



UNIVERSITI PUTRA MALAYSIA

***STRUCTURAL, THERMAL AND OPTICAL PROPERTIES OF ZINC
BORO-ALUMINOSILICATE GLASSES FOR OPTICAL POWER
AMPLIFICATION***

KAWA MUDHHER

FK 2018 15



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AMPLIFICATION**

By

KAWA MUDHHER

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

January 2018

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

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Chairman : Sharudin Omar Baki, PhD
Faculty : Engineering

Recently, glasses doped with different rare earth (RE) ions are considered promising materials for lasers and optical amplifier applications. In order to investigate new candidate glasses for optical wave guide, structural, thermal, and optical properties of zinc boro-aluminosilicate glasses have been prepared in addition to different alkali (Li, Na, and K) and alkaline oxides (Mg, Ca, Sr, and Ba). Ten mol% of alkali and alkaline oxides were incorporated into Zinc boro-aluminosilicate glasses within high optical quality. Glasses were fabricated using melt-quenching method and prepared into two forms: well-polished solid state and powders. Samples were characterized using X-ray Diffraction (XRD), attenuated total reflectance-fourier transform infrared (ATR-FTIR) spectroscopy, Raman spectroscopy, thermo-gravimetric analysis (TGA), differential scanning calorimetry (DSC), and optical absorption spectroscopy. The presence of various functional groups such as triangular and tetrahedral-borate (BO_3 and BO_4) were confirmed by ATR-FTIR and Raman spectra. TGA analysis presented low weight loss for all synthesized glasses. From the DSC profiles the glass transition temperature (T_g), onset crystallization temperature (T_x), and crystallization temperature (T_c), were identified and different related thermal parameters were evaluated. From the optical absorption spectra, cut-off wavelength was calculated, showing a spectral shifting to longer wavelength with alkali ($\text{Li} \rightarrow \text{Na} \rightarrow \text{K}$), and alkaline ($\text{Mg} \rightarrow \text{Ca} \rightarrow \text{Sr} \rightarrow \text{Ba}$) modifiers. Optical band gap energy was also investigated for allowed transitions in UV-Visible region using two methods: indirect and absorption spectrum fitting (ASF). Consequently, it was difficult to designate the best host among seven samples to dope with Rare Earth ions. Based on that, Er^{3+} was doped with the lowest cut-off wavelength glasses among alkali and alkaline, which are H1 and H4 with Li_2O and MgO , respectively. A total of 10 glasses were prepared using melt-quenching techniques with the compositions of $(40-x)\text{B}_2\text{O}_3 - 10\text{SiO}_2 - 10\text{Al}_2\text{O}_3 - 30\text{ZnO} - x\text{Er}_2\text{O}_3$ and $(40-x)\text{B}_2\text{O}_3 - 10\text{SiO}_2 - 10\text{Al}_2\text{O}_3 - 30\text{ZnO}$

– 10MgO – xEr₂O₃ (mol %) (x= 0.1, 0.25, 0.5, 1.0, and 2.0). Amorphous-like structure was observed for all the prepared glasses using XRD. In order to study the functional groups of the glass composition after the melt-quenching process, Raman spectroscopy was used. All samples were characterized using optical absorption for UV, visible and NIR region. Judd-Ofelt (JO) intensity parameters (Ω_λ , $\lambda=2, 4$ and 6) were calculated from the optical absorption spectra of two glasses, LiEr 2.0 and MgEr 2.0, which was doped with 2 mol % of Er³⁺.

Furthermore, using Judd–Ofelt intensity parameters, the radiative A (s⁻¹), branching ratio (β), radiative decay lifetimes τ_{rad} (μs) of emissions from excited Er³⁺ ions in LiEr 2.0 and MgEr 2.0 to all lower levels were obtained in this work. In order to investigate these glasses for visible laser applications (green emission), quantum efficiency (η) of ⁴I_{13/2} and ⁴S_{3/2} levels of LiEr 2.0 and MgEr 2.0 were calculated, with and without ⁴D_{7/2}, using the radiative decay lifetimes τ_{rad} (μs) and measured lifetimes τ_{exp} (μs). Visible photoluminescence was measured under 377 nm excitation for both LiEr and MgEr glass series within the region of 390–580 nm. Decay lifetimes for emissions at 407 nm, 530 nm, and 554 nm were measured, showing single exponential behavior for all the LiEr and MgEr glass series. Lastly, following the photoluminescence and radiative decay lifetimes (τ_{rad}), full-width at half-maximum (FWHM), emission cross-section (σ_P^E) and bandwidth gain (FWHM $\times \sigma_P^E$) parameters were calculated. Near-infrared photoluminescence under 980 nm excitation was measured for all the LiEr and MgEr glass series in the region of 1420–1620 nm. NIR emissions showed a broadband centered at ~ 1530 nm due to the transition of Er³⁺: ⁴I_{13/2} → ⁴I_{15/2}. Decay lifetimes for NIR emission at ~1530 nm were measured, presenting a single exponential nature for all the LiEr and MgEr glass series.

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

**SIFAT-SIFAT STRUKTUR, TERMA DAN OPTIK KACA-KACA ZINK
BORO-ALUMINOSILIKAT UNTUK KEGUNAAN PENGGANDA KUASA
OPTIK**

Oleh

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Terkini, kaca yang didopkan dengan pelbagai ion nadir bumi (RE) dicadangkan sebagai bahan yang berpotensi untuk kegunaan laser dan pengganda optik. Bagi tujuan penyelidikan terhadap pemilihan kaca-kaca terbaru untuk pemanduan gelombang optik, sifat-sifat struktur, terma, dan optik kaca-kaca zink boro-aluminosilikat dengan kepelbagaian alkali (Li, Na, K) dan oksida alkalin (Mg, Ca, Sr, dan Ba) telah dihasilkan. Sejumlah 10 % mol oksida-oksida alkali dan alkalin telah dimasukkan ke dalam kaca-kaca zink boro-aluminosilikat dengan dicirikan oleh kualiti optik yang tinggi. Kaca-kaca telah dihasilkan melalui kaedah leburan-lindap. Dua bentuk hasil kaca-kaca telah disediakan: bentuk pepejal yang digilap dan serbuk.

Sampel-sampel telah dicirikan menggunakan pembelauan sinar-X (XRD), spektroskopi jumlah pantulan dilemahkan Fourier inframerah (ATR-FTIR), spektroskopi Raman, analisis Thermo-gravimetrik (TGA), pengimbasan pembeza kalorimetri (DSC) dan spektroskopi penyerapan optik. Kehadiran pelbagai kumpulan-kumpulan fungsian seperti segi tiga dan tetrahedron-borat (BO_3 dan BO_4) telah disahkan oleh ATR-FTIR dan spektrum Raman. Analisis TGA mendapati kehilangan berat yang rendah bagi semua kaca-kaca yang telah dihasilkan; dapatan profail DSC telah mengenal pasti suhu peralihan kaca (T_g), permulaan suhu penghabluran (T_x) dan suhu penghabluran (T_c), di mana penilaian pelbagai parameter-parameter terma berkaitan telah dijalankan. Melalui spektra penyerapan optik, panjang gelombang pintasan telah ditentukan dan menunjukkan anjakan spektrum kepada panjang gelombang yang lebih besar untuk pengubahsuai alkali (Li→Na→K) dan alkalin (Mg→Ca→Sr→Ba). Jurang tenaga optik telah diselidiki untuk peralihan dibenarkan dalam julat UV-Nampak menggunakan dua kaedah; tidak-langsung dan pepadanan spektrum penyerapan (ASF). Hasil dapatan mendapati adalah sukar menentukan

sampel hos yang terbaik di antara tujuh sampel-sampel untuk didopkan dengan ion-ion nadir bumi. Atas asas di atas, Er^{3+} telah didopkan dengan kaca-kaca dengan pintasan panjang gelombang terendah, di kalangan alkali-alkalin H1 dan H4, masing-masing dengan LiO_2 dan MgO . Sejumlah 10 kaca-kaca telah disediakan melalui kaedah leburan-lindap dengan komposisi-komposisi $(40-x) \text{B}_2\text{O}_3 - 10\text{SiO}_2 - 10\text{Al}_2\text{O}_3 - 30\text{ZnO} - 10\text{Li}_2\text{O} - x\text{Er}_2\text{O}_3$ dan $(40-x) \text{B}_2\text{O}_3 - 10\text{SiO}_2 - 10\text{Al}_2\text{O}_3 - 30\text{ZnO} - 10\text{MgO} - x\text{Er}_2\text{O}_3$ (mol %) ($x = 0.1, 0.25, 0.5, 1.0, \text{ dan } 2.0$). Struktur amorfus telah disahkan untuk kesemua kaca-kaca tersedia menggunakan XRD. Bagi mengkaji kumpulan fungsian komposisi-komposisi kaca-kaca setelah proses leburan-lindap, spektroskopi Raman telah digunakan. Kesemua sampel-sampel telah dicirikan melalui penyerapan optik untuk julat UV, nampak dan NIR. Parameter keamatan ($\Omega_\lambda, \lambda = 2, 4 \text{ dan } 6$) Judd-Ofelt (JO) telah ditentukan daripada spektra penyerapan optik untuk dua kaca, LiEr 2.0 dan MgEr 2.0 yang didopkan dengan 2 mol% Er^{3+} .

Didapati juga, melalui parameter-parameter keamatan JO, parameter-parameter kebarangkalian sinaran A (s^{-1}), nisbah cabang (β), susutan hayat sinaran τ_{rad} (μs) daripada aras teruja ion Er^{3+} di dalam LiEr 2.0 dan MgEr 2.0 ke aras lebih rendah telah diperolehi di dalam kajian ini. Bagi menyelidiki kaca-kaca yang diperolehi untuk kegunaan laser nampak (pancaran hijau), kecekapan kuantum (η) aras-aras $^4\text{I}_{13/2}$ dan $^4\text{S}_{3/2}$ LiEr 2.0 dan MgEr 2.0 telah ditentukan untuk kewujudan dan tanpa kewujudan $^4\text{D}_{7/2}$, menggunakan susutan sinaran hayat τ_{rad} (μs) dan ukuran hayat yang diukur, τ_{exp} (μs). Fotoluminesen nampak telah diukur pada pengujaan 377 nm untuk kedua-dua siri kaca LiEr dan MgEr dalam julat 390-580 nm. Susut hayat untuk pancaran-pancaran pada 407 nm, 530 nm, dan 554 nm telah diukur dan kesemuanya menunjukkan sifat eksponen tunggal untuk kesemua siri kaca LiEr dan MgEr. Akhirnya, berdasarkan fotoluminesen dan susutan hayat sinaran (τ_{rad}), parameter-parameter lebar penuh pada separuh maksimum (FWHM), keratan-rentas pancaran (σ_p^E) dan gandaan lebar-jalur ($\text{FWHM} \times \sigma_p^E$) telah ditentukan. Fotoluminescence inframerah-dekat (NIR) pada pengujaan 980 nm telah diukur untuk kesemua siri kaca LiEr dan MgEr di dalam julat 1420-1620 nm. Pancaran NIR menunjukkan jalur lebar berpusat pada ~ 1530 nm disebabkan oleh peralihan $\text{Er}^{3+}: ^4\text{I}_{13/2} \rightarrow ^4\text{I}_{15/2}$. Susut hayat untuk pancaran NIR pada ~ 1530 nm telah diukur dan menunjukkan sifat eksponen tunggal untuk kesemua siri kaca LiEr dan MgEr.

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

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LIST OF ABBREVIATIONS

RE	Rare Earth
XRD	X-ray Diffraction
ATR-FTIR	Attenuated Total Reflectance-Fourier Transform Infrared
TGA	Thermo-Gravimetric Analysis
DSC	Differential Scanning Calorimetry
T_g	Transition Temperature
T_x	Crystallization Temperature
T_m	Melting Temperature
VIS	Visible
UV	Ultra Violet
ASF	Absorption Spectrum Fitting
Er^{3+}	Erbium ions
NIR	Near Infrared
JO	Judd-Ofelt
Ω_λ	JO Intensity Parameters
$A (S^{-1})$	Radiative Probability
β	Branching Ratio
τ_{rad}	Radiative Decay Lifetimes
η	Quantum Efficiency
$\tau_{exp.}$	Measured Lifetimes
PL	Photo Luminescence
PLE	Photo Luminescence Excitation
FWHM	Full-Width at Half-Maximum

σ_P^E	Emission Cross-Section
RI	Refractive Indices
MW	Molecular Weight
$f_{exp.}$	Oscillator Strengths Measured
$f_{cal.}$	Oscillator Strengths Calculated
λ_P	Peak position
TTT	Time-Temperature-Transformation
ESA	Excited State Absorption
LD	Laser Diode
$\alpha(\lambda)$	Optical Absorption Coefficient
SSL	Sold-State Laser
WDM	Wavelength Division Multiplexing
DWDM	Dense Wavelength Division Multiplexing
EDFA	Erbium Doped Fiber Amplifier
CN	Co-ordination Number
RNM	Random Network Model
Ø	Bridging Oxygen
NBO	Non-Bridging Oxygen
TDA	Differential Thermal Analysis
Δ	Glass Stability Factor
H _R	Huruby's Parameter
n _D	Refractive Indices at wavelength of 589.3 nm
$\rho(v)$	Radiation Density
Γ	Orbital Angular Momentum

J	Total Angular Momentum
OD	Optical Density
ED	Electric Dipoles
MD	Magnetic Dipoles
$S_{\text{meas.}}$	Measured Line Strength
$S_{\text{ed.}}$	Electric Dipole Line Strength
$S_{\text{calc.}}$	Theoretical Electric Dipole Line Strength
W_{nr}	Nonradiative Rate
p	Phonon Energy
CR	Cross Relaxation
ΔE	Energy Gap
I_{em}	Light Intensity
ρ_L	Liquid Density
D.W.	Distilled Water
V_M	Molar Volume
OPD	Oxygen Packing Density
R_m	Molar Refractivity
M	Metallization Criterion
RL	Reflection Loss
α_m	Molar Polarizability
$\wedge$	Glass Optical Basicity
γ	Basicity Moderating Parameter
χ_i	Pauling Electronegativity

CHAPTER 1

INTRODUCTION

1.1 Optical glasses

Recently, optical glasses gained much attention for different technological and scientific applications. Optical glasses show higher stability when compared to polymers, wide range of temperature operations and better physical properties [1].

Optical glasses have found applications in radiation shielding, solid-state lasers, solar energy utilization and data transmission. Glasses became more interesting in data transmission compared to crystals due to the amorphous nature of the glass, which gives broadband of tens of nanometers, while crystals with long atomic range show sharp peaks resulting in only a few nanometers. Moreover, optical fiber waveguides crystals could produce light reflection, which affects data transmission [2–5].

Glasses show promising features for optical amplifiers in telecommunication, with an ability of transmitting gigabits of optical data. This made it to become the main network element as optical fiber waveguide or optical amplifiers and solid-state laser [5]. Apart from economic benefits, the increasing demand for new optical material systems leads to focus on developing compact, multifunctional features, which are capable of transmitting huge number of data information with higher speed, longer distances, and higher accuracies than traditional equipment [1].

Optical materials have played an important role in these advances and promised even greater impact in the future. In signal processing and transmission, the benefits of optical over electronic techniques have already changed modern lives in a major way by allowing access to the information super-highway. This advancement results from the development of novel optical materials that could not only handle larger signal bandwidth but also transmit a great number of communication channels over global distances. The linearity of the transmission media allows the superposition of optical signals without mixing, thus making a possibility of processing massive amounts of data simultaneously and in parallel. The materials that exhibit a strongly nonlinear response to optical radiation make possible the development of large optical memories, optical switches, and computational logic operations. Complex logic processes such as image analysis could be executed more quickly and accurately optically rather than electronically, using signal-processing operations such as amplification, wavelength-division multiplexing, and switching [1, 5].

Intense research efforts have been currently under way to integrate multiple optical technologies on-chip. One can easily envision a system in which optical signals are generated by micro-lasers modulated by light-signal modulators, transmitted and

shaped by thin-film digital lenses, coupled into optical waveguide channels by nonlinear optical switches, analyzed by optical logic gates that work as part of complex neural network logic systems, and finally, stored as information in three-dimensional holographic data-storage media, all within the space of a computer chip.

1.2 Rare-Earth-doped glasses

Glasses are considered optical materials that could be used to manipulate the flow of light. These changes could be absorbing, reflecting, splitting or focusing the optical beam. In order to manipulate the injected light, the necessity of materials such as rare-earth-doped glasses has started to gain much attention, being implemented in variety of optical amplification applications. Once the light passes through the medium doped with rare-earth, it will excite these ions into another higher energy level [6].

Recently, the rapid growth of advanced optical communication networks became the hotspot for researchers to cover the increasing demand of information's technology. Optical signal transmission for telecommunications has been conducted at 1550 nm. Long communication distances require optical amplifiers, which in turn require finding and improving optical materials' extensibility in order to carry on the high-speed capacity, broadband wavelength division multiplexing (WDM) and dense wavelength division multiplexing (DWDM) for optical amplifier usage where wide and flat gain spectrum became an important key in optical telecommunication [7, 8].

In order to study optical amplification at several desired optical frequencies, it is necessary to understand the population inversion mechanism of rare-earths. Generally, rare-earth ions can be classified into two groups. The first one is used as a main dopant such as; Nd^{3+} (900-950, 1030-1100 and 1320-1350) nm, Yb^{3+} (980-1100) nm, Er^{3+} (550, 1500-1600 and 2700) nm, Tm^{3+} (480, 800, 1450-1530 and 1700-2100) nm, Ho^{3+} (2100 and 2800-2900) nm, Pr^{3+} (490, 520, 600, 635 and 1300) nm and Ce^{3+} (280 and 330) nm. While the second group used as co-dopant which contains; Y^{3+} , Sm^{3+} , Eu^{3+} , Gd^{3+} , Tb^{3+} , Dy^{3+} and Lu^{3+} [3,6, 9–12].

Rare-earths (REs) Er^{3+} [13], Tm^{3+} [14], and Yb^{3+} [15] doped glasses such as tellurite [16], germanate [17], silicate [18], phosphate [19], and borate [20] have started to gain more attention for optical amplifier applications in the communication bands (O-, E-, S-, C-, L- and U) [21]. RE-doped fibers have a variety of applications such as optical amplifiers, lasers, optical switches, and nonlinear devices [6, 22,23]. Er^{3+} has interesting emission cross-sections, band width, and transition levels.

Generally, Er^{3+} shows three emissions in ultraviolet, visible and infrared regions, with transitions at $^4\text{I}_{11/2} \rightarrow ^4\text{I}_{13/2}$ at 3000 nm, $^4\text{I}_{13/2} \rightarrow ^4\text{I}_{15/2}$ nearly at 1500 nm, and $^4\text{S}_{3/2} \rightarrow ^4\text{I}_{15/2}$ at 550 nm, respectively, and the first transition used for medical purposes, while the second transition is applicable for third telecommunication window, and the last

transition employed in display applications with green emission [24]. In fact, the third window in optical communication is called zero loss window, due to its minimum loss.

The EDFA (erbium doped fiber amplifier) can cover 1500-1600 nm, which is an efficient repeater for long-distance communications. Generally, optical fiber amplifiers behave as a laser source, forming into cavities at various intervals in a continuous fiber by using photosensitive gratings. It is well known that exciting Er^{3+} energy levels between $^4\text{I}_{15/2}$ and $^4\text{I}_{11/2}$ with 980 nm wavelength can give emission at about 1550 nm due to the relaxation from $^4\text{I}_{13/2}$ to ground state $^4\text{I}_{15/2}$. This highlights the role of EDFA as the key for global communication with considerable cost [25].

1.3 Problem statement

Borosilicate glasses are considered low cost materials that are available commercially in large quantities by several vendors. Besides that, they can be easily produced in different compositions based on the application. Additionally, these glasses showed their ability for ion-exchange which made them suitable host for different optical applications. Moreover, borosilicate has refractive indices close to that of silica (n_D of Borosilicate = ~ 1.473 and n_D of silica = 1.458) which decrease the losses in connecting borosilicate and optical fiber-based silica, which is the base material used for optical fibers in existing telecommunication networks. Consequently, borosilicate glasses present an interesting platform for the development of integrated optical and microwave circuits [26].

Light dispersion in optical waveguide materials can occur due to the variation of the refractive indices with wavelength, which is a fundamental parameter in all optical materials including silica or borosilicate glasses. Silica glasses have been used for optical telecommunication network for three decades. The refractive indices is measured at specific wavelength lying within the transmission region, with sufficient accuracy. It is necessary to compare the measured refractive indices values with those calculated through empirical or mathematical expression to make it more accurate. Table 1.1 presents refractive indices values of different types of silica, borosilicate and tellurite glasses. It is clear that borosilicate has refractive indices matching silicates, making these glasses good candidates as hosts in optical applications.

Table 1.1 : Refractive indices of different glass compositions where fibers have been successfully produced

Glass composition (mol %)	Refractive indices
19.9 Na ₂ O – 9.1 CaO – 71 SiO ₂	1.518 (n_D)
30 Na ₂ O – 10MgO – 60 SiO ₂	1.5138 (n_D)
16 Na ₂ O – 6 Al ₂ O ₃ – 89 SiO ₂	1.499 (n_D)
16.9 Na ₂ O – 32 B ₂ O ₃ – 50.6 SiO ₂	1.525 (n_D)
44 Na ₂ O – 22.6 Al ₂ O ₃ – 31 P ₂ O ₃ – 2 PbO – 0.4 Er ₂ O ₃	1.5037 (n_D)
5 Na ₂ O – 20 ZnO – 75 TeO ₂	2.031 (633 nm)

(Source : Hewak. 1998)

The current EDFA is manufactured using silicate host glass that has phonon energy around 1200 cm^{-1} [25]. Recent researchers found that with host glass having higher phonon energy, more probability to bridge the energy difference in RE dopant such as the $\text{Er}^{3+}:^4\text{I}_{11/2} \rightarrow ^4\text{I}_{13/2}$ could occur [27]. Moreover, the intensity at $1.5\text{ }\mu\text{m}$ region of Er^{3+} -doped glasses were found to be quenched whenever the concentration of Er^{3+} crosses $1.0\text{ mol}\%$ [28]. Additionally, the available EDFA based silicate glasses show about 40 nm bandwidth, which is considered as one of the limitations of the EDFA.

In fact, current available lasers are restricted to be used for display purposes due to the high power of amplifying, which can be hazardous on eye or skin [28]. Erbium doped glasses emitting in the visible region with wavelength range of $510\text{-}570\text{ nm}$, which can be a safe source for green laser emission since it has limited power [30].

In the present thesis, prepared glasses covered the 3rd window (low loss) of optical telecommunication using Er^{3+} ions containing boro-silicate glasses with different modifier oxides such as (Al, Zn and alkali-alkaline). It is well known that borate glass possesses phonon energy around 1400 cm^{-1} which can enhance the non-radiative energy transfer processes through energy diffusion, leading to a reduction in the quantum efficiency which limits the emission intensity, while additional glass former with lower phonon energy can reduce the non-radiative transition probability substantially [8].

1.4 Objectives

In this thesis, visible and NIR optical band of Er^{3+} doped zinc boro-aluminosilicate glasses have been investigated systematically with additional alkali/alkaline modifiers in order to explore new lasers and EDFA candidate. The main objectives of this thesis can be concluded as follows:

- (i). In order to investigate a new suitable candidate as host glass to be doped with Er^{3+} , structural, thermal and optical features of zinc boro-aluminosilicate glasses have been studied systematically with different alkali and alkaline modifiers.
- (ii). Visible laser emissions of Er^{3+} doped zinc boro-aluminosilicate and ($\text{Li}_2\text{O}/\text{MgO}$) modifiers have been investigated with different concentrations of Er^{3+} .
- (iii). NIR emissions for the fabricated glasses have been studied furthermore to find the modifier, which offer highest emission to be obtained as $1.5\text{ }\mu\text{m}$ broadband optical amplifier.

1.5 Thesis outlines

In this section, the six chapters of the present thesis are outlined as follows:

Chapter 1 presents the overview of optical materials based on oxide glasses and their features in different applications. Additionally, RE-doped optical glasses were reviewed based on the features of Er^{3+} in broadband optical amplifiers. Moreover, the problem statement and the main objectives of this thesis are also mentioned.

Chapter 2 reviews fundamental information about glass forming. Glass formers which play an important role for optical materials (e.g., glasses), reviewed in this chapter, are borate, silicate and boro-silicate glasses. In this part, the reason for choosing boro-silicate as a glass former in order to achieve the research objectives is explained. The role of Er^{3+} is discussed in detail.

Chapter 3 presents the RE phenomena and some of its fundamental characteristics, which are very important resources in this study especially for the role of Er ions in the boro-silicate glass host. In the beginning, the basic RE spectroscopic theory is presented, which accounts for the observed intensity absorption spectra of the rare-earth ions in solids. This is followed by the theory of Judd-Ofelt where the related absorption intensity parameters Ω_t ($t = 2, 4, 6$) are obtained through a comprehensive numerical calculation procedure. Moreover, energy transfer and ions interaction is explained for Er^{3+} doped host glasses.

Chapter 4 highlights the glass sample preparation and method of characterizations. The detailed steps of important preparation procedure are described here. Starting with glass sample calculations, followed by batching procedure, and glass fabrication are clearly explained systematically. The particulars of the material characterizations for structural, thermal and optical analysis including the instrumentation are also specified.

Chapter 5, investigates the effect of alkali-alkaline on broadband amplification, being divided into two sections. Firstly, section 5.1 presents the structural, thermal and optical properties of zinc boro-aluminosilicate glass introduced with additional 10 mol% of alkali-alkaline, as a result, it shows that all those glasses have similar structural and thermal properties. Later, the purpose of choosing Li_2O and MgO among alkali-alkaline, is mentioned respectively. Finally, section 5.2 presents Er^{3+} doped zinc boro-aluminosilicate with additional 10 mol% of $\text{Li}_2\text{O}/\text{MgO}$. In this section, Visible and NIR emission with related Decay lifetimes is presented. The result identified Li_2O as the highest emission compared to MgO in both visible and NIR regions.

Chapter 6 concludes the findings of the thesis. The results of all systematic objectives are presented in order to obtain a suitable host glass for optical amplifier so it can be employed for green emission and the 3rd window of optical communication.



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