra Malaysia.

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 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: Abdulkarim Muhammad Hamza GS48983

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) were adhered to.

Signature:	______________________
Name of Chairman of Supervisory Committee:	Professor Dr. Halimah Binti Mohamed Kamari

Signature:	______________________
Name of Member of Supervisory Committee:	Dr. Farah Diana Muhammad

Signature:	______________________
Name of Member of Supervisory Committee:	Dr. Chan Kar Tim

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

TeO_2	Tellurium dioxide
B_2O_3	Boron oxide
SiO_2	Silicon oxide
RE	Rare earth
Er_2O_3	Erbium oxide
IR	Infrared
EDFA	Erbium doped fibre amplifiers
FTIR	Fourier Transforms Infrared Spectroscopy
XRD	X-ray diffraction
TEM	Transmission Electron Microscopy
Er^{3+} NPs	Erbium ion nanoparticle
Er^{3+}	Erbium ion
J-O	Judd-Ofelt
Ag_2O	Silver oxide
Ag^+	Silver ion
GBW	Gain band width
FOM	Figure of merit
MIR	Mid infrared
RDFs	Radial distribution functions
PL	Photoluminescence
HCI	Hydrochloric acid
h	Hour
M	Molar
XRF	X-ray fluorescence
μm	Micro meter

DSC	Differential scanning calorimetry
NBO	Non-bridging oxygen
Sm_2O_3	Samarium oxide
eV	Electron volt
Ω_2	Omega two
Ω_4	Omega four
Ω_6	Omega six
M	Metallization criterion
R_m	Molar refraction
V	Molar volume
βn	Nephelauxetic ratios
δ	Bonding parameter
T_g	Transition temperature
T_c	Crystallization temperature
T_m	Melting temperature
T_s	Thermal stability
H_r	Hruby parameter
T_{rg}	Reduced glass transition
F	Thermodynamic fragility
E_a	Activation energy
β	Heating rate
α	Absorption coefficient
λ	Wavelength
d	Thickness of the sample
A	Absorbance
B	Constant related to the extent of the band tailing

E_{opt}	Optical band gap energy
$h\omega$	Incident photon energy
ΔE	Urbach energy
ln	Natural logarithm
K	extinction coefficient
δ_s	Skin depth
σ_c	Optical conductivity
n	Refractive index
NBO	Non-bridging oxygen
BO	Bridging oxygen
χ	Optical electronegativity
α_m	Electronic polarizability
Λ	optical basicity
f_{exp}	Experimental oscillator strength
f_{cal}	Calculated oscillator strength
m	Electron mass
e	Electronic charge
c	Speed of light
N_o	Avogadro's number
ε	Molar extinction coefficient
aJ	Ground state
aJ'	Excited state
X_{md}	Lorentz localize field correction responsible for magnetic dipole transitions
X_{ed}	Lorentz localize field correction responsible for electric dipole transitions
h	Planck's constant

S_{md}	Magnetic dipoles line strength
S_{ed}	Electric dipoles line strength
RMS	Root mean square
$A(J\text{-}J')$	Spontaneous transition probability
A_{ed}	Average electric dipole
A_{md}	Average magnetic dipole
β_r	Branching ratio
τ_r	Radiative lifetime
σ_{abs}	Absorption cross section
σ_{em}	Emission cross section
OD	Optical density
G	Gain
P	Population inversion
Dq	Crystal field strength
R and C	Racah parameters
ESA	Excited state absorption
GSA	Ground state absorption
m_{object}	Mass of object
m_{liquid}	Mass of liquid
ρ_{object}	Density of object
ρ_{liquid}	Density of liquid
w_{object}	Weight of object
w_{liquid}	Weight of liquid
$w_{apparent}$	Apparent weight
REI	Rare earth ion
UV-Vis	Ultra violet visible

FWHM	Full width half maximum
σem_{max}	Peak emission cross section

CHAPTER 1

INTRODUCTION

This chapter deals with the overview of the study that is made up of the basic nature of glass, glass formation process and the chemical compositions used in the glass formation. The chapter also includes the objective of the research, scope of the study, problem statement, hypothesis and the thesis outline.

1.1 Overview

Generally, glasses are formed by melting crystalline material at high temperatures which are afterward rapidly cooled to rigid conditions without crystallization. It is a super cooled liquid with solid form appearance. The glass appearance depends mainly on the rate of cooling (Schawe, 1995). Glasses have irregular and disordered arrangements with short range order in periodic arrangements. Thus, a unit cell is insufficient to describe the glass structure.

Chalcogens are one of the families of interest among glass researchers and tellurium is one among them, along with oxygen, sulphur, and selenium from group VI A of the periodic table. From the year 1980, when glass research begun to be tailored towards the various properties of glasses to be utilized in several application, Tellurite glasses became of special interest to glass researchers. Tellurium dioxide (TeO_2) is the most stable oxide of tellurium (Te). The stability nature of TeO_2 is one of the properties that fascinated researchers to tellurite glasses. Some of the properties of tellurite glasses that enable them to attain stability are their chemical durability, high refractive index, high thermal stability, good non-hygroscopic and low phonon energy (Pandarinath et al., 2016).

Most materials that have borate as one of its constituents, have high propensity for glass formation because B_2O_3 does not crystallize by itself, the glasses have high viscosity. The attention given to borate glasses is due to their electrochemical and optical applications, such as optical waveguides, solid-state batteries and luminescent materials. Borate glass is particularly suitable for optical material due to its high transparency, low melting point, high thermal stability, different coordination numbers, and good solubility of rare-earth ions (Ravi et al., 2015). Pure borate glasses possess low refractive index, high melting point and high phonon energies in the range of 1300–1500 cm^{-1} (Ramadevudu et al., 2017).

Boro-tellurite glasses are formed when tellurite combine with borates. They are intensively studied for their practical applications in terms of enhancing the quality, transparency and refractive index of the glass (Pavani et al., 2011). Borate and tellurite glasses each have a dual coordination numbers of 3 and 4 with oxygens.

As for silica, it can be found in agricultural waste such as rice husk and palm ashvia. The large amount of this waste can be a new source of silica production in Malaysia in contrast to the one produced from quartz or sand by the extraction process. Silica (SiO_2) is an excellent glass former that easily forms glassy phases even at very low melt-quenching rates (Leenakul et al., 2016). Silicate glasses have good transmission to visible light. They are used for windows and bottle containers.

One example is borosilicate glasses which have excellent chemical durability, high resistance and low thermal expansion coefficient. They are used in laboratory, sealed headlights, pharmaceutical containers, pipelines etc. (Zhao et al., 2019).

Currently, doping glasses with rare-earth ions is getting much consideration from researchers across the globe. This is due to the extensive used of the rare-earth ions to improve the optical and physical properties of host glasses because of their unique spectroscopic properties resulting from their optical transitions in the intra 4f shell (Nandi et al., 2009). In addition, it is very essential to know the relationship between the host composition and radiative or non-radiative characters of the RE ions in order to design lasing glasses with high performance (Shen et al., 2007). Quite recently, glasses doped with RE ions are found to be potential in the development of luminescent devices suitable for Infrared (IR) lasers, infra-red to visible up-convertors, fibre and waveguide amplifiers for optical transmission network (Miniscalco, 2001; Xu et al., 2004). Erbium (Er_2O_3) ions are considered to be the most important among all the RE ions, due to their potential applications in the fields of optical fibre amplifiers, microchip lasers, infrared lasers, erbium doped fibre amplifiers (EDFA) in the wavelength division multiplexing (WDM) System, eye-safe lasers in medical fields (Swapna et al., 2015).

1.2 Statements of the research problem

The investigation on the new glass of different compositions so as to obtain the most suitable host glasses that fit in to various applications by researchers have been made for some decades.

Around 90% of rice husk are discarded as waste products and either burned in open air or left to settle in waste ponds which causes damage to the land and environmental pollution. Moreover, the open burning of rice husk can lead to heavy air pollution (Lee et al., 2013). Therefore, useful applications of rice husk are desirable to solve this problem. Extensive several works had been conducted on the extraction of silica from agricultural wastes (e.g. rice husk), because silica is an important raw material for industrial application. Although, silica production from agricultural wastes is relatively less compared to that from quartz or sand, it can still serve the needs of the industries. This research will focus on non-destructive and cost-effective method to utilize rice husk for production of SiO_2 using a dilute hydrochloric acid leaching, instead of the conventional strong acid process. This will go a long way in turning waste into wealth.

Tellurite glasses are of interest for both scientific and technological point of view, because of their exceptional and promising physical properties. While the crystalline structure of solids as well as their physical properties are now understood, the reverse is the case for amorphous materials including glass. The theoretical complications in understanding the structures and properties of amorphous solids are amplified by the lack of precise experimental information. Therefore, there is a need for research to fill this gap.

A novel type of glasses containing both rare earth (RE) ions and Ag ions has recently emerged and already attracted significant attention (Liu et al., 2018). The reason for such interest lies in the efficient enhancement of the fluorescent properties in RE-doped glasses when an appropriate Ag ion is introduced to it.

The possibility of obtaining new laser transition wavelengths for specific applications (such as biomedical, surgery, sensing and data storage) has driven the investigation of laser materials made with rare earths. Laser action has been demonstrated in optical fibres doped with erbium, ytterbium, neodymium, thulium, samarium holmium and praseodymium. Laser action at multiple wavelengths within the same fibre species has also been demonstrated (Nguyen, 2014).

However, there is no information and knowledge on the effect of silver oxide on the thermal properties of erbium and erbium nanoparticles doped borotellurite silicate glass system.

The Judd-Ofelt intensity parameters and spectroscopic properties of erbium oxide, erbium oxide nanoparticles and silver oxide doped borotellurite silicate glass system have never been investigated to reveal their possible application in optical communication and solid state laser. Thus, this research is aimed at the studying the influence of erbium oxide, erbium oxide nanoparticles and silver oxide on the physical, structural, linear optical and thermal properties of borotellurite silicate glasses as well as its potential application in fibre drawing, optical communication window and solid state laser.

1.3 Scope and limitation of this thesis

The scope of this research is limited to the physical, structural, linear optical and thermal properties. For the physical properties, the density of the glass was measured using Archimedes' principle while the molar volume, polaron radius and interionic distance of the glasses were calculated. Fourier Transforms Infrared Spectroscopy (FTIR), X-ray diffraction (XRD) spectroscopy and Transmission Electron Microscopy (TEM) were used to characterize the structural properties of the glasses. The linear optical properties comprise of the optical absorption, band gap energy, refractive index, Urbach energy, electronic polarizability, optical basicity, metallization criterion and electronegativity. Thermal properties (thermal stability, activation energy and Hruby parameters) were also analysed. Additionally, the radiative properties of several excited states of Er^{3+} and Er^{3+} NPs ions in the glass were calculated using J-O parameters. Absorption cross-section and calculated emission cross-section, using the McCumber theory, for the $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition was determined and the spectroscopic properties (gain band width, full width half maximum and figure of merit) were evaluated.

1.4 Significance of the study

The significance of this research will include providing the fundamental bases of new optical glasses with many new applications, particularly borotellurite silicate -based optical fibers. These function and properties are achieved through a simplified melt quenching technique by utilizing a new material as composites in glass. Hence, the significance of the current study is to find a possible solution to some of the aforementioned challenges through synthesizing erbium, erbium nanoparticles and silver oxide doped borotellurite silicate glasses with enhanced thermal, optical and spectroscopic properties.

1.5 Objectives of the study

The main objective of this research is to study the physical, structural, optical and thermal properties of erbium doped borotellurite silicate glass system with silver oxide incorporation. In order to achieve this, five objectives have been designed which are as follows;

1. To extract silica (SiO_2) from rice husk and utilize it to fabricate a borotellurite silicate glasses doped with erbium, erbium nanoparticles and silver oxide.
2. To examine the structural and optical changes in borotellurite silicate glasses doped with erbium/erbium nanoparticles by adding an appropriate mass of silver oxide.
3 To evaluate the radiative properties such as lifetime, branching ratio and transition probabilities of the glass using Judd-Ofelt theory.
4 To determine the emission cross section, spectroscopic properties and gain using McCumber theory.
5 To investigate the thermal properties such as the transition temperature, crystallization temperature, melting temperature, thermodynamic fragility and glass forming ability of the prepared borotellurite silicate glasses.

1.6 Hypothesis

The hypothesis of this research is listed as follows;

1. The glass density of the prepared glass is expected to increase with Er_2O_3 and Er_2O_3 NPs contents. This could be due to the higher molecular weight of Er_2O_3 and Er_2O_3 NPs when compared to TeO_2-B_2O_3-SiO_2 (Umar et al., 2017a).
2. The addition of Er_2O_3, Er_2O_3 NPs and Ag_2O are expected to enhance the linear optical properties of the borotellurite silicate glasses. the energy band gap is expected to decrease with increasing Er_2O_3 and Er_2O_3 NPs concentration and with introduction of and Ag_2O.
3. The incorporation of silver oxide into the glass system would modify the glass structure and increase the refractive index due to the creation of more non-bridging oxygen which has higher polarity than the bridging oxygen (Awang et al., 2013).
4. The Ag^+ ions will play a role of sensitizer; thus, it will clearly promote an efficient energy transfer among the Er^{3+} ions with longer radiative lifetime of the ${}^4I_{13/2}\rightarrow{}^4I_{15/2}$ transition.
5. Bonding nature between Er^{3+} ions and their surrounding ligands would be observed through Judd-Ofelt parameters and bonding parameter. Moreover, the Judd-Ofelt parameters are expected predict the spectroscopic quality of the glasses and as well use to compute the radiative properties of the glass samples.
6. By incorporating Ag_2O in to Er_2O_3 and Er_2O_3 NPs doped borotellurite silicate glass, it is expected that the stimulated emission cross-section, gain band width (GBW) and the figure of merit (FOM) obtained from the McCumber theory would be enhanced.

1.7 Thesis outline

This thesis comprises of six chapters. The first chapter consists of the overview of the research, and short introduction of the individual oxides used in the glass fabrication and their significant roles in the glass compositions. The chapter also focuses on the problem statements, objectives, scope and limitations, significance and expected outcomes of this research. The second chapter gives a brief review of the earlier researches that are related to the present study. These literatures give reports on silica borotellurite glasses, rare-earth doped glasses, erbium doped glasses, physical and structural properties, thermal properties, optical properties, spectroscopic properties, bonding parameters, Judd-Ofelt and McCumber theory. Chapter three gives the existing theories and equations used in this study. The derivation of some theoretical equations are also shown in this chapter. The fourth chapter of this thesis describes the method used in the extraction of silica from rice husk and techniques employed by the conventional melt quenching process for sample fabrication. The chapter also highlights the basic techniques used in this research for sample characterization. Chapter five discusses the analysed results and trends of the findings in the present work. This covers the structural, physical, thermal and non-linear optical properties of the synthesized glasses. Judd-Ofelt analysis, McCumber theory and spectroscopic parameters are also discussed in this chapter. The comparative studies between some of the parameters of the studied glass with the previous researches are also discussed while chapter six summarizes the important findings of this research, with some suggestions and recommendations for future study.

REFERENCES

Abdel-Baki, M., Abdel-Wahab, F. A., Radi, A., & El-Diasty, F. (2007). Factors affecting optical dispersion in borate glass systems. *Journal of Physics and Chemistry of Solids*, *68*(8), 1457-1470.

Abdul Aziz, S. H., El-Mallawany, R., Badaron, S. S., Kamari, H. M., & Amin Matori, K. (2015). Optical properties of erbium zinc tellurite glass system. *Advances in Materials Science and Engineering*, *2015*, 5.

Afef, B., Alqahtani, M. M., Hegazy, H. H., Yousef, E., Damak, K., & Maâlej, R. (2018). Green and near infrared emission of Er^{3+} doped PZS and PZC glasses. *Journal of Luminescence*, *194*, 706-712.

Alazoumi, S. H., Aziz, S. A., El-Mallawany, R., Aliyu, U. S. A., Kamari, H. M., Zaid, M. H. M. M., & Ushah, A. (2018). Optical properties of zinc lead tellurite glasses. *Results in Physics*, *9*, 1371-1376.

Annapoorani, K., Basavapoornima, C., Murthy, N. S., & Marimuthu, K. (2016b). Investigations on structural and luminescence behavior of Er^{3+} doped Lithium Zinc borate glasses for lasers and optical amplifier applications. *Journal of Non-Crystalline Solids*, *447*, 273-282.

Annapoorani, K., Maheshvaran, K., Arun Kumar, S., Murthy, N. S., Soukka, T., & Marimuthu, K. (2015). Structural and spectroscopic behavior of Er^{3+}: Yb^{3+} co-doped lithium telluroborate glasses. *Physica B: Condensed Matter*, *457*, 66-77.

Annapoorani, K., Murthy, N. S., Ravindran, T. R., & Marimuthu, K. (2016a). Influence of Er^{3+} ion concentration on spectroscopic properties and luminescence behavior in Er^{3+} doped strontium telluroborate glasses. *Journal of Luminescence*, *171*, 19-26.

Assadi, A. A., Damak, K., Lachheb, R., Herrmann, A., Yousef, E., Rüssel, C., & Maalej, R. (2015). Spectroscopic and luminescence characteristics of erbium doped TNZL glass for lasing materials. *Journal of Alloys and Compounds*, *620*, 129-136.

Awang, A., Ghoshal, S. K., Sahar, M. R., Dousti, M. R., Amjad, R. J., & Nawaz, F. (2013). Enhanced spectroscopic properties and Judd–Ofelt parameters of Er-doped tellurite glass: Effect of gold nanoparticles. *Current Applied Physics*, *13*(8), 1813-1818.

Azevedo, J., Coelho, J., Hungerford, G., & Hussain, N. S. (2010). Lasing transition ($^4F_{3/2} \rightarrow$ $^4I_{11/2}$) at 1.06 μm in neodymium oxide doped lithium boro tellurite glass. *Physica B: Condensed Matter*, *405*(22), 4696-4701.

Azlan, M. N., Halimah, M. K., & Sidek, H. A. A. (2017a). Linear and nonlinear optical properties of erbium doped zinc borotellurite glass system. *Journal of Luminescence*, *181*, 400-406.

Azlan, M. N., Halimah, M. K., El-Mallawany, R., Faznny, M. F., & Eevon, C. (2017b). Optical properties of zinc borotellurite glass system doped with erbium and erbium nanoparticles for photonic applications. *Journal of Materials Science: Materials in Electronics*, *28*(5), 4318-4327.

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.

Azlan, M. N., Halimah, M. K., Shafinas, S. Z., & Daud, W. M. (2014). Polarizability and optical basicity of Er3+ ions doped tellurite-based glasses. *Chalcogenide letters*, *11*(7), 319-335.

Azuraida, A., Halimah, M. K., Sidek, A. A., Azurahanim, C. A. C., Iskandar, S. M., Ishak, M., & Nurazlin, A. (2015). Comparative studies of bismuth and barium boro-tellurite glass system: Structural and optical properties. *Chalcogenide Letters*, *12*(10), 497-503.

Babu, P., Seo, H. J., Kesavulu, C. R., Jang, K. H., & Jayasankar, C. K. (2009). Thermal and optical properties of Er^{3+}-doped oxyfluorotellurite glasses. *Journal of Luminescence*, *129*(5), 444-448.

Baki, S. O., Tan, L. S., Kan, C. S., Kamari, H. M., Noor, A. S. M., & Mahdi, M. A. (2013). Structural and optical properties of Er^{3+}-Yb^{3+} codoped multicomposition TeO_2-ZnO-PbO-TiO_2-Na_2O glass. *Journal of Non-Crystalline Solids*, *362*, 156-161.

Basavapoornima, C., Linganna, K., Kesavulu, C. R., Ju, S., Kim, B. H., Han, W. T., & Jayasankar, C. K. (2017). Spectroscopic and pump power dependent upconversion studies of Er^{3+}-doped lead phosphate glasses for photonic applications. *Journal of Alloys and Compounds, 699*, 959-968.

Benmadani, Y., Kermaoui, A., Chalal, M., Khemici, W., Kellou, A., & Pelle, F. (2013). Erbium doped tellurite glasses with improved thermal properties as promising candidates for laser action and amplification. *Optical Materials*, *35*(12), 2234-2240.

Berwal, N., Dhankhar, S., Sharma, P., Kundu, R. S., Punia, R., & Kishore, N. (2017). Physical, structural and optical characterization of silicate modified bismuth-borate-tellurite glasses. *Journal of Molecular Structure*, *1127*, 636-644.

Boetti, N. G., Lousteau, J., Chiasera, A., Ferrari, M., Mura, E., Scarpignato, G. C., & Milanese, D. (2012). Thermal stability and spectroscopic properties of erbium-doped niobic-tungsten–tellurite glasses for laser and amplifier devices. *Journal of Luminescence*, *132*(5), 1265-1269.

Bolundut, L., Culea, E., Borodi, G., Stefan, R., Munteanu, C., & Pascuta, P. (2015). Influence of Sm^{3+}: Ag codoping on structural and spectroscopic properties of lead tellurite glass ceramics. *Ceramics International*, *41*(2), 2931-2939.

Brüning, R. (2003). On the glass transition in vitreous silica by differential thermal analysis measurements. *Journal of non-crystalline solids*, *330*(1-3), 13-22.

Brady, G. W. (1957). Structure of tellurium oxide glass. *The Journal of Chemical Physics*, *27*(1), 300-303.

Brady, G. W. (1956). X-Ray study of tellurium oxide glass. *The Journal of Chemical Physics*, *24*(2), 477-477.

Burtan-Gwizdała, B., Reben, M., Cisowski, J., Grelowska, I., Algarni, H., Lisiecki, R., & Nosidlak, N. (2017). Spectroscopic properties of Er^{3+}-doped fluorotellurite glasses containing various modifiers. *Optical Materials*, *73*, 509-516.

Carnall, W. T., Fields, P. R., & Rajnak, K. (1968). Electronic energy levels in the trivalent lanthanide aquo ions. I. Pr^{3+}, Nd^{3+}, Pm^{3+}, Sm^{3+}, Dy^{3+}, Ho^{3+}, Er^{3+}, and Tm^{3+}. *The Journal of Chemical Physics*, *49*(10), 4424-4442.

Chen, H., Liu, Y. H., Zhou, Y. F., & Jiang, Z. H. (2005). Spectroscopic properties of Er^{3+}-doped tellurite glass for 1.55 μm optical amplifier. *Journal of Alloys and Compounds*, *397*(1-2), 286-290.

Cheng, P., Zhou, Y., Su, X., Zhou, M., & Zhou, Z. (2017). The near-infrared band luminescence in silver NPs embedded tellurite glass doped with $Er^{3+}/Tm^{3+}/Yb^{3+}$ ions. *Journal of Alloys and Compounds*, *714*, 370-380.

Chopra, N., Kaur, S., Kaur, M., Singla, S., Marwaha, R., Sharma, G., & Heer, M. S. (2018). Optical, Physical and Structural Properties of Er^{3+} Doped Low-Phonon Energy Vitreous Matrix: ZnO-B_2O_3-TeO_2. *Physica Status Solidi (a)*, 1700934.

Culea, E., Vida-Simiti, I., Borodi, G., Culea, E. N., Stefan, R., & Pascuta, P. (2014). Effects of Er^{3+}: Ag codoping on structural and spectroscopic properties of lead tellurite glass ceramics. *Ceramics International*, *40*(7), 11001-11007.

Damas, P., Coelho, J., Hungerford, G., & Hussain, N. S. (2012). Structural studies of lithium boro tellurite glasses doped with praseodymium and samarium oxides. *Materials Research Bulletin*, *47*(11), 3489-3494.

Davis, E. A., & Mott, N. (1970). Conduction in non-crystalline systems V. Conductivity, optical absorption and photoconductivity in amorphous semiconductors. *Philosophical Magazine*, *22*(179), 0903-0922.

Dimitriev, Y. B., Bursukova, M. A., Kashchieva, E. P., & Gotchev, G. P. (1997). Short-range order in TeO_2-B_2O_3-SiO_2 glasses. *Journal of Materials Science Letters*, *16*(19), 1622-1624.

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. *J. Univ. Chem. Technol. Metall*, *45*(3), 219-250.

Dogra, M., Singh, K. J., Kaur, K., Anand, V., Kaur, P., Singh, P., & Bajwa, B. S. (2018). Investigation of gamma ray shielding, structural and dissolution rate properties of Bi_2O_3-BaO-B_2O_3-Na_2O glass system. *Radiation Physics and Chemistry*, *144*, 171-179.

Dousti, M. R., Sahar, M. R., Ghoshal, S. K., Amjad, R. J., & Samavati, A. R. (2013). Effect of AgCl on spectroscopic properties of erbium doped zinc tellurite glass. *Journal of Molecular Structure*, *1035*, 6-12.

Duffy, J. A. (1990). *Bonding, energy levels and bands in inorganic solids*. New York: Longman.

Duffy, J. A. (1992). Optical basicity of sulfide systems. *Journal of the Chemical Society, Faraday Transactions*, *88*(16), 2397-2400.

Duffy, J. A. (1996). Optical basicity: A practical acid-base theory for oxides and oxyanions. *Journal of Chemical Education*, *73*(12), 1138.

Effendy, N., Wahab, Z. A., Abdul Aziz, S. H., Matori, K. A., Zaid, M. H. M., & Rashid, S. S. A. (2017). Characterization and optical properties of erbium oxide doped ZnO–SLS glass for potential optical and optoelectronic materials. *Materials Express*, *7*(1), 59-65.

Elazoumi, S. H., Sidek, H. A. A., Rammah, Y. S., El-Mallawany, R., Halimah, M. K., Matori, K. A., & Zaid, M. H. M. (2018). Effect of PbO on optical properties of tellurite glass. *Results in Physics*, *8*, 16-25.

El-Deen, L. S., Al Salhi, M. S., & 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., & El-Mallawany, R. (2015). Optical and kinetics parameters of lithium boro-tellurite glasses. *Ceramics International*, *41*(3), 3561-3567.

Elkhoshkhany, N., & Syala, E. (2017a). Kinetic characterization of TeO_2–Bi_2O_3–V_2O_5–Na_2O–TiO_2 glass system. *Ceramics International*, *43*(8), 6156-6162.

Elkhoshkhany, N., & Syala, E. (2018a). Kinetics characterization of erbium-doped tellurite glass. *Ceramics International*, *44*(6), 6829-6835.

Elkhoshkhany, N., Abbas, R., & Khamis, N. M. (2019). Effect of heat treatment on erbium-doped tellurite glass. *Materials Chemistry and Physics*, *221*, 467-476.

Elkhoshkhany, N., Abbas, 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*(9), 14477-14481.

Elkhoshkhany, N., Marzouk, S. Y., & Shahin, S. (2017b). Synthesis and optical properties of new fluoro-tellurite glass within (TeO_2-ZnO-LiF-Nb_2O_5-NaF) system. *Journal of Non-Crystalline Solids*, *472*, 39-45.

Elkhoshkhany, N., Marzouk, S. Y., Moataz, N., & Kandil, S. H. (2018b). Structural and optical properties of TeO_2-Li_2O-ZnO-Nb_2O_5-Er_2O_3 glass system. *Journal of Non-Crystalline Solids*, *500*, 289-301.

El-Mallawany, R. (1992). Structural and vibrational investigations of thermal properties of tellurite glasses. *Journal of materials research*, *7*(1), 224-228.

El-Mallawany, R., & Ahmed, I. A. (2008). Thermal properties of multicomponent tellurite glass. *Journal of Materials Science*, *43*(15), 5131-5138.

Eraiah, B. (2010). Optical properties of lead-tellurite glasses doped with samarium trioxide. *Bulletin of Materials Science*, *33*(4), 391-394.

European Society of Computational Methods in Science and Engineering. (2004). Computational aspects of electric polarizability calculations: Atoms, molecules and clusters. New York: IOS Press.

Faizul, C. P., Abdullah, C., & Fazlul, B. (2013). Extraction of silica from palm ashvia citric acid leaching treatment. *Advances in Environmental Biology*, *7*(12), 3690-3695.

Fang, Y., Hu, L., Wen, L., & Liao, M. (2007). Judd–Ofelt intensity parameters of Er^{3+} doped mixed alkali aluminophosphate glasses. *Journal of Alloys and Compounds*, *431*(1-2), 246-249.

Fares, H., Elhouichet, H., Gelloz, B., & Férid, M. (2015). Surface plasmon resonance induced Er^{3+} photoluminescence enhancement in tellurite glass. *Journal of Applied Physics*, *117*(19), 193102.

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.

Fudzi, F. M., Kamari, H. M., Muhammad, F. D., Latif, A. A., & Ismail, Z. (2018). Structural and Optical Properties of Zinc Borotellurite Glass Co-Doped with Lanthanum and Silver Oxide. *Journal of Materials Science and Chemical Engineering*, *6*(04), 18.

Gaafar, M. S., & Marzouk, S. Y. (2017). Judd–Ofelt analysis of spectroscopic properties of Er^{3+} doped TeO_2-BaO-ZnO glasses. *Journal of Alloys and Compounds*, *723*, 1070-1078.

Gao, F., & Zhang, S. (1997). Investigation of mechanism of nephelauxetic effect. *Journal of Physics and Chemistry of Solids*, *58*(12), 1991-1994.

Gelija, D., Kadathala, L., & Borelli, D. P. R. (2018). Energy transfer dynamics of Er^{3+}/Nd^{3+} embedded SiO_2-Al_2O_3-Na_2CO_3-SrF_2-CaF_2 glasses for optical communications. *Optical Materials*, *78*, 172-180.

Giridhar, G., Sastry, S. S., & Rangacharyulu, M. (2011). Spectroscopic studies on Pb_3O_4–ZnO–P_2O_5 glasses doped with transition metal ions. *Physica B: Condensed Matter*, *406*(21), 4027-4030.

Gomes, J. F., Lima, A. M. O., Sandrini, M., Medina, A. N., Steimacher, A., Pedrochi, F., & Barboza, M. J. (2017). Optical and spectroscopic study of erbium doped calcium borotellurite glasses. *Optical Materials*, *66*, 211-219.

Goyal, P., Sharma, Y. K., Pal, S., Bind, U. C., Huang, S. C., & Chung, S. L. (2017). The effect of SiO_2 content on structural, physical and spectroscopic properties of Er^{3+} doped B_2O_3–SiO_2–Na_2O–PbO–ZnO glass systems. *Journal of Non-Crystalline Solids*, *463*, 118-127.

Gupta, N., Khanna, A., Gonzàlez, F., & Iordanova, R. (2017). Thermal characteristics, Raman spectra, optical and structural properties of TiO_2-Bi_2O_3-B_2O_3-TeO_2 glasses. In *AIP Conference Proceedings* (Vol. 1832, No. 1, p. 070005). AIP Publishing.

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

Hajer, S. S., Halimah, M. K., Zakaria, A., & Azlan, M. N. (2016). Effect of samarium nanoparticles on optical properties of zinc borotellurite glass system. In *Materials Science Forum* (Vol. 846, pp. 63-68). Trans Tech Publications.

Halimah, M. K., & Eevon, C. (2019). Comprehensive study on the effect of Gd_2O_3 NPs on elastic properties of zinc borotellurite glass system using non-destructive ultrasonic technique. *Journal of Non-Crystalline Solids*, *511*, 10-18.

Halimah, M. K., Azlan, M. N., & Shafinas, S. Z. (2015). Optical properties of erbium doped borotellurite glass system. In *Advanced Materials Research* (Vol. 1112, pp. 7-10). Trans Tech Publications.

Halimah, M. K., Daud, W. M., Sidek, H. A. A., Zaidan, A. W., & Zainal, A. S. (2010). Optical properties of ternary tellurite glasses. *Mater. Sci. Pol*, *28*(1), 173.

Halimah, M. K., Faznny, M. F., Azlan, M. N., & Sidek, H. A. A. (2017). Optical basicity and electronic polarizability of zinc borotellurite glass doped La^{3+} ions. *Results in Physics*, *7*, 581-589.

Halimah, M. K., Hazlin, M. A., & Muhammad, F. D. (2018). Experimental and theoretical approach on the optical properties of zinc borotellurite glass doped with dysprosium oxide. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *195*, 128-135.

Hamza, A. M., Halimah, M. K., Muhammad, F. D., & Chan, K. T. (2019). Physical Properties, Ligand Field and Judd-Ofelt Intensity Parameters of Bio-silicate Borotellurite Glass System Doped with Erbium Oxide. *Journal of Luminescence*, 207, 497-506.

Hamzaoui, M., Soltani, M. T., Baazouzi, M., Tioua, B., Ivanova, Z. G., Lebullenger, R., & Zavadil, J. (2012). Optical properties of erbium doped antimony-based glasses: Promising visible and infrared amplifiers materials. *physica status solidi (b)*, *249*(11), 2213-2221.

Hassan, M. A. (2013). Effect of halides addition on the ligand field of chromium in alkali borate glasses. *Journal of Alloys and Compounds*, *574*, 391-397.

Hassanien, A. S., & Akl, A. A. (2015). Influence of composition on optical and dispersion parameters of thermally evaporated non-crystalline $Cd_{50}S_{50}-$ xSex thin films. *Journal of Alloys and Compounds*, *648*, 280-290.

Hazlin, M. A., Halimah, M. K., & Muhammad, F. D. (2018). Absorption and emission analysis of zinc borotellurite glass doped with dysprosium oxide nanoparticles for generation of white light. *Journal of Luminescence*, *196*, 498-503.

Henrie, D. E., Fellows, R. L., & Choppin, G. R. (1976). Hypersensitivity in the electronic transitions of lanthanide and actinide complexes. *Coordination Chemistry Reviews*, *18*(2), 199-224.

Herzfeld, K. F. (1927). On atomic properties which make an element a metal. *Physical Review*, *29*(5), 701.

Hocdé, S., Jiang, S., Peng, X., Peyghambarian, N., Luo, T., & Morrell, M. (2004). Er^{3+} doped boro-tellurite glasses for 1.5 μm broadband amplification. *Optical Materials*, *25*(2), 149-156.

Huang, B., Zhou, Y., Yang, F., Wu, L., Qi, Y., & Li, J. (2016). The 1.53 μm spectroscopic properties of $Er^{3+}/Ce^{3+}/Yb^{3+}$ tri-doped tellurite glasses containing silver nanoparticles. *Optical Materials*, *51*, 9-17.

Hussain, N. S., El-Mallawany, R., Hungerford, G., Gomes, M. J. M., Mendiratta, S. K., Santos, J. D., & Buddhudu, S. (2008). Optical Properties of Rare-Earth Ions Doped Lithium Boro Tellurite Glasses. *Physics and Chemistry of Rare-Earth Ions Doped Glasses*.

Ibrahim, S. E., Rammah, Y. S., Hager, I. Z., & El-Mallawany, R. (2018). UV and electrical properties of TeO_2-WO_3-Li_2O-Nb_2O_5/Sm_2O_3/Pr_6O_{11}/Er_2O_3 glasses. *Journal of Non-Crystalline Solids*, 498, 443-447.

Inoue, H., Soga, K., & Makishima, A. (2002). Simulation of the optical properties of Er: ZBLAN glass. *Journal of non-crystalline solids*, *298*(2-3), 270-286.

Jaba, N., Mansour, H. B., Kanoun, A., Brenier, A., & Champagnon, B. (2009). Spectral broadening and luminescence quenching of 1.53 μm emission in Er^{3+}-doped zinc tellurite glass. *Journal of Luminescence*, *129*(3), 270-276.

Jayachandraiah, C., & Krishnaiah, G. (2015). Erbium induced raman studies and dielectric properties of Er-doped ZnO nanoparticles. *Adv. Mater. Lett*, *6*(8), 743-748.

Jlassi, I., Elhouichet, H., & Ferid, M. (2011). Thermal and optical properties of tellurite glasses doped erbium. *Journal of Materials Science*, *46*(3), 806-812.

Jlassi, I., Elhouichet, H., Ferid, M., & Barthou, C. (2010). Judd–Ofelt analysis and improvement of thermal and optical properties of tellurite glasses by adding P_2O_5. *Journal of Luminescence*, *130*(12), 2394-2401.

Jlassi, I., Elhouichet, H., Hraiech, S., & Ferid, M. (2012). Effect of heat treatment on the structural and optical properties of tellurite glasses doped erbium. *Journal of Luminescence*, *132*(3), 832-840.

Jlassi, I., Fares, H., & Elhouichet, H. (2018). Enhancement of spectroscopic and luminescence properties of Er^{3+} doped tellurite glasses by adding P_2O_5 for lasing materials. *Journal of Luminescence*, *194*, 569-578.

Joshi, P., Shen, S., & Jha, A. (2008). Er^{3+}-doped boro-tellurite glass for optical amplification in the 1530–1580 nm. *Journal of Applied Physics*, *103*(8), 083543.

Kaky, K. M., Lakshminarayana, G., Baki, S. O., Lira, A., Caldiño, U., Meza-Rocha, A. N & Mahdi, M. A. (2017). Structural and optical studies of Er^{3+}-doped alkali/alkaline oxide containing zinc boro-aluminosilicate glasses for 1.5 μm optical amplifier applications. *Optical Materials*, *69*, 401-419.

Kaky, K. M., Sayyed, M. I., Laariedh, F., Abdalsalam, A. H., Tekin, H. O., & Baki, S. O. (2019). Stuctural, optical and radiation shielding properties of zinc boro-tellurite alumina glasses. *Applied Physics A*, *125*(1), 32.

Kaminskii, A. A., Schultze, D., Hermoneit, B., Sarkisov, S. E., Li, L., Bohm, J., & Balashov, V. A. (1976). Spectroscopic properties and stimulated emission in the $^4F_{3/2} \rightarrow {}^4I_{11/2}$ and $^4F_{3/2} \rightarrow {}^4I_{13/2}$ transitions of Nd^{3+} ions from cubic $Bi_4Ge_3O_{12}$ crystals. *Physica Status Solidi (a)*, *33*(2), 737-753.

Karthikeyan, P., Suthanthirakumar, P., Vijayakumar, R., & Marimuthu, K. (2015a). Structural and luminescence behaviour of Er^{3+} doped telluro-fluoroborate glasses. *Journal of Molecular Structure*, *1083*, 268-277.

Karthikeyan, P., Suthanthirakumar, P., Vijayakumar, R., & Marimuthu, K. (2015b, June). Investigations on structural and optical behavior of Er^{3+} doped lead boro-tellurite glasses. In *AIP Conference Proceedings* (Vol. 1665, No. 1, p. 070008). AIP Publishing.

Kashif, I., Ratep, A., & Adel, G. (2018). Polarizability, optical basicity and optical properties of SiO_2-B_2O_3-Bi_2O_3-TeO_2 glass system. *Applied Physics A*, *124*(7), 486.

Kaur, S., Pandey, O. P., Jayasankar, C. K., & Chopra, N. (2019). Spectroscopic, thermal and structural investigations of Dy^{3+} activated zinc borotellurite glasses and nano-glass-ceramics for white light generation. *Journal of Non-Crystalline Solids*, *521*, 119472.

Kaur, N., & Khanna, A. (2014). Structural characterization of borotellurite and alumino-borotellurite glasses. *Journal of Non-Crystalline Solids*, *404*, 116-123.

Kaur, A., Khanna, A., Kaur, A., Gonzàlez-Barriuso, M., & Gonzàlez, F. (2018). Effects of annealing on density, glass transition temperature and structure of tellurite, silicate and borate glasses. *Journal of Non-Crystalline Solids*, *500*, 443-452.

Kesavulu, C. R., Kim, H. J., Lee, S. W., Kaewkhao, J., Wantana, N., Kothan, S., & Kaewjaeng, S. (2016). Influence of Er^{3+} ion concentration on optical and photoluminescence properties of Er^{3+}-doped gadolinium-calcium silica borate glasses. *Journal of Alloys and Compounds*, *683*, 590-598.

Kira, M., & Koch, S. W. (2005). Microscopic theory of optical excitations, photoluminescence, and terahertz response in semiconductors. *The European Physical Journal D-Atomic, Molecular, Optical and Plasma Physics*, *36*(2), 143-157.

Kissinger, H. E. (1956). Variation of peak temperature with heating rate in differential thermal analysis. *Journal of research of the National Bureau of Standards*, *57*(4), 217-221.

Kissinger, H. E. (1957). Reaction kinetics in differential thermal analysis. *Analytical Chemistry*, *29*(11), 1702-1706.

Krogh-Moe, J. (1962). Structural interpretation of melting point depression in the sodium borate system. *Phys. Chem. Glasses*, *3*(4), 101-110.

Kumar, S., & Singh, K. (2012). Glass transition, thermal stability and glass-forming tendency of Se_{90}− xTe_5Sn_5Inx multi-component chalcogenide glasses. *Thermochimica acta*, *528*, 32-37.

Kupracz, P., Karczewski, J., Prześniak-Welenc, M., Szreder, N. A., Winiarski, M. J., Klimczuk, T., & Barczy'nski, R. J. (2015). Microstructure and electrical properties of manganese borosilicate glasses. *Journal of Non-Crystalline Solids*, *423*, 68-75.

Lakshminarayana, G., Baki, S. O., Kaky, K. M., Sayyed, M. I., Tekin, H. O., Lira, A., & Mahdi, M. A. (2017c). Investigation of structural, thermal properties and shielding parameters for multicomponent borate glasses for gamma and neutron radiation shielding applications. *Journal of Non-Crystalline Solids*, *471*, 222-237.

Lakshminarayana, G., Baki, S. O., Lira, A., Kityk, I. V., & Mahdi, M. A. (2017a). Structural, thermal, and optical absorption studies of Er^{3+}, Tm^{3+}, and Pr^{3+}-doped borotellurite glasses. *Journal of Non-Crystalline Solids*, *459*, 150-159.

Lakshminarayana, G., Kaky, K. M., Baki, S. O., Lira, A., Nayar, P., Kityk, I. V., & Mahdi, M. A. (2017b). Physical, structural, thermal, and optical spectroscopy studies of TeO2–B2O3–MoO_3–ZnO–R_2O (R= Li, Na, and K)/MO (M= Mg, Ca, and Pb) glasses. *Journal of Alloys and Compounds*, *690*, 799-816.

Langar, A., Bouzidi, C., Elhouichet, H., & Férid, M. (2014). Er–Yb codoped phosphate glasses with improved gain characteristics for an efficient 1.55 µm broadband optical amplifiers. *Journal of Luminescence*, *148*, 249-255.

Lee, T., Othman, R., & Yeoh, F. Y. (2013). Development of photoluminescent glass derived from rice husk. *Biomass and Bioenergy*, *59*, 380-392.

Leenakul, W., Tunkasiri, T., Tongsiri, N., Pengpat, K., & Ruangsuriya, J. (2016). Effect of sintering temperature variations on fabrication of $45S_5$ bioactive glass-ceramics using rice husk as a source for silica. *Materials Science and Engineering: C*, *61*, 695-704.

Linda, D., Duclère, J. R., Hayakawa, T., Dutreilh-Colas, M., Cardinal, T., Mirgorodsky, A., & Thomas, P. (2013). Optical properties of tellurite glasses elaborated within the TeO_2–Tl_2O–Ag_2O and TeO_2–ZnO–Ag_2O ternary systems. *Journal of Alloys and Compounds*, *561*, 151-160.

Lines, M. E., & Glass, A. M. (2001). *Principles and applications of ferroelectrics and related materials*. Oxford: Clarendon Press.

Liu, Q., Tian, Y., Tang, W., Jing, X., Zhang, J., & Xu, S. (2018). Comprehensive studies of the Ag^+ effect on borosilicate glass ceramics containing Ag nanoparticles and Er-doped hexagonal $NaYF_4$ nanocrystals: morphology, structure, and 2.7 μm emission. *Nanophotonics*, *7*(5), 913-923.

Lourenco, S. A., Dantas, N. O., Serqueira, E. O., Ayta, W. E. F., Andrade, A. A., Filadelpho, M. C., & Pereira-da-Silva, M. A. (2011). Eu^{3+} photoluminescence enhancement due to thermal energy transfer in Eu_2O_3-doped SiO_2–B_2O_3–PbO_2 glasses system. *Journal of Luminescence*, *131*(5), 850-855.

Lüthi, B. (1980). Crystal field effects in rare earth systems. *Journal of Magnetism and Magnetic Materials*, *15*, 1-8.

M., & Ushah, A. (2018). Optical properties of zinc lead tellurite glasses. *Results in Physics*, *9*, 1371-1376.

Maaoui, A., Haouari, M., Bulou, A., Boulard, B., & Ouada, H. B. (2018). Effect of BaF_2 on the structural and spectroscopic properties of Er^{3+}/Yb^{3+} ions codoped fluoro-tellurite glasses. *Journal of Luminescence*, *196*, 1-10.

Maheshvaran, K., Arunkumar, S., Krishnaiah, K. V., & Marimuthu, K. (2015). Investigations on luminescence behavior of Er^{3+}/Yb^{3+} co-doped boro-tellurite glasses. *Journal of Molecular Structure*, *1079*, 130-138.

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.

Mahraz, Z. A. S., Sahar, M. R., & Ghoshal, S. K. (2014a). Band gap and polarizability of boro-tellurite glass: influence of erbium ions. *Journal of Molecular Structure*, *1072*, 238-241.

Mahraz, Z. A. S., Sahar, M. R., & Ghoshal, S. K. (2014b). Improved chemical durability and thermal stability of zinc boro-tellurite glass. *Chalcogenide Lett*, *11*, 453-460.

Mahraz, Z. A. S., Sahar, M. R., & Ghoshal, S. K. (2017). Reduction of non-radiative decay rates in boro-tellurite glass via silver nanoparticles assisted surface plasmon impingement: Judd Ofelt analysis. *Journal of Luminescence*, *190*, 335-343.

Mahraz, Z. A. S., Sahar, M. R., & Ghoshal, S. K. (2018). Near-infrared up-conversion emission from erbium ions doped amorphous tellurite media: Judd-Ofelt evaluation. *Journal of Alloys and Compounds*, *740*, 617-625.

Mahraz, Z. A. S., Sahar, M. R., Ghoshal, S. K., & Dousti, M. R. (2013b). Concentration dependent luminescence quenching of Er^{3+}-doped zinc boro-tellurite glass. *Journal of Luminescence*, *144*, 139-145.

Mahraz, Z. A. S., Sahar, M. R., Ghoshal, S. K., Dousti, M. R., & Amjad, R. J. (2013a). Silver nanoparticles enhanced luminescence of Er^{3+} ions in boro-tellurite glasses. *Materials Letters*, *112*, 136-138.

Mariyappan, M., Marimuthu, K., Sayyed, M. I., Dong, M. G., & Kara, U. (2018). Effect Bi2O3 on the physical, structural and radiation shielding properties of Er^{3+} ions doped bismuth sodium fluoroborate glasses. *Journal of Non-Crystalline Solids*, *499*, 75-85.

Maroulis, G. (2006). Computational aspects of electric polarizability calculations: Atoms, molecules and clusters. Amsterdam: IOS Press.

Mattarelli, M., Montagna, M., Moser, E., Vishnubhatla, K. C., Armellini, C., Chiasera, A., & Righini, G. C. (2007). Silver to erbium energy transfer in phosphate glasses. *Journal of Non-Crystalline Solids*, *353*(5-7), 498-501.

Mhareb, M. H. A., Hashim, S., Ghoshal, S. K., Alajerami, Y. S. M., Saleh, M. A., Dawaud, R. S., & Azizan, S. A. B. (2014). Impact of Nd^{3+} ions on physical and optical properties of Lithium Magnesium Borate glass. *Optical Materials*, *37*, 391-397.

Miguel, A., Morea, R., Gonzalo, J., Arriandiaga, M. A., Fernández, J., & Balda, R. (2013). Near-infrared emission and upconversion in Er^{3+}-doped TeO_2–ZnO–ZnF_2 glasses. *Journal of Luminescence*, *140*, 38-44.

Miniscalco, W. J. (2001). Optical and electronic properties of rare earth ions in glasses. Optical engineering-New york-marcel dekker incorporated-, 71, 17-112.

Mohamed, E. A., Ahmad, F., & Aly, K. A. (2012). Effect of lithium addition on thermal and optical properties of zinc–tellurite glass. *Journal of Alloys and Compounds*, *538*, 230-236.

Mohd Fudzi, F., Mohamed Kamari, H., Abd Latif, A., & Muhammad Noorazlan, A. (2017). Linear Optical Properties of Zinc Borotellurite Glass Doped with Lanthanum Oxide Nanoparticles for Optoelectronic and Photonic Application. *Journal of Nanomaterials*, 4150802, 1-8.

Morrison, M. A., Estle, T. L., & Lane, N. F. (1976). *Quantum states of atoms, molecules, and solids*. Englewood Cliffs, N.J: Prentice-Hall.

Moustafa, S. Y., Sahar, M. R., & Ghoshal, S. K. (2016). Erbium ions oscillator strength and emission enhancement in antimony phosphate amorphous matrix. *Journal of Non-Crystalline Solids*, *433*, 87-94.

Moustafa, S. Y., Sahar, M. R., & Ghoshal, S. K. (2017). Comprehensive thermal and structural characterization of antimony-phosphate glass. *Results in physics*, *7*, 1396-1411.

Mustafa, I. S., Razali, N. A. N., Ibrahim, A. R., & Kamari, H. M. (2015). From rice husk to transparent radiation protection material. *J. Intelek*, *9*(2), 1.

Nandi, P., Srinivasan, A., & Jose, G. (2009). Structural dependent thermal and optical properties of rare earth doped glass with mixed glass formers. *Optical Materials*, *31*(4), 653-659.

Nazrin, S. N., Halimah, M. K., Muhammad, F. D., Yip, J. S., Hasnimulyati, L., Faznny, M. F., & Zaitizila, I. (2018). The effect of erbium oxide in physical and structural properties of zinc tellurite glass system. *Journal of Non-Crystalline Solids*, *490*, 35-43.

Nguyen, T. B. (2004). *Determining rare earth dopant concentrations in optical fibres and waveguides* (Doctoral dissertation, Victoria University of Technology).

Nian, S., Zhang, Y., Cao, W., Wu, Z., Tang, J., Li, M., ... & Shu, Y. (2018). Optical properties of Er^{3+}/Yb^{3+} co-doped bismuth calcium borate glass system for NIR lasers and fiber amplifiers. *Journal of Luminescence*, *194*, 440-445.

Noorazlan, A. M., Kamari, H. M., Baki, S. O., & Mohamad, D. W. (2015). Green emission of tellurite based glass containing erbium oxide nanoparticles. *Journal of Nanomaterials*, *16*(1), 407.

Noorazlan, A. M., Kamari, H. M., Zulkefly, S. S., & Mohamad, D. W. (2013). Effect of erbium nanoparticles on optical properties of zinc borotellurite glass system. *Journal of Nanomaterials*, *2013*, 168.

Novatski, A., Somer, A., Gonçalves, A., Piazzetta, R. L., Gunha, J. V., Andrade, A. V. C., & El-Mallawany, R. (2019). Thermal and Optical Properties of Lithium-Zinc-Tellurite Glasses. *Materials Chemistry and Physics, 231*, 150-158.

Obadina, V. O., & Reddy, B. R. (2013). Investigation of silver nanostructures and their influence on the fluorescence spectrum of erbium-doped glasses. *Optics and Photonics Journal*, *3*(01), 45.

Ofelt, G. S. (1962). Intensities of crystal spectra of rare-earth ions. *The Journal of Chemical Physics*, *37*(3), 511-520.

Oo, H. M., Mohamed-Kamari, H., & Wan-Yusoff, W. M. D. (2012). Optical properties of bismuth tellurite based glass. *International journal of molecular sciences*, *13*(4), 4623-4631.

Pal, I., Sanghi, S., Agarwal, A., & Aggarwal, M. P. (2012). Spectroscopic and structural investigations of Er^{3+} doped zinc bismuth borate glasses. *Materials Chemistry and Physics*, *133*(1), 151-158.

Pan, Z., & Morgan, S. H. (1997). Raman spectra and thermal analysis of a new lead–tellurium–germanate glass system. *Journal of Non-crystalline Solids*, *210*(2-3), 130-135.

Pandarinath, M. A., Upender, G., Rao, K. N., & Babu, D. S. (2016). Thermal, optical and spectroscopic studies of boro-tellurite glass system containing ZnO. *Journal of Non-Crystalline Solids*, *433*, 60-67.

Pascuta, P., Pop, L., Rada, S., Bosca, M., & Culea, E. (2008). The local structure of bismuth borate glasses doped with europium ions evidenced by FT-IR spectroscopy. *Journal of Materials Science: Materials in Electronics*, *19*(5), 424-428.

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

Paz, E. C., Dias, J. D. M., Melo, G. H. A., Lodi, T. A., Carvalho, J. O., Façanha Filho, P. F., & Steimacher, A. (2016). Physical, thermal and structural properties of Calcium Borotellurite glass system. *Materials Chemistry and Physics*, *178*, 133-138.

Peng, Y., Yuan, X., Zhang, L., Yan, P., Zhang, W., & Ruan, S. (2019). Efficient improvement of 2.7 μm luminescence of Er^{3+}: oxyfluorideglass containing gallium by Yb^{3+} ions codoping. *Journal of Rare Earths* 37(5), 487-491.

Prabhu, N. S., Hegde, V., Sayyed, M. I., Şakar, E., & Kamath, S. D. (2019). Investigations on the physical, structural, optical and photoluminescence behavior of Er^{3+} ions in Lithium Zinc Fluoroborate glass system. *Infrared Physics & Technology*. 98, 7-15.

Raju, K. V., Raju, C. N., Sailaja, S., & Reddy, B. S. (2013). Judd–Ofelt analysis and photoluminescence properties of RE^{3+} (RE= Er & Nd): cadmium lithium boro tellurite glasses. *Solid State Sciences*, *15*, 102-109.

Rakpanich, S., Kaewkhao, J., Boonin, K., Park, J., Kim, H. J., & Limsuwan, P. (2013). Spectroscopic Studies of $50Bi_2O_3$-(50-x) B_2O_3-xSm_2O_3 Glasses System. *New Journal of Glass and Ceramics*, *3*(01), 6.

Ramadevudu, G., Chary, M. N., & Shareefuddin, M. (2017). Physical and spectroscopic studies of Cr^{3+} doped mixed alkaline earth oxide borate glasses. *Materials Chemistry and Physics*, *186*, 382-389.

Rasmussen, S. C. (2012). *How Glass Changed the World: The History and Chemistry of Glass from Antiquity to the 13th Century*. Springer Science & Business Media.

Ravi, O., Dhoble, S. J., Ramesh, B., Devarajulu, G., Reddy, C. M., Linganna, K., & Raju, B. D. P. (2015). NIR fluorescence spectroscopic investigations of Er^{3+}-ions doped borate based tellurium calcium zinc niobium oxide glasses. *Journal of Luminescence*, *164*, 154-159.

Ravi, O., Reddy, C. M., Manoj, L., & Raju, B. D. P. (2012). Structural and optical studies of Sm^{3+} ions doped niobium borotellurite glasses. *Journal of Molecular Structure*, *1029*, 53-59.

Rayappan, I. A., & Marimuthu, K. (2013). Luminescence spectra and structure of Er^{3+} doped alkali borate and fluoroborate glasses. *Journal of Physics and Chemistry of Solids*, *74*(11), 1570-1577.

Razali, N. A. N., Mustafa, I. S., Azman, N. Z. N., Kamari, H. M., Rahman, A. A., Rosli, K., & Tajuddin, N. A. (2018, August). The Physical and Optical Studies of Erbium Doped Borosilicate Glass. In *Journal of Physics: Conference Series* (Vol. 1083, No. 1, p. 012004). IOP Publishing.

Reddy, D. K., Taherunnisa, S., Prasanna, A. L., Rao, T. S., Veeraiah, N., & Reddy, M. R. (2019). Enhancement of the red emission of Eu^{3+} by Bi^{3+} sensitizers in yttrium alumino bismuth borosilicate glasses. *Journal of Molecular Structure*, *1176*, 133-148.

Reddy, K. S. R. K., Swapna, K., Mahamuda, S., Venkateswarlu, M., Prasad, M. S., Rao, A. S., & Prakash, G. V. (2018). Structural, optical absorption and photoluminescence spectral studies of Sm^{3+} ions in Alkaline-Earth Boro Tellurite glasses. *Optical Materials*, *79*, 21-32.

Reddy, R. R., Ahammed, Y. N., Gopal, K. R., & Raghuram, D. V. (1998). Optical electronegativity and refractive index of materials. *Optical materials*, *10*(2), 95-100.

Rijal, S. (2017). *Effect of Host Glass and Semiconducting Nanoarticles on the Optical Properties of Rare Earth Ions in Lead/Bismuth Telluroborate Glasses*. Western Illinois University. M.Sc Dissertation.

Rivera, V. A. G., & Barbosa, L. C. (2014). Spectroscopic properties of Er^{3+}-doped sodium-modified tellurite glasses for use as optical amplifiers at 1540 nm. *Journal of Luminescence*, *156*, 116-123.

Rodin, N. L. A., & Sahar, M. R. (2018). Erbium doped sodium magnesium boro-tellurite glass: Stability and Judd-Ofelt analysis. *Materials Chemistry and Physics*, *216*, 177-185.

Rodrigues, A. M., Narváez-Semanate, J. L., Cabral, A. A., & Rodrigues, A. C. M. (2013). Determination of crystallization kinetics parameters of a Li1. 5Al0. 5Ge1. 5 $(PO_4)_3$ (LAGP) glass by differential scanning calorimetry. *Materials Research*, *16*(4), 811-816.

Rolli, R., Montagna, M., Chaussedent, S., Monteil, A., Tikhomirov, V. K., & Ferrari, M. (2003). Erbium-doped tellurite glasses with high quantum efficiency and broadband stimulated emission cross section at 1.5 μm. *Optical materials*, *21*(4), 743-748.

Ross, M. (1972). On the Herzfeld theory of metallization. Application to rare gases, alkali halides, and diatomic molecules. *The Journal of Chemical Physics*, *56*(9), 4651-4653.

Sabadel, J. C., Armand, P., Cachau-Herreillat, D., Baldeck, P., Doclot, O., Ibanez, A., & Philippot, E. (1997). Structural and nonlinear optical characterizations of tellurium oxide-based glasses: TeO_2–BaO–TiO_2. *Journal of Solid State Chemistry*, *132*(2), 411-419.

Saddeek, Y. B., El-Maaref, A. A., Moustafa, M. G., El-Okr, M. M., & Showahy, A. A. (2018). A comprehensive study of electrical and optical properties of phosphate oxide-based glasses doped with Er_2O_3. *Journal of Materials Science: Materials in Electronics*, *29*(12), 9994-10007.

Saddeek, Y. B., Shaaban, E. R., & Moustafa, H. M. (2008). Spectroscopic properties, electronic polarizability, and optical basicity of Bi_2O_3–Li_2O–B_2O_3 glasses. *Physica B: Condensed Matter*, *403*(13-16), 2399-2407.

Sahar, M. R., Sulhadi, K., & Rohani, M. S. (2008). The preparation and structural studies in the (80− x) TeO_2–20ZnO–(x) Er_2O_3 glass system. *Journal of Non-Crystalline Solids*, *354*(12-13), 1179-1181.

Sajna, M. S., Thomas, S., Mary, K. A., Joseph, C., Biju, P. R., & Unnikrishnan, N. V. (2015). Spectroscopic properties of Er^{3+} ions in multicomponent tellurite glasses. *Journal of Luminescence*, *159*, 55-65.

Saleem, S. A., Jamalaiah, B. C., Sasikala, T., Mohan Babu, A., Jayasimhadri, M., & Rama Moorthy, L. (2011). Erbium‐doped fluoroborate glasses for near infrared broadband amplifiers. *International Journal of Applied Glass Science*, *2*(3), 215-221.

Schawe, J. E. K. (1995). Principles for the interpretation of modulated temperature DSC measurements. Part 1. Glass transition. *Thermochimica Acta*, *261*, 183-194.

Schweizer, T., Brady, D. J., & Hewak, D. W. (1997). Fabrication and spectroscopy of erbium doped gallium lanthanum sulphide glass fibres for mid-infrared laser applications. *Optics Express*, *1*(4), 102-107.

Selvaraju, K., and K. Marimuthu. "Structural and spectroscopic studies on Er^{3+} doped boro-tellurite glasses." *Physica B: Condensed Matter* 407, no. 7 (2012): 1086-1093.

Selvi, S., Venkataiah, G., Arunkumar, S., Muralidharan, G., & Marimuthu, K. (2014). Structural and luminescence studies on Dy^{3+} doped lead boro–telluro-phosphate glasses. *Physica B: Condensed Matter*, *454*, 72-81.

Shaaban, E. R., Shapaan, M., & Saddeek, Y. B. (2008). Structural and thermal stability criteria of Bi_2O_3–B_2O_3 glasses. *Journal of Physics: Condensed Matter*, *20*(15), 155108.

Shamshad, L., Ali, N., Kaewkhao, J., Rooh, G., Ahmad, T., & Zaman, F. (2018). Luminescence characterization of Sm^{3+}-doped sodium potassium borate glasses for laser application. *Journal of Alloys and Compounds*, *766*, 828-840.

Sharma, Y. K., Surana, S. S. L., & Singh, R. K. (2008). Optical absorption and fluorescence spectra of Pr (III) doped borosilicate glasses and their Judd-Ofelt analysis to study lasing characteristics. *IJPAP* 46 (04),239-244.

Shelby, J. E. (2007). *Introduction to glass science and technology*. Royal Society of Chemistry.

Shen, X., Nie, Q., Xu, T., & Gao, Y. (2005). Optical transitions of Er^{3+}/Yb^{3+} codoped TeO_2–WO_3–Bi_2O_3 glass. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *61*(13-14), 2827-2831.

Shen, X., Nie, Q., Xu, T., Dai, S., & Wang, X. (2007). Effect of B_2O_3 on luminescence of erbium doped tellurite glasses. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *66*(2), 389-393.

Shih, P. Y. (2004). Thermal, chemical and structural characteristics of erbium-doped sodium phosphate glasses. *Materials Chemistry and Physics*, *84*(1), 151-156.

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.

Sklepić, K., Vorokhta, M., Mošner, P., Koudelka, L., & Moguš-Milanković, A. (2014). Electrical mobility of silver ion in Ag_2O–B_2O_3–P_2O_5–TeO_2 glasses. *The Journal of Physical Chemistry B*, *118*(41), 12050-12058.

Soltan, A. S., Abu-Sehly, A. A., Joraid, A. A., & Alamri, S. N. (2013). The activation energy and fragility index of the glass transition in Se_{76}-Te_{21}-Sb_3 chalcogenide glass. *Thermochimica Acta*, *574*, 73-78.

Soltani, I., Hraiech, S., Horchani-Naifer, K., Massera, J., Petit, L., & Férid, M. (2016). Thermal, structural and optical properties of Er^{3+} doped phosphate glasses containing silver nanoparticles. *Journal of Non-Crystalline Solids*, *438*, 67-73.

Som, T., & Karmakar, B. (2011). Nephelauxetic effect of low phonon antimony oxide glass in absorption and photoluminescence of rare-earth ions. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *79*(5), 1766-1782.

Souri, D. (2015). Crystallization kinetic of Sb–V_2O_5–TeO_2 glasses investigated by DSC and their elastic moduli and Poisson’s ratio. *Physica B: Condensed Matter*, *456*, 185-190.

Stambouli, W., Elhouichet, H., & Ferid, M. (2012). Study of thermal, structural and optical properties of tellurite glass with different TiO_2 composition. *Journal of Molecular Structure*, *1028*, 39-43.

Stambouli, W., Elhouichet, H., Barthou, C., & Férid, M. (2013). Energy transfer induced photoluminescence improvement in $Er^{3+}/Ce^{3+}/Yb^{3+}$ tri-doped tellurite glass. *Journal of Alloys and Compounds*, *580*, 310-315.

Stepien, R., Buczynski, R., Pysz, D., Kujawa, I., Filipkowski, A., Mirkowska, M., & Diduszko, R. (2011). Development of thermally stable tellurite glasses designed for fabrication of microstructured optical fibers. *Journal of Non-Crystalline Solids*, *357*(3), 873-883.

Suthanthirakumar, P., Karthikeyan, P., Manimozhi, P. K., & Marimuthu, K. (2015). Structural and spectroscopic behavior of Er^{3+}/Yb^{3+} co-doped boro-tellurite glasses. *Journal of Non-Crystalline Solids*, *410*, 26-34.

Swapna, K., Mahamuda, S., Venkateswarlu, M., Rao, A. S., Jayasimhadri, M., Shakya, S., & Prakash, G. V. (2015). Visible, up-conversion and NIR (~ 1.5 μm) luminescence studies of Er^{3+} doped zinc alumino bismuth borate glasses. *Journal of Luminescence*, *163*, 55-63.

Tanabe, S. (2005). Development of rare-earth doped fiber amplifiers for broad band wavelength-division-multiplexing telecommunication. *Photon. Based Wavel. Integr. Manip. IPAP Books*, *2*, 101-112.

Tanabe, S., Ohyagi, T., Soga, N., & Hanada, T. (1992). Compositional dependence of Judd-Ofelt parameters of Er^{3+} ions in alkali-metal borate glasses. *Physical Review B*, *46*(6), 3305.

Tanko, Y. A., Ghoshal, S. K., & Sahar, M. R. (2016a). Ligand field and Judd-Ofelt intensity parameters of samarium doped tellurite glass. *Journal of Molecular Structure*, *1117*, 64-68.

Tanko, Y. A., Sahar, M. R., & Ghoshal, S. K. (2016b). Prominent spectral features of Sm^{3+} ion in disordered zinc tellurite glass. *Results in Physics*, *6*, 7-11.

Tian, Y., Jing, X., & Xu, S. (2013). Spectroscopic analysis and efficient diode-pumped 2.0 μm emission in Ho^{3+}/Tm^{3+} codoped fluoride glass. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *115*, 33-38.

Tikhomirov, V. K., Iakoubovskii, K., Hertogen, P. W., & Adriaenssens, G. J. (1997). Visible luminescence from Pr-doped sulfide glasses. *Applied Physics Letters*, *71*(19), 2740-2742.

Uma, V., Marimuthu, K., & Muralidharan, G. (2018). Effect of modifier oxides (SrO, Al_2O_3, ZnO, CdO, PbO and Bi_2O_3) on the luminescence properties of Er^{3+} doped telluroborate glasses for laser and optical amplifier applications. *Journal of Luminescence*, *207*, 534-544.

Umar, S. A., Halimah, M. K., Chan, K. T., & Latif, A. A. (2017a). Physical, structural and optical properties of erbium doped rice husk silicate borotellurite (Er-doped RHSBT) glasses. *Journal of Non-Crystalline Solids*, *472*, 31-38.

Umar, S. A., Halimah, M. K., Chan, K. T., & Latif, A. A. (2017b). Polarizability, optical basicity and electric susceptibility of Er^{3+} doped silicate borotellurite glasses. *Journal of Non-Crystalline Solids*, *471*, 101-109.

Upender, G., Ramesh, S., Prasad, M., Sathe, V. G., & Mouli, V. C. (2010). Optical band gap, glass transition temperature and structural studies of (100− 2x) TeO_2–xAg_2O–xWO_3 glass system. *Journal of Alloys and Compounds*, *504*(2), 468-474.

Usman, A., Halimah, M. K., Latif, A. A., Muhammad, F. D., & Abubakar, A. I. (2018). Influence of Ho^{3+} ions on structural and optical properties of zinc borotellurite glass system. *Journal of Non-Crystalline Solids*, *483*, 18-25.

Vasudevan, B., Sivasubramanian, A., & Babu, M. R. (2017). Optical study on Er-Yb Co-doped boro-tellurite glasses for optical amplifiers. *Journal of optoelectronics and advanced materials*, *19*(1-2), 11-15.

Vijayakumar, R., Nagaraj, R., Suthanthirakumar, P., Karthikeyan, P., & Marimuthu, K. (2018). Silver (Ag) nanoparticles enhanced luminescence properties of Dy^{3+} ions in borotellurite glasses for white light applications. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *204*, 537-547.

Walsh, B. M. (2006). Judd-Ofelt theory: principles and practices. In *Advances in Spectroscopy for Lasers and Sensing* (pp. 403-433). Springer, Dordrecht.

Wang, J. S., Vogel, E. M., & Snitzer, E. (1994). Tellurite glass: a new candidate for fiber devices. *Optical materials*, *3*(3), 187-203.

Wei, T., Chen, F., Tian, Y., & Xu, S. (2014). Broadband 1.53 μm emission property in Er^{3+} doped germa-silicate glass for potential optical amplifier. *Optics Communications*, *315*, 199-203.

Wellen, R. M., & Canedo, E. L. (2014). On the Kissinger equation and the estimate of activation energies for non-isothermal cold crystallization of PET. *Polymer Testing*, *40*, 33-38.

Wui, R. H. C., Awang, A., Voi, A. L. S., Pien, C. F., Abdullah, N., & Dayou, J. (2017). Tuning Optical Properties of Erbium-Doped Zinc-Sodium Tellurite Glass Via Incorporation of Gold Nanoparticles. *Trans. Sci. Technol*, *4*(3), 209-217.

Xu, S., Yang, Z., Zhang, J., Wang, G., Dai, S., Hu, L., & Jiang, Z. (2004). Upconversion fluorescence spectroscopy of Er^{3+}/Yb^{3+}-codoped lead oxyfluorosilicate glass. *Chemical Physics Letters*, *385*(3-4), 263-267.

Yadav, A., Dahiya, M. S., Hooda, A., Chand, P., & Khasa, S. (2017). Structural influence of mixed transition metal ions on lithium bismuth borate glasses. *Solid State Sciences*, *70*, 54-65.

Yang, J., Dai, S., Zhou, Y., Wen, L., Hu, L., & Jiang, Z. (2003). Spectroscopic properties and thermal stability of erbium-doped bismuth-based glass for optical amplifier. *Journal of Applied Physics*, *93*(2), 977-983.

Yoshizawa, T. (2015). *Handbook of optical metrology: principles and applications*. Boca Raton: CRC Press.

Yusof, N. N., Sib Krishna Ghoshal, and Ramli Arifin (2017) "Improved self-cleaning and spectral features of erbium doped tellurite glass with titania nanoparticles sensitization." In *Solid State Phenomena*, vol. 268, pp. 48-53. Trans Tech Publications, 2017.

Yusoff, N. M., & Sahar, M. R. (2015). The incorporation of silver nanoparticles in samarium doped magnesium tellurite glass: Effect on the characteristic of bonding and local structure. *Physica B: Condensed Matter*, *470*, 6-14.

Zaitizila, I., Halimah, M. K., Muhammad, F. D., & Nurisya, M. S. (2018a). Influence of manganese doping on elastic and structural properties of silica borotellurite glass. *Journal of Non-Crystalline Solids*, *492*, 50-55.

Zaitizila, I., Halimah, M. K., Muhammad, F. D., Nurisya, M. S., & Zaid, M. H. M. (2018b). Thermal stability, structural and optical properties of rice husk sillica borotellurite glasses containing MnO2. *Chalcogenide Letters*, *15*(4), 187-197.

Zampiva, R. Y. S., Acauan, L. H., Venturini, J., Garcia, J. A. M., da Silva, D. S., Han, Z., & Bergmann, C. P. (2018). Tunable green/red luminescence by infrared upconversion in biocompatible forsterite nanoparticles with high erbium doping uptake. *Optical Materials*, *76*, 407-415.

Zamyatin, O. A., Plotnichenko, V. G., Churbanov, M. F., Zamyatina, E. V., & Karzanov, V. V. (2018). Optical properties of zinc tellurite glasses doped with Cu^{2+} ions. *Journal of Non-Crystalline Solids*, *480*, 81-89.

Zanotto, E. D., & Mauro, J. C. (2017). The glassy state of matter: Its definition and ultimate fate. Journal of Non-Crystalline Solids, 471, 490-495.

Zhang, Y., Lu, C., Feng, Y., Sun, L., Ni, Y., & Xu, Z. (2011). Effects of GeO_2 on the thermal stability and optical properties of Er^{3+}/Yb^{3+}-codoped oxyfluoride tellurite glasses. *Materials Chemistry and Physics*, *126*(3), 786-790.

Zhao, G., Xu, L., Meng, S., Du, C., Hou, J., Liu, Y., & Hu, L. (2019). Facile preparation of plasmon enhanced near-infrared photoluminescence of Er^{3+}-doped Bi_2O_3-B_2O_3-SiO_2 glass for optical fiber amplifier. *Journal of Luminescence*, *206*, 164-168.

Zhu, Y., Shen, X., Su, X., Zhou, M., Zhou, Y., Li, J., & Yang, G. (2019). Concentration dependent structural, thermal and luminescence properties in Er^{3+}/Tm^{3+} doped tellurite glasses. *Journal of Non-Crystalline Solids*, *507*, 19-29.

Zielinski, T. J., Harvey, E., Sweeney, R., & Hanson, D. M. (2005). Quantum states of atoms and molecules, *82,* 12, 1880.