# DOSIMETRIC PROPERTIES OF LITHIUM ALUMINIUM BORATE GLASS DOPED WITH DYSPROSIUM OXIDE FOR IONIZING RADIATION MEASUREMENTS

**By**

**OSAMA BAGI MOHAMED ALJEWAW**

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

**December 2022**

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# DEDICATION

*This thesis is dedicated*
*To my darling wife for her love, understanding, and supporting me.*
*To my dear parents and all family and siblings for their endless prayers to me for success.*

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

# DOSIMETRIC PROPERTIES OF LITHIUM ALUMINIUM BORATE GLASS DOPED WITH DYSPROSIUM OXIDE FOR IONIZING RADIATION MEASUREMENTS

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**December 2022**

**Chairman : Muhammad Khalis bin Abdul Karim, PhD**
**Faculty : Science**

Thermoluminescence (TL) properties of glass dosimetry are known for their drawback, which is less sensitivity and a high fading effect. Hence, the purpose of this research is to investigate the influence of $Dy^{3+}$ ion doped on the TL characteristics of Lithium Alumina Borate (LAB) glass, which was fabricated by using the melt quenching technique. The structures of $23Li_2O$ - $7.5Al_2O_3$ - (69.5-x) $B_2O_3$: x $Dy_2O_3$ glasses, with x = 0, 0.2, 0.4, 0.6, 0.8, 1, 1.5, 2, 2.5, and 3 mol% were studied by using X-ray diffraction (XRD) technique and Fourier Transform Infrared (FTIR) spectroscopy, where the samples of glass system were completely as an amorphous phase and showed the existence of $BO_3$ and $BO_4$ structural units. At room temperature, the photoluminescence (PL) emission spectra of the glass series at 350 nm exhibit two strong peaks located at 481 nm and 575 nm in the visible region, corresponding to the transitions $^4F_{9/2} \rightarrow {}^6H_{15/2}$ and $^4F_{9/2} \rightarrow {}^6H_{13/2}$, respectively. All the samples were irradiated at the Malaysia Nuclear Agency with the gamma-ray from Co-60 teletherapy. For undoped LAB glass, TL response and intensity were found to be very low and have no apparent curve compared with doped samples, which indicates the doping influence on the pure host glass. The optimum TL intensity was recorded with a heating rate of 10 ºC /s of doped the host glass samples. Thermal treatments at 300 ºC for 40 minutes were obtained for undoped and doped samples, respectively. The TL glow curves of LAB: Dy (0.8 mol%) revealed a single prominent peak at a maximum temperature ($T_m$) of 238 ºC. The dose-response of the glass of undoped shows a non-linearity effect; meanwhile, the doped glass (0.8 mol% of Dy) shows a good linearity on a dose range from 0.5 to 5 Gy gamma-ray with relative error values around 0.064% and 0.389%, respectively. Overall, the sensitivity of the undoped and optimum doped LAB glass was found about almost 0.607 and 12.530 (nC $mg^{-1}$ $Gy^{-1}$) with relative error values around 0.6% and 0.3%, respectively. The minimum detectable dose of the glass samples undoped and doped with 0.8 mol% Dy was found to be 1437.98 and 36.63 mGy with relative error values around 0.0431% and 4.463%, respectively. Reproducibility of the LAB glass samples exhibits undoped a high reproducibility of around 13.49% with relative error values of around 0.00891% and doped with 0.8 mol% Dy resulted in a low reproducibility to be 2.33% with relative error values of around 0.4 ± 0.2%, and Fading of LAB: 0.8 mol% Dy and undoped glass are found almost 15% and 9% over the time 627 hours with relative error values around 0.3 ± 0.1%. LAB: undoped and 0.8 mol% Dy doped glasses were found to have a good $Z_{eff}$ = 7.34 and 10.59 of tissue and bone biological human, respectively, which best implies passive dose measurement. Other TL kinetic parameters such as activation energy ($E$) and escape frequency factor ($s$) for the glass samples were found as 0.527 eV and $7.14 \times 10^{7}$ $s^{-1}$, also optimized for dosimetry and validated by Chen's method. Hence, the study ascertained that the optimized TL glass LAB: Dy (0.8 mol%) has the potential to be used for passive dose monitoring.

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

# SIFAT DOSIMETRIK KACA BORAT LITHIUM ALUMINIUM DOP DENGAN DYSPROSIUM OXIDE UNTUK PENGUKURAN SINARAN MENGION

Oleh

**OSAMA BAGI MOHAMED ALJEWAW**

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Sifat pendarcahaya haba (TL) dosimetri kaca terkenal dengan kelemahannya iaitu kurang sensitiviti dan kesan pudar yang tinggi. Tujuan penyelidikan ini adalah untuk mengkaji pengaruh dop ion $Dy^{3+}$ terhadap ciri-ciri TL ke atas kaca lithum alumina borat (LAB) dengan kepekatan yang berbeza nadir bumi dengan menggunakan teknik sepah lindup leburan. Struktur kaca $23Li_2O$ - $7.5Al_2O_3$ - (69.5-x) $B_2O_3$: x $Dy_2O_3$ dengan x = 0, 0.2, 0.4, 0.6, 0.8, 1, 1.5, 2, 2.5, dan 3 mol% telah dikaji menggunakan teknik pembelauan sinar-X (XRD), dan Jelmaan Fourier Inframerah (FTIR), di mana sampel sistem kaca sepenuhnya sebagai fasa amorfus, dan menunjukkan kewujudan unit struktur $BO_3$ dan $BO_4$. Dalam suhu bilik, analisis pendarcahaya foto (PL) sampel kaca pancaran spektra pada 350 nm pamerkan dua puncak kuat yang terletak pada 481 nm dan 575 nm di rantau cahaya nampak, yang sepadan masing-masing dengan peralihan $^4F_{9/2} \rightarrow {}^6H_{15/2}$ dan $^4F_{9/2} \rightarrow {}^6H_{13/2}$. Semua sampel telah disinari di Agensi Nuklear Malaysia dengan sinaran mengion sinar gamma daripada teleterapi Co-60. Untuk kaca LAB yang tidak didop, tindak balas dan keamatan TL didapati sangat rendah dan tidak mempunyai bentuk keluk yang jelas berbanding dengan sampel terdop, yang menandakan kesan doping pada kaca perumah tulen. Keamatan TL optimum direkodkan dengan kadar pemanasan 10 ºC/s sampel kaca perumah yang didopkan. Rawatan terma pada suhu 300 ºC selama 40 minit, masing-masing diperoleh untuk sampel tidak didop dan didop. Keluk cahaya TL LAB: Dy (0.8 mol%) mendedahkan satu puncak yang menonjol pada suhu maksimum ($T_m$) 238 ºC. Tindakbalas dose pada kaca bukan dop menunjukkan graf yang tidak linear manakala kaca yang terdop (0.8 mol%) mempunyai sifat linear yang tinggi bagi julat dos sinar gamma 0.5-5 Gy dengan nilai ralat relatif masing-masing sekitar 0.064% dan 0.389%. Secara keseluruhannya, sensitiviti bagi kaca LAB yang tidak didop dan optimum didop didapati kira-kira hampir 0.607 dan 12.530 (nC $mg^{-1}$ $Gy^{-1}$) dengan nilai ralat relatif masing-masing sekitar 0.6% dan 0.3%. Dos minimum yang boleh dikesan bagi sampel kaca yang dinyahdop dan didopkan dengan 0.8 mol% Dy didapati ialah 1437.98 dan 36.63 mGy dengan nilai ralat relatif masing-masing sekitar 0.0431% dan 4.463%. Kebolehulangan sampel kaca LAB mempamerkan kebolehulangan semula yang tinggi sekitar 13.49% dengan nilai ralat relatif sekitar 0.00891% dan didopkan dengan 0.8 mol% Dy menghasilkan kebolehulangan rendah menjadi 2.33% dengan nilai ralat relatif sekitar 0.4 ± 0.2% dan sifat pudar LAB: 0.8 mol% Dy dan kaca tidak didop didapati hampir 15% dan 9% sepanjang masa 627 jam dengan nilai ralat relatif sekitar 0.3 ± 0.1%. KAca LAB yang tidak didop dan didop Dy 0.8 mol% didapati mempunyai $Z_{eff}$ masing-masing 7.34 dan 10.59 bagi tisu dan tulang manusia yang baik, sesuai sebagai ukuran dos pasif. Parameter kinetik TL yang lain seperti tenaga pengaktifan (*E*), faktor kekerapan melarikan diri (*s*), dan susunan kinetik untuk sampel kaca didapati optimum dan disahkan dengan kaedah Chen. Oleh yang demikian, kajian ini mendapati yang kaca TL yang optimum LAB: Dy (0.8 mol%) adalah berpotensi sebagai pemantauan pasif sinaran.

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

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| | |
|---|---|
| $<d_{B-B}>$ | Average boron–boron separation |
| $\mu_g$ | Geometrical factor |
| CB | Conduction band |
| CV | Coefficient of variation |
| $D_T$ | Absorbed dose |
| *DVI* | The detector variability index |
| $E_f$ | Fermi level |
| FTIR | Fourier transform infrared |
| Gy | Grey |
| $H_T$ | Equivalent dose |
| IRm | Initial Rise method |
| IR | Ionizing Radiation |
| LAB | Lithium Alumina Borate |
| LAB: DY | Lithium Alumina Borate: Dysprosium oxide |
| LiF | Lithium fluoride |
| $M_{av}$ | The average molecular weight |
| MDD | The minimum detectable dose |
| mSv | Millisievert |
| NBO | Non-bridging oxygen |
| NWFs | Network Formers |
| NWIs | Network Intermediates |
| $NWM_S$ | Network Modifiers |
| OPD | Oxygen packing density |

| | |
|---|---|
| OSL | Optically stimulated luminescence |
| PL | Photoluminescence |
| PM | Photomultiplier |
| PMT | Photomultiplier tube |
| PSm | Peak Shape method |
| RE | Rare Earth |
| RPL | Radio-photoluminescence |
| *RVI* | The reader variability index |
| STD | Standard deviation |
| *SVI* | The system variability index |
| $T_g$ | Transition temperature |
| TL | Thermoluminescent |
| TLD | Thermoluminescence dosimeter |
| TLD-reader | Thermoluminescence dosimeter reader |
| TTP | Time-temperature profile |
| VB | Valence band |
| $V_M$ | Molar volumes |
| $w_R$ | Radiation weighting factors |
| $w_T$ | Tissue weighting factors |
| XRD | X-ray diffraction |
| $Z_{eff}$ | Effective atomic number |
| $\rho$ | Density |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background Research

A century and a half ago (1895), Wilhelm Roentgen made the ground-breaking discovery of the X-ray. This Radiation describes electromagnetic waves (e.g., X-ray and gamma-ray) or particles (e.g., alpha, beta, and neutron) moving through space (Damulira et al., 2019).

Radiation describes the energy emission or transmission by means of electromagnetic waves or particle beams. Radiation sources act as energy reservoirs, releasing energy in the forms of fundamental carriers of photons and particles. Specifically, radiation-induced active species through radiolysis or photolysis can substitute common reductants/oxidants as in situ reagents that initiate the desired chemical reactions (Sowa et al., 2012). Energetic particles induce a knock-on effect on the irradiated target, introducing defects and doping to the material (Calvente et al., 2010). Radiation also has two kinds of radiation, ionizing, and non-ionizing radiation, by how it interacts with matter.

Ionizing radiation defines radiation that can dismiss electrons from atoms or molecules, that is, ionize them. Such radiations can be electromagnetic waves or particle beams whose photon energy is high enough to surmount the electron binding energy. Table 1.1 details the typical categorization of the electromagnetic spectrum according to its wavelength and photon energy. Electromagnetic waves in the spectrum range of γ-rays, X-rays, and high-frequency UV readily ionize atoms or molecules belonging to ionizing radiations (Baoping, 2018).

Among them, γ-rays are known to be the most energetic and penetrating electromagnetic wave that can cause deadly harm to human bodies. In addition, high-energy particle beams made of subatomic particles (protons, electrons, and positrons that carry positive/negative charges, or neutral neutrons) and ions (α particles) are also grouped into ionizing radiations (Garcia Sanchez et al., 2018). The charged particles come from either the radioactive decay or the acceleration to a high velocity by applying a high-voltage electric field. Generating ionizing radiations requires sophisticated instruments, and the operation warrants professional training to protect the users. Table 1.1, Common categorization of the electromagnetic spectrum into γ-ray, X-ray, UV, visible light, IR, and microwave radiations based on the wavelength and photon energy (Guo et al., 2020).

**Table 1.1 : Common categorization of the electromagnetic spectrum**

| Category | Subcategory | Wavelength (nm) | Photon Energy (eV) |
|---|---|---|---|
| **X-ray** | Hard X-ray<br>Soft X-ray | $10^{-3}$–$10^{-1}$<br>$10^{-1}$–10 | $1.24\times10^{4}$–$1.24\times10^{6}$<br>124–$1.24\times10^{4}$ |
| **γ-ray** | - | < $10^{-3}$ | > $1.24\times10^{6}$ |
| **UV** | Extreme UV<br>Far UV<br>Middle UV<br>Near UV | 10–121<br>122–200<br>200–300<br>300–400 | 10.2–124<br>6.2–10.2<br>4.1–6.2<br>3.1–4.1 |
| **Visible light** | - | 400–700 | 1.8–3.1 |
| **IR** | Near IR<br>Middle IR Far<br>IR | 700–$1.4\times10^{3}$<br>$1.4\times10^{3}$–$3\times10^{3}$<br>3×103–$10^{6}$ | 0.89–1.8<br>0.41–0.89<br>$1.2\times10^{-3}$–0.41 |
| **Microwave** | - | $10^{6}$–$10^{9}$ | $1.2\times10^{-6}$–$1.2\times10^{-3}$ |

(Guo et al., 2020)

In contrast, non-ionizing radiations have lower photon energy than ionizing radiations. Such radiations excite electrons or molecules to higher energy states (molecular transition) and cause molecular vibration and rotation. The excitement of electrons or molecules leads to photochemical reactions with the production of active free radicals (Belpomme et al., 2018). On the other hand, molecular vibration and rotation are often translated into the emission of thermal energy (Gunde Ziegelberger, 2020). Examples of non-ionizing radiation are in the electromagnetic spectrum range of low-frequency UV, visible light, IR, and microwave (Table 1). Note that there is no clear dividing line between ionizing and non-ionizing radiations in the spectrum of electromagnetic waves. Although the single photon may not be able to ionize atoms or molecules, multiple photons of lower energy can still take effect collectively and lead to the ionization of atoms and molecules, especially in the cases of UV and visible lights (Gupta et al., 2022). Contrary to ionizing radiation, sources of non-ionizing radiation are more ubiquitous, less costly, and less hazardous. Therefore, it is much easier to have routine access to non-ionizing radiation than ionizing radiation in the laboratory (Guo et al., 2020).

So, in recent years, the utilization of ionizing radiation (IR) has been growing in the industry, medicine, energy, and research in recent decades. However, despite the many benefits of using these rays, the risks that may arise from exposure require the utmost caution due to the biological effects of their ability to produce free radicals (ions) when it interacts with matter. High doses of ionizing radiation may be induced cause tissue damage, mutations, cancer, and death when its energy is absorbed by human tissues (Abushab et al., 2017; Shams et al., 2021).

Based on the above, it is significant to measure the amount of the energy absorbed from exposure to radiation (also known as dose) delivered to patients or workers in the radiation field or a radiation environment to diminish radiation hazards. A "dose" in radiation biology is a precise meaning particular. The dose describes how much radiation energy an organ, tissue, or cell absorbs per unit of mass. The dose is commonly given either in gray (Gy) or in rad (1 Gy = 100 rad) (McParland, 2013). The dose ranges of interest are approximately 0.01–1 mSv for personal dosimetry, 0.1–100 mGy for clinical X-ray diagnostics, and 1–5 Gy for radiotherapy (ICRU, 1998) (Alajerami et al., 2013).

Radiation monitoring and dosimetry are critical to determining the absorbed dose of ionizing radiation in such applications (There are two kinds of radiation dosimetry, such as active radiation dosimeters, such as diodes, ion chambers, and scintillators). However, they have several drawbacks, such as being costly, requiring batteries, and not being resistant to some conditions like the humidity and practical point of measurement of the film; thermoluminescence dosimeters TLD, optically stimulated luminescence dosimeters are commonly used as passive radiation dosimeters (Pedro, 2014; Zubair et al., 2020).

TLD dosimeter is a passive dosimeter used in either short-term (e.g., days and weeks) or long-term (e.g., months to years) dose measurements. Here we define passive dosimeters as those which integrate dose over the entire exposure period (Aramrun et al., 2018). Consequently, in some types of material, when subjected to ionizing radiation, the free charge carrier in the crystalline solid, which may be electrons or holes, gets trapped in the lattice defects. TL refers to the light emission by materials when heated, which occurs after the materials have absorbed energy from radiation (Kartikasari et al., 2018).

TL dosimetry has played an essential role in the area of medicine in protecting both. Therefore, patients and employees from needless radiation exposure become part of the most widely used radiation dosimetry (Hashim et al., 2019; Saidu et al., 2018). Due to their small energy dependency, small physical size and variety of forms, easy to handle, reusability, ability to monitor radiation dose from almost all kinds of ionizing radiation across a broad dose range, and simple adaptation to the patient's body (Brian McParland, 2019). In recent years, numerous studies have been done to enhance the dosimeter's performance and investigate novel TL materials (Lim et al., 2015). For the best use of TL dosimetry, it has essential to have high sensitivity, a linear dose-response, stability in ambient conditions, and a simple glow curve with a prominent peak at about 200 °C (Alqahtani et al., 2020; Azorin, 2014).

In addition, most common TLDs are made of crystals, ceramics, and phosphors. Nevertheless, they have high light output per unit dosage absorbed but quick signal fading, saturation at higher doses, difficulties annealing for reuse, and moisture assault (Prabhu et al., 2020). The opaque quality of certain materials scatters light. This discourages long-term use. Growing a single crystal or manufacturing phosphor is difficult and time-consuming. Researchers are currently looking for amorphous, transparent solid-state materials like glass that may address the shortcomings of the previous without affecting the TLD's primary properties.

Glass is more accessible to prepare and synthesize than phosphor and crystal (Prabhu et al., 2020; Sinclair and Pech, 2022). A common TLD such as Lithium fluoride such as LiF doped with Mg, Ti, produced by Harshaw/Bicron and LiF doped by Mg, Cu, P, was the first reported by Maria Ranogajec (2003). Those TLDs have the main drawbacks, like a complex glow curve consisting of overlapping individual peaks, and separating these peaks is very difficult. Also, it has complex annealing procedures (Liuzzi et al., 2015).

Glass solid-state dosimeters have the property of being transparent, which lowers the scattering and absorption of TL light. Glass dosimeters are available in many forms and phases, including phosphate glass, borosilicate glass, fluorophosphate glass, borate glass, lithium borate glass (Faramawy et al., 2021). Lithium borate is the most common form, both of which are dosage-sensitive and tissue comparable. However, these phosphors have significant disadvantages, including hygroscopicity and limited spatial resolution (up to a few millimeters), as well as energy dependency at lower energies (Rozaila et al., 2017).

Furthermore, according to Furetta (2003), manganese was the first activator for their lithium borate dosimeter to be offered as an activator. The material had good TL, but its radiation sensitivity was weak. The lower sensitivity was related to the incompatibility of the manganese emission at 600 nm, which is far away from the spectral sensitivity of photomultiplier (PM) tubes (at around 400 nm) commonly used in TL readers (Nieto, 2016; Prokic, 2001; Sanyal et al., 2019).

Several studies have been conducted to improve the TL dosimetry performance of lithium borate by host modification, doping, and co-doping. Efforts are made to improve the performance of borate as TL materials utilizing different preparation methods, host modification, as well as activation and co-activation of the host materials such as alkaline and alkaline earth oxides (Anjaiah et al., 2015; Hamzah et al., 2017; Yusub et al., 2013), and transition metals as reported by Marzouk et al. (2006) and Palan et al. ( 2016), to create deep and stable complex defects and enhance electron emission. Complex defects are known for establishing deep and stable traps, thereby increasing the life time of a phosphor. We propose a lithium borate with distinct modifiers to find a suitable TL material. For the first time, the $Al_2O_3$ as co-doping is to additional synthesis strategy that enhances chemical stability and allows tuning of the host properties for technological applications, and doping with trivalent rare-earth (RE) ions ($Dy_2O_3$) impurities in the host materials may cause the changes in its (TL) features as well as absorbed dose amount in their glassy form to tested TL dosimetry (TLD) properties.

## 1.2 Problem statement

Currently, most thermoluminescence dosimeters do not have tissue equivalence, high sensitivity, excellent stability, simple glow curve structure, which is ideally a single glow peak at about 200 ºC, a simple annealing procedure for reuse, and as well cost. Therefore, several researchers have always attempted to introduce new dosimetry materials with better thermoluminescence characteristics or simply improve upon the existing dosimetric materials by varying the concentration of the impurities or by co-doping the phosphor with other elements or doping new impurities in new matrices.

However, Prokic (2001) indicated that the thermoluminescence properties of the first TL material based on lithium borate, which was introduced in radiation dosimetry, was

$Li_2B_4O_7$: Mn phosphor with low TL sensitivity caused partly by the emission in the 600 nm region of the spectra, far from the response region of most photomultipliers. Hence, the $Li_2O$-$Al_2O_3$-$B_2O_3$ based glass as the host material has an optimum effective atomic number that is close to human tissue equivalence ($Z_{eff}$ = 7.42) or bone ($Z_{eff}$ = 11.6 to 13.8), which has demonstrated excellent TL properties owing to the high concentration of electron and hole trapping centers in a glass matrix and rare-earth ionic dopants. Additionally, glass compounds ideal materials because they can be efficiently and economically fabricated in large structures and complex shapes for optically device applications (Fujimoto et al., 2017).

Nevertheless, it does not meet all dosimetric properties, so studies to improve its properties are still being continued (Alajerami et al., 2017). Previously Ayta et al. (2010) and (2011) reported the TL properties of $Li_2O$-$Al_2O_3$-$B_2O_3$ glasses co-doped by $CaF_2$, Mn, LiF, and $TiO_2$ with different concentrations. From the study, these glasses are found to show a good linear response to high-dose gamma-ray. However, it has not been thoroughly studied. According to our knowledge, the optical, structure, and TL properties of $Li_2O$-$Al_2O_3$-$B_2O_3$ based glass activated by $Dy^{3+}$ have not been reported up to now. The research framework of the thesis is illustrated in Figure 1.1.

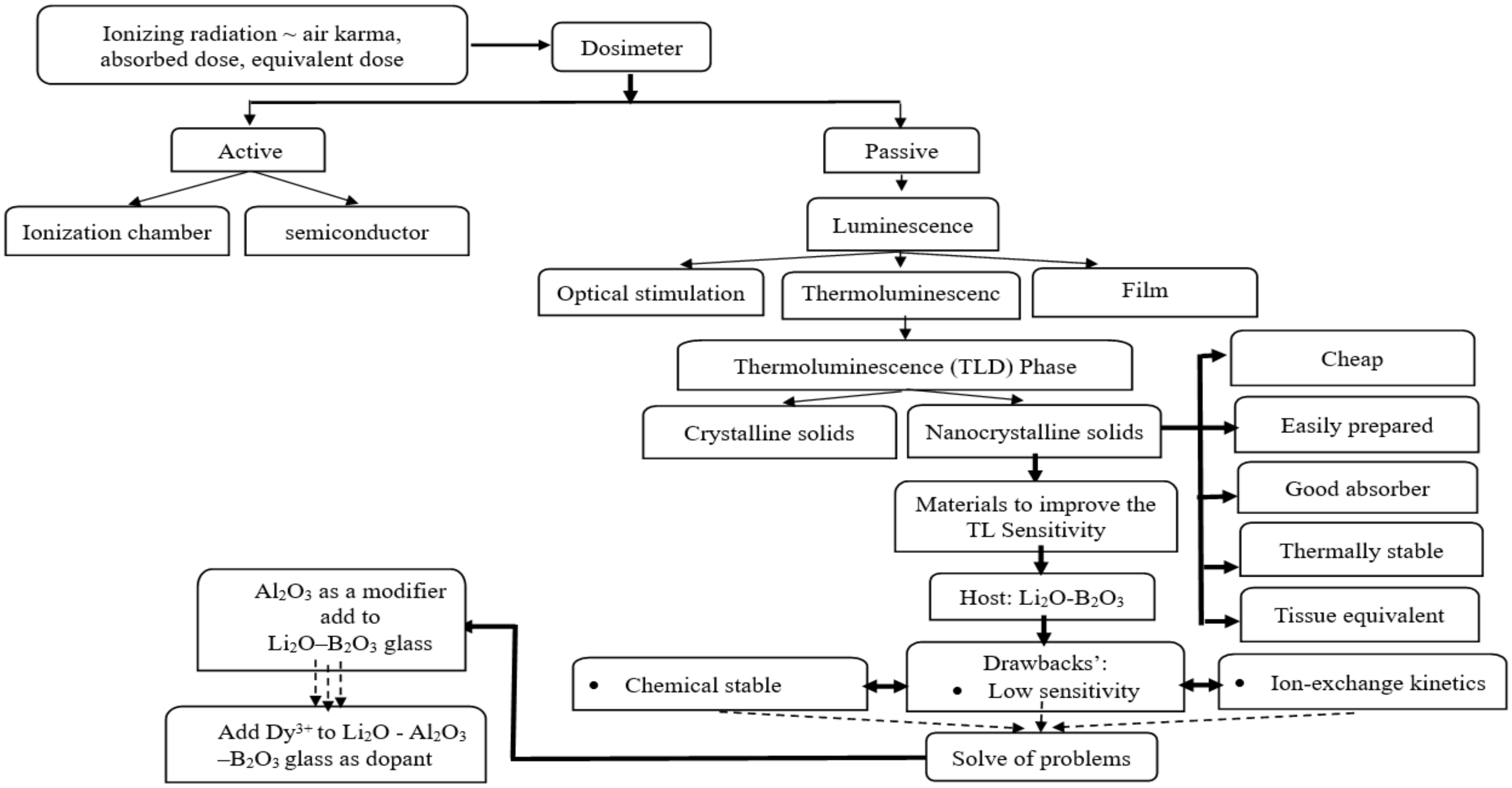

Figure 1.1 : Research framework for this study

## 1.3 Research Objective

### 1.3.1 General Objective

This study proposed $Li_2O–Al_2O_3–B_2O_3$-based as novel materials for dosimetric applications and to evaluate the influence of rare-earth dopant dysprosium oxide ($Dy_2O_3$) on its TL properties. This work also evaluates the glass system's physical, structural, and optical properties.

### 1.3.2 Specific Objective

Specifically, this thesis embarks on the following objectives:

i. To synthesize and evaluate the physical properties of the proposed glass of LAB and the influence of ion $Dy^{3+}$ for an understanding of their structure.

ii. To investigate the glass formulation's optical, structural, and TL properties of the $23Li_2O$-(69.5-x) $B_2O_3$-$7.5Al_2O_3$: x $Dy_2O_3$ where $0.0 \leq x \leq 3$ by using PL, XRD, FTIR, and TL reader.

iii. To establish the optimum time-temperature profile (TTP) of the proposed TL dosimeters of the glasses.

iv. To evaluate the TL kinetic parameters, TL glow-curve, fading, photon dose-response, reproducibility, sensitivity, and effective atomic number ($Z_{eff}$) of the proposed dosimeters to find their applicability for passive dosimetry.

## 1.4 Thesis Outline

Six chapters make up this thesis. The following is a synopsis of each chapter;

**Chapter 1** provides an introduction to the research background, and a problem statement and objectives for the research are also included.

**Chapter 2** provides the literature review, which contains scientific facts such as TL materials, glass formation, borate glass, and materials used in this study. We review previous investigations and related work in the second section of this chapter.

**Chapter 3** covers the theories, mathematical equations, and models utilized in work.

**Chapter 4** outlines the instruments and techniques used throughout the study to get findings and perform the project. These devices are separated into characterization analysis such as XRD and FTIR, optical properties such as (PL), and TL investigations (Ionizing radiation sources and TLD-reader) devices.

**Chapter 5** covers the experimental findings mentioned in Chapter 4. These outcomes comprise the outputs from the glass composition, the characterization of analysis and PL characteristics, and the TL measurements.

Finally, **Chapter 6** summarizes the study of findings and recommendations for future studies.

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# LIST OF PUBLICATIONS

## Journal article

Aljewaw, O. B., Khalis, M., Karim, A., Kamari, H. M., Hafiz, M., Zaid, M., Noor, N. M., Nurzawani, I., Isa, C., Hasan, M., & Mhareb, A. (2020). Impact of $Dy_2O_3$ Substitution on the Physical, Structural and Optical Properties of Lithium – Aluminium – Borate Glass System. *Journal of Applied Sciences, 10*(22), 10228183. https://doi.org/10.3390/app10228183

Aljewaw, O. B., Karim, M. K. A., Kamari, H. M., Zaid, M. H. M., Salim, A. A., & Mhareb, M. H. A. (2022). Physical and spectroscopic characteristics of lithium-aluminium-borate glass: Effects of varying $Nd_2O_3$ doping contents. *Journal of Non-Crystalline Solids*, *575*(July 2021), 121214. https://doi.org/10.1016/j.jnoncrysol.2021.121214

Aljewaw, O. B., Karim, M. K. A., Zaid, M. H. M., Halimah, M. K., Noor, N. M., Mhareb, M. H. A., & Alajerami, Y. S. (2021). Impact of $Al_2O_3$ and $Dy_2O_3$ substitution on the physical, structural and radiation shielding properties of $Li_2O$-$B_2O_3$ glass system. *Journal of Sains Malaysiana*, *50*(10), 3127–3138. https://doi.org/10.17576/jsm-2021-5010-24

## Conferences attended

Osama Bagi Aljewaw, M.K.A Karim, M.H.M Zaid, H.M Kamari, N.M Noor, Structural and Optical Properties of glasses based on $Li_2O$-$B_2O_3$ glass with $Al_2O_3$ as a modifier and doped $Dy_2O_3$ system. *11th International Fundamental Science Congress (IFSC (IFSC2019), UPM Putrajaya Serdang Selangor .30-31th August 2019*

Osama Bagi Aljewaw, Muhammad Khalis Abdul Karim1, Halimah Mohamed Kamari, Mohd Hafiz Mohd Zaid, Noramaliza Mohd Noor and Noriza Mohd Isa, Influence of annealing temperature and heating rate on the thermoluminescence properties of Lithium Alumina Borate glass doped with $Dy^{3+}$ .*4th International Forum on Advances in Radiation Physics (IFARP-4), Riyadh – Saudi Arabia. 27 – 31th March 2022*

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