DEVELOPMENT OF ALUMINIUM-LITHIUM-ZINC OXIDE BORATE GLASS ACTIVATED WITH DYSPROSIUM (DY+3) FOR ENHANCED RADIATION DOSIMETRY APPLICATIONS

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by

EFENJI GODWIN IRINAM

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DEDICATION

I dedicate this work to almighty God.

To my dear parents

Whose love, kindness, patience, and prayer have brought me thus far.

To my beloved wife

For her love, understanding and support through my endeavour.

To my children

Whose presence fills my life with joy.

To my brother and sisters

For their endless prayers and support

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LIST OF SYMBOLS

c	Celsius Degree
f	Fahrenheit Degree
α	Alpha Particle
β	Beta Particle
γ	Gamma Rays
λ	Wavelength
υ	Frequency
Ʈ	The Average Lifetime of an Electron in a Trap
ΔE	Energy of the Photoelectron
η(E)	The Energy Dependent Prorated to the TL Efficiency
σ	Standard Deviation
σT/D	The Relative Total Standard Deviation
σs	Relative Standard Deviation
φ	The Intensity at Time t
BI	Levels of Band Gap
B*	The Average TL Background
b	Kinetic Order
c	Velocity of Light
C	Coulomb
C_B	Conduction Band
D	Absorbed Dose
D_o	The Lowest Detectable Dose
e	Electronic Charge
E	Energy – Activation Energy for Trapped Electron
Eγ	Energy of the Incident Photon

F	Calibration Factor
F	Ground Level
F(D)	Linearity Index
I_m	Maximum Intensity
ITL	Thermoluminescence Intensity
k	Boltzmann Constant
M	Metastable State
m(t)	The Centres Recombination
N	The Total Density of Traps
n(t)	The Concentration of Trapped Electrons
P	Trap
S	Stopping Power
s	Frequency Factor of the Electron Trap
T	Temperature
T_m	Maximum Temperature
T_g	Glass Transition
T_c	Crystaline Temperature
V_B	Valence Band
W_i	Fraction of The Element i
Z	Atomic Number
$Z_{eff.}$	The Effective Atomic Number

LIST OF ABBREVIATIONS

BG	Band Gap
BOHC	Boron Oxygen Hole Centre
DTA	Differential Thermal Analysis
ESR,	Electro Signal Resonance
FESEM	Field Emission Scanning Electron Microscope
FTIR	Fourier transform infrared spectroscopy
FWHM	Full Width at Half Maximum
GFA	Glass Former Ability
GS	Glass Stability
ICRU	International Commission of Radiation Units
IR	Infra-Red
Kerma	Kinetic Energy Released in Materials
Al_2	Aluminium
Li	Lithium
Zn	Zinc
B	Borate
Dy^{3+}	Dysprosium
LiB_3O_5	Lithium Triborate
CS	Control Sample
LiF	Lithium Fluoride
Li_2CO_3	Lithium Carbonate
LET	Linear Energy Transfer
MDD	Minimum Delectable Dose
MOSFET	Metal-oxide Semiconductor Field Effect Transistor
PC	Personal Computer
PL	Photoluminescence
PMT	Photomultiplier Tube
RCF	Read Calibration Factor

RER	Relative Energy Response
RSD	Relative Standard Deviation
SEM	Scanning Electron Microscope
SSD	Source Skin Distance
SSDL	Secondary Standard Dosimeter Lab
TA	Thermal Analysis
TL	Thermoluminescence
TLD	Thermoluminescence Dosimetry
UV	Ultra Visible
XRD	X-Ray Diffraction

LIST OF APPENDICES

PENGEMBANGAN KACA BORAT OKSIDA ALUMINIUM-LITHIUM-ZINK YANG DIAKTIFKAN DENGAN DISPROSIUM (DY+3) UNTUK APLIKASI PENINGKATAN DOSIMETRI RADIASI

ABSTRAK

Dalam kajian ini, kaca borat aluminium–litium–zink yang didopkan dengan Dy^{3+} telah dirumuskan sebagai pengganti dosimeter termoluminesen tradisional yang berdaya maju dengan menawarkan kepekaan yang lebih tinggi, kestabilan yang lebih baik, dan ciri optik boleh laras untuk penilaian dos radiasi yang lebih tepat. Berbeza dengan sistem yang sering digunakan seperti LiF: Mg, Ti dan $CaSO_4$:Dy, sistem kaca ini menggabungkan rangkaian borat disesuaikan dengan pengaktifan unsur nadir bumi untuk mencapai keseimbangan yang unik bagi meminimumkan kehilangan isyarat (fading), julat linear dos yang luas, dan kestabilan suhu yang baik. Kajian ini melibatkan penghasilan kaca menggunakan teknik pencairan dan pelindapkejutan cair (melt-quenching), diikuti dengan pencirian terhadap sifat fizikal, optik, dan termoluminesen kaca tersebut, dengan perbandingan dibuat terhadap bahan dosimetri komersial. Kaca yang dihasilkan menunjukkan isipadu molar sebanyak 29.78 cm^3/mol dan ketumpatan 2.675 g/cm^3. Julat jalur tenaga (bandgap) langsung dan tidak langsung masing-masing adalah antara 1.8 eV hingga 5.2 eV dan 1.3 eV hingga 3.7 eV. Kestabilan suhu sampel kaca borat Al-Li-Zn ditunjukkan melalui Analisis Termogravimetri (TGA), membuktikan kesesuaiannya untuk aplikasi dosimetri radiasi. Kegunaannya dalam dosimetri radiasi turut disokong oleh nombor atom berkesan masing-masing 9.3 dan 7.3. Imej yang diperoleh menggunakan Mikroskop Imbasan Pancaran Medan Elektron (FESEM) menunjukkan struktur yang jelas dengan taburan zarah yang seragam. Struktur kimia kaca ini didedahkan melalui Spektroskopi Fourier Transformasi Inframerah (FTIR), yang menunjukkan puncak ketara berkaitan dengan kumpulan OH, unit BO_3 dan BO_4. Kajian ini menentukan bahawa kepekatan

ideal ion Dy^{3+} ialah 1.5 dan 2.5 mol%, yang menunjukkan peralihan tenaga dengan pancaran fotoluminesens tertinggi pada $^4F_{9/2} \rightarrow {}^6H_{15/2}$, $^4F_{9/2} \rightarrow {}^6H_{j/2}$, dan $^4F_{9/2} \rightarrow {}^6H_{13/2}$. Kaca ini mempunyai faktor frekuensi sebanyak 0.74 dan tenaga pengaktifan sebanyak 1.74 eV, yang merupakan faktor penting yang mempengaruhi ciri termoluminesennya. Didapati bahawa kaca ini sensitif terhadap pancaran sinar-X; pada dos 80.0 mGy, sampel tanpa dopan dan bersama dopan masing-masing menunjukkan keamatan isyarat sebanyak 2731.08 dan 6527.9 nC/mGy. Kebolehupayaan kaca untuk aplikasi dosimetri dibuktikan melalui kebolehulangan dos sebanyak 7.1 bagi sampel yang didopkan dengan 1.5 mol% Dy^{3+}. Kaca ini juga menunjukkan kadar kehilangan isyarat (fading) adalah minimum dari semasa ke semasa, sekali gus menjamin kestabilannya. Kaca ini mempamerkan kestabilan suhu dan keupayaan penyerapan dos yang baik, menjadikannya bahan yang menjanjikan untuk aplikasi pengesanan radiasi. Semua keputusan ini menunjukkan potensi kaca borat aluminium-litium-zink yang diaktifkan dengan Disprosium sebagai bahan yang sesuai untuk kegunaan dosimetri radiasi. Penemuan ini mengesahkan bahawa kaca borat Al-Li-Zn yang diaktifkan dengan disprosium adalah bahan yang sangat sesuai untuk kegunaan dosimetri radiasi disebabkan oleh kestabilan, kepekaan, dan kebolehupayaan yang unggul berbanding dosimeter konvensional.

DEVELOPMENT OF ALUMINIUM-LITHIUM-ZINC OXIDE BORATE GLASS ACTIVATED WITH DYSPROSIUM (DY+3) FOR ENHANCED RADIATION DOSIMETRY APPLICATIONS

ABSTRACT

In this study, Dy^{3+}-doped aluminium–lithium–zinc borate glass has been formulated as a viable substitute for traditional thermoluminescent dosimeters, providing superior sensitivity, stability, and adjustable optical characteristics for accurate radiation dose assessment. In contrast to the often-utilised LiF: Mg, Ti and $CaSO_4$:Dy systems, this glass system integrates a customised borate network with rare-earth activation to attain a distinctive equilibrium of minimal fading, extensive dosage linearity, and strong thermal stability. This study involved the production of glass using the melt-quenching technique, followed by a thorough characterisation of its physical, optical, and thermoluminescent properties, with results compared to commercial dosimetry materials. The fabricated glass yields a material with a molar volume of 29.78 cm^3/mol. and a density of 2.675 g/cm^3. The direct and indirect bandgaps range was 1.8 eV to 5.2 eV and 1.3 eV to 3.7 eV, respectively. The thermal stability of the Al-Li-Zn borate glass samples was shown by Thermogravimetric Analysis (TGA), proving their appropriateness for radiation dosimetry applications. Its usefulness for radiation dosimetry was further reinforced by effective atomic numbers of 9.3 and 7.3, respectively. Images obtained using field emission scanning electron microscopy (FESEM) demonstrated a distinct structure with identical particle distribution. The chemical structure of the glass was revealed by Fourier-transform infrared (FTIR) spectroscopy, which showed prominent peaks linked to OH groups, BO_3, and BO_4 units. The study determined the ideal concentrations of 1.5 and 2.5 mol% Dy^{3+}ions showed transitions indicating peak photoluminescence emission at $^4F_{9/2} \rightarrow {}^6H1_{5/2}$,

$^4F_{9/2} \rightarrow {}^6H_{J/2}$, and $^4F_{9/2} \rightarrow {}^6H_{13/2}$. The glass had a frequency factor of 0.74 and an activation energy of 1.74 eV, crucial factors affecting its thermoluminescent characteristics. It was found that the glass is sensitive to X-ray doses; at 80.0 mGy doses, the undoped and doped samples displayed signal intensities of 2731.08 and 6527.9 nC/mGy, respectively. The glass's dependability for dosimetry applications was demonstrated by its dose repeatability of 7.1 for samples doped with 1.5 mol% Dy^{3+}. The glass showed minimum signal loss of fading rates over time, guaranteeing stability. The glass exhibited good thermal stability and absorption capability, making it a promising material for radiation detection applications. All these results indicate the possibility of dysprosium-activated aluminum-lithium-zinc oxide borate glass as a material that shows promise for radiation dosimetry. These findings establish dysprosium-activated Al-Li-Zn borate glass as a highly promising material for radiation dosimetry, demonstrating superior stability, sensitivity, and reliability compared to conventional dosimeters.

CHAPTER 1

INTRODUCTION

1.1 Overview

Any solid with an amorphous structure that undergoes a glass transition when heated is referred to as a glass. It is a solid specifically created by quick melt quenching. It is optically clear, challenging, and breakable (Satkar et al., 2021; Stanković Petrović et al., 2021). Glass can be made from various materials, including polymers, metal alloys, aqueous solutions, molecular liquids, ionic melts, etc. Usually, additional elements are added to conventional glasses to modify their physical and chemical properties (Bastos et al., 2011; Shafaei and Moradi, 2023). The physical-chemical characteristics of glasses are substantially influenced by the type of materials employed and the difference in composition. The three main components in oxide glasses are the network formers, the intermediates, and the modifiers. The network formers are a system of highly crosslinked chemical bonds. Still, the intermediates and modifiers, often present as ions, change the network structure by acting as a counterweight to the nonbridging oxygen atoms covalently bound by the glass network (Saidu et al., 2015).

The development of advanced materials for radiation dosimetry has been a focal point in scientific research, driven by the need for accurate and reliable measurement tools in medical diagnostics, radiation therapy, and nuclear energy. Among the innovative materials explored for this purpose, aluminium-lithium-zinc oxide borate glass activated with dysprosium (Dy^{3+}) emerges as a promising candidate. This cutting-edge research endeavours to harness the unique properties of this glass composition, tailored explicitly for enhanced performance in radiation dosimetry applications (Pekpak et al., 2014). In addition to their intrinsic structural versatility and optical clarity, glass materials, especially those enhanced with dopants and oxides, possess distinctive trapping and recombination characteristics that render them effective for detecting and measuring ionising radiation, thereby facilitating their use in radiation dosimetry (Stanković Petrović et al., 2021).

This research aims to elucidate the fundamental mechanisms governing the interaction between ionizing radiation and the developed glass material. The choice of dysprosium as the activator is particularly significant due to its unique energy levels and emission characteristics, offering a distinctive signature in response to radiation exposure. Understanding the intricate details of the luminescent response of the aluminium-lithium-zinc oxide borate glass activated with dysprosium is paramount for achieving precise and reliable radiation dose measurements (Alajerami et al., 2019).

The potential applications of this advanced glass material extend across diverse fields, including medical dosimetry, where accurate radiation measurements are crucial for optimizing treatment plans and ensuring patient safety. Moreover, in nuclear energy and industrial settings, where precise dosimetry is essential for monitoring radiation exposure levels, this research promises to provide a sophisticated and efficient solution (El-Faramawy et al., 2021a).

As we delve into developing this novel material, the goal is to contribute to the evolution of radiation dosimetry technologies, offering a material that exhibits high sensitivity and accuracy, and addresses challenges associated with traditional dosimetric materials. This interdisciplinary research at the intersection of materials science, physics, and dosimetry underscores the commitment to advancing technology for improving healthcare, safety, and industrial practices (Furetta et al., 2001).

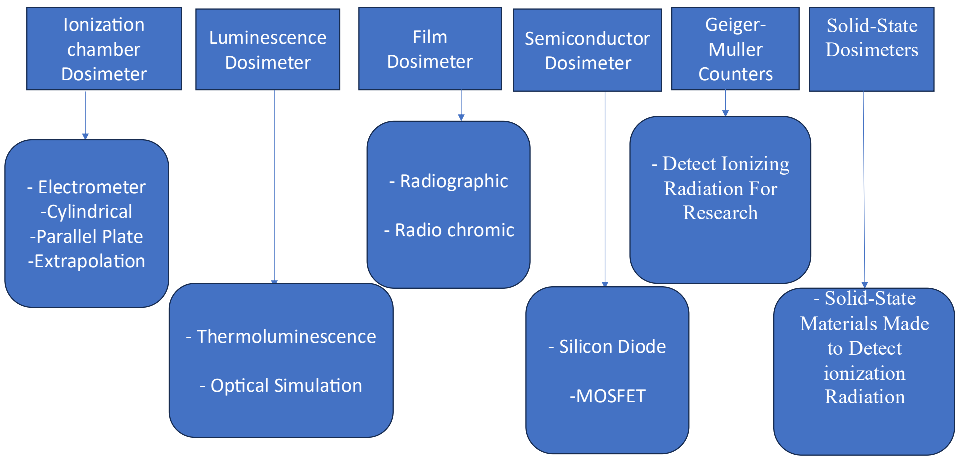

Figure 1.1 The Most Popular Dosimeters for Ionizing Radiation Measurement

The many kinds of radiation detectors and measurement devices used in the environmental and medical domains are depicted in Figure 1.1 (MOSFET: metal-oxide-semiconductor field effect transistor and diamond detectors). The dosimeter and readout device are components of passive dosimetry systems. As a result, the information will not be available immediately. An active dosimeter is a device that directly detects ionising radiation for environmental and personal monitoring. It may deliver results, such as dose and dose rate, instantly (Konnai et al., 2008).

Additionally, several admixtures are examined following the specifications of suitable dosimeters. These dosimeters are thought to be the most widely used ones, especially in medicine and the environment (Moscovitch and Horowitz, 2006; Swinnen et al., 2004). The uses and chemical makeup of the TL phosphors are displayed in Table 1.1.

Glass has become a material of choice because of its versatility and range of uses, from commonplace containers to cutting-edge technology components. Some glasses have an exciting characteristic called thermoluminescence, which makes them useful for radiation and dosimetry applications (Oliveira et al., 2014; Satkar et al., 2021). This conversation examines glass's thermoluminescent qualities, going into the mechanisms, uses, and future directions for this research. Glass's thermoluminescent qualities, caused by activator ions, make it an excellent material for various applications in dating, environmental monitoring, and dosimetry (Moscovitch and Horowitz, 2006; Swinnen et al., 2004). Ongoing research aims to improve performance characteristics like linearity, sensitivity, and others to increase the possible uses of thermoluminescent glass in radiation-related domains (Azorin, 2014; Godwin et al., 2023b).

Borate glasses are used as thermoluminescence dosimeters in medical applications and for personal monitoring. Furthermore, this dosimeter was preferred above the other phosphors due to its excellent availability and inexpensive manufacturing cost (Depçi, T. et al., 2008). Lithium borates' appealing chemical, physical, and optical characteristics provide opportunities to improve TLD efficiency. Lithium borate is a surface acoustic wave that enhances electrical circuits (Sinclair & Pech-Canul, 2022) moreover, using lithium borate as a piezoelectric and pressure probe produced extremely encouraging outcomes (Mhareb et al., 2020). The first lithium borate dosimeter was a manganese-doped lithium tetraborate $Li_2B_4O_7$ with poor TL sensitivity. This limitation is ascribed to the incompatibility between the photomultiplier tube sensitivity of the TLD reader and the region of trapped electron emission (600 nm) (Prokie, 2002).

The effectiveness of lithium borate as an ionising radiation detector has been demonstrated by numerous research. Based on the type of dopant and modifier materials added to the borate host, the results demonstrate a change in the dosimetric properties (sensitivity, dosage dependency, energy response, fading, and reproducibility). Furetta et al. (2000) reported that the light curve of lithium borate exhibits two distinct and separated glow peaks. The glow curve, which creates a schematic spectrum to show the relationship between the strength of TLD signals and the heat treatment that traps electrons between the valence and conducting areas, is shown in Figure 1.2.

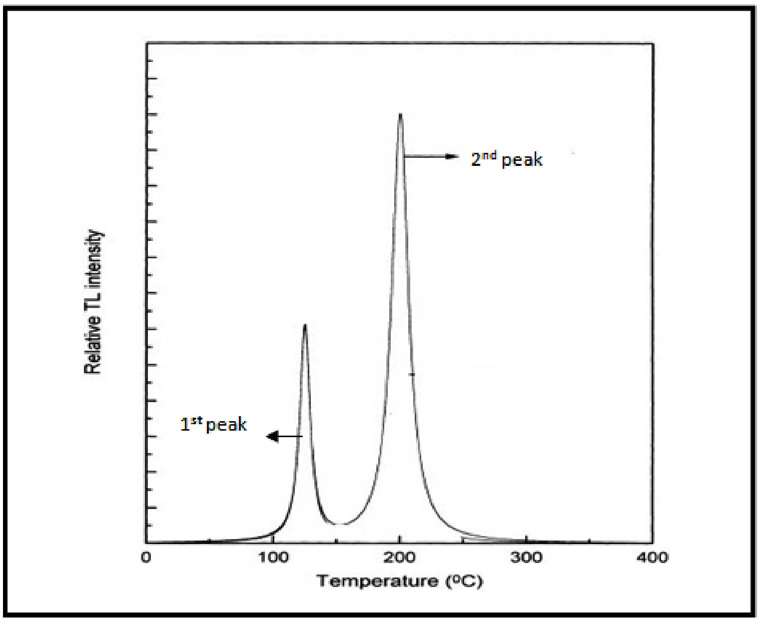

Figure 1.2 The Two TLD Peaks Caused by the Thermal Induction of Lithium Borate (Furetta et al., 2001)

Figure 1.2 shows that the lithium borate forms two distinct peaks, the first of which emerged at 125 ^{0}C and the second at 200 ^{0}C. After a full day of radiation, the first peak declines (disappearance). The supersaturating condition happened at 1 Gy and 103 Gy for the first and second peaks, respectively (Furetta et al., 2001). Attractive results were obtained after activating the lithium bromide lattice with co-dopants of copper (Cu) and indium (In) (Kaur et al., 2017; Prabhu et al., 2021).

1.2 Problem Statement

The risk associated with radiation dispersion increases with increasing therapeutic dose due to the complexity of modern radiotherapy treatment systems. One efficient dosimetry technique for lowering these risks and raising treatment quality is in vivo dosimetry. TLDs, or thermoluminescence dosimeters, are the best option for in vivo dosimetry due to their affordability, versatility, and small size. It is appropriate to use tissue or whole-body TL dosimeters with high sensitivity (Godwin et al., 2023; Moradi et al., 2022).

TL materials that are most used compromise one of their advantageous characteristics. LiF is considered tissue-equivalent due to its similar atomic composition to human tissue; for example, it can be doped with Mg, Ti, $Li_2B_4O_7$ doped with Cu or Mn contaminants, or Be_2O_3 doped with different impurities, although its sensitivity is limited. LiF: Mg, Cu, P phosphor (TLD-100H) exhibits high TL sensitivity but suffers from complex glow curve behaviour, irreversible sensitivity loss, and unstable annealing properties. This necessitates alternative dosimetric materials with enhanced thermal stability and response consistency, such as Dy^{3+}-doped Al-Li-Zn borate glass. Furthermore, a shift in the glow curve caused by annealing TLD-100H at 240 ^{0}C causes irreversible sensitivity loss, leaving a sizable residual dosage (Pekpak, E et al., 2010).

The LiF: Mg, Cu, P (TLD-100H) and LiF: Mg, Ti (TLD 100) have remarkably low dose sensitivity thresholds of 10 Gy and 1 Gy, respectively. Furetta et al. (2000) report that the dosimeters have about equal energy sensitivities over a 100 keV range; however, TLD-100 reacts poorly to lower-energy X-rays, whereas TLD-100H underreacts to the same energies. LiF: Mg, Cu, P, and Al_2O_3:C materials' high sensitivity to dosage. The TL of materials decreases as the ionised densities of the radiation field grow, which could lead to an underestimation of the dosage at high-charged particle irradiation (El-Faramawy et al., 2021a).

Furthermore, the preparation procedures for the standard industrial TL dosimeters and the lithium fluoride series, TLD-100, TLD-600, and TLD-700, are all difficult (Bengisu, 2016). Both TLD-400 and TLD-800 domain names are available. The radiation detectors showed a continuous dosage range of 0.1 Gy to 10 Gy for TLD-200 and 1 Gy to 100 Gy for TLD-400 and TLD-800 when exposed to Co-60 rays (Bengisu, 2016). Furthermore, using TLDs for postal radiation dosimetry assessments is restricted to the proper use of available TLD powders. There are several disadvantages to the highly sensitive MgB_4O_7 TL dosimeters used in Yugoslavia for radiation protection that was authorised by law. One limitation of the MgB_4O_7 TL dosimeter that has been mentioned is its light reactivity, which causes optical fading. Batch variability and sensitivity reduction are caused by the high moisture content of the MgB_4O_7 TL dosimeters (Stanković Petrović et al., 2021).

The sensitivity, stability, and cost-effectiveness of today's radiation dosimetry materials are all challenged. The accuracy and dependability of traditional dosimeters may be limited, particularly under specific environmental circumstances. The need for advanced materials with better dosimetric qualities has prompted the search for novel glass systems. Commercial TLDs encounter constraints, including inadequate tissue equivalence and degradation; however, the proposed Dy^{3+}-doped aluminium-lithium-zinc-borate glass presents a cost-effective, trap depth, elevated activation energy, and efficient 4f–4f transitions, which enhance thermoluminescence sensitivity, stability, and reproducibility relative to other rare-earth dopants. thermally stable, optically transparent alternative with commendable TL performance, warranting its advancement in the context of contemporary research on rare-earth-doped glasses and other novel dosimetric materials (Rivera, 2012; N. Seth et al., 2024).

The project will look at the synthesis, characterization, and dosimetric performance of this glass system to assist in developing more precise and effective radiation dosimeters for various industrial, medical, and research applications.(Godwin et al., 2023; Mhareb et al., 2020).

1.3 Objectives of The Study

1. To synthesize and characterize Dy^{3+}-doped borate glass compositions for thermoluminescent (TL) dosimeters.
2. To optimize Dy^{3+} ion concentration to achieve maximum TL efficiency, stability, and dosimetric accuracy.
3. To evaluate the TL performance of the fabricated glass in terms of sensitivity, dose response, reproducibility, fading, and effective atomic number.
4. To investigate key thermal and structural parameters, including phase transition behaviour, TL glow curve characteristics, and thermal stability.

1.4 Limitation and Justification

The necessity for improvements in dosimetry technology supports the research on creating aluminium-lithium-zinc oxide borate glass activated by dysprosium (Dy^{3+}) for radiation dosimetry. Commercial thermoluminescent dosimetry materials including LiF:Mg,Ti (TLD-100), BeO, and MgB_4O_7: Dy exhibits significant limitations. LiF demonstrates low sensitivity to minimal dosages and degradation; BeO presents toxicity and handling issues; MgB_4O_7 has restricted stability and necessitates high-temperature reading (Saidu et al., 2018).

LiF provides enough tissue equivalency but exhibits reduced sensitivity. Beryllium oxide (BeO) exhibits heightened sensitivity but diminished safety. MgB_4O_7-based dosimeters exhibit stability but demonstrate reduced reproducibility under fluctuating settings. All demonstrate constraints in sensitivity, environmental durability, or reproducibility under repeated exposure to irradiation (El-Adawy et al., 2010).

This research's heart is innovation, as it investigates non-traditional materials and doping methods. This proactive strategy is essential for staying up to date with developments in radiation-based technologies and guaranteeing the effectiveness and safety of applications that span from industrial radiography to medical radiation treatment. The research's interdisciplinary character creates opportunities for cooperation between radiation oncology, physics, and materials science, among other disciplines (Aljewaw et al., 2021).s

In addition to its practical applications, the research will advance basic scientific knowledge by examining the relationship between radiation and materials. Researching the suggested glass matrix triggered with dysprosium could yield insights with wider ramifications and possibly spur more advancements in adjacent fields. Dy^{3+}-doped aluminium-lithium-zinc-borate glass solves these constraints by offering increased thermoluminescence intensity, improved stability, low fading, and good repeatability due to efficient electron trapping and recombination pathways facilitated by Dy^{3+}. The borate network promotes rare-earth ion dispersion while lithium and zinc oxides contribute to transparency and thermal stability, making it a promising alternative to conventional TLDs for personal and environmental radiation monitoring.
(Aljewaw et al., 2021).

1.5 Thesis Outlines

The scope of the research on the development of Aluminium-Lithium-Zinc Oxide Borate glass activated with Dysprosium (Dy^{3+}) for radiation dosimetry encompasses several dimensions, reflecting the breadth and depth of the study. Here are vital aspects of the research scope organised into five chapters:

Chapter 1 presents the background, problem statement, objectives, and research contributions. In addition, this chapter summarizes the importance of choosing the new glass dosimeters.

Chapter 2 contains a review of the literature. It comprehensively summarises optical characteristics, thermoluminescence phenomena, TL parameters, and a concise synopsis based on general knowledge about borate compounds and glass forms. Furthermore, additional information based on the glow curve must be obtained by applying the theoretical equation (kinetic energy parameters: activation energy, frequency factor, and degree of binding energy). The physical and chemical ideas about the dosimetric qualities are also covered in this chapter. For instance, annealing condition, energy dependency, dose rate effect, repeatability, relative energy response, and glow curve parameters.

The equipment and procedures utilised in the research to obtain the necessary data and complete the project are covered in Chapter 3. This equipment can be categorised into three groups: thermoluminescence studies (Ionising radiation sources and TLD-reader), optical properties (PL and UV-VIS-NIR spectrophotometer), and characterization analysis (XRD, FTIR, FESEM, and DTA).

The results of the glass composition are given in Chapter 4. The first of this chapter's three sections explains how the newly created samples were characterised. These subsequently clarify the new compounds' optical and thermoluminescence characteristics. More specifically, the comparison and the results are well explored.

Chapter 5 concludes by summarising the significant conclusions from this study that justified the aim and making several recommendations for more research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Radiation

Radiation is the energy released from a source that travels in space and even through various materials. Radiation is classified more often into two type types: ionizing and non-ionizing radiation. Non-ionizing radiation is also known as low-energy radiation. Less energetic forms of radiation such as infrared, visible light and ultraviolet (UV) do not have sufficient energy to remove an electron from a molecule or atom. High-energy ionising radiation can also exited and impair the electrons of molecules or atoms (Vinodkumar et al., 2024). It can be divided into protons and charged particles like alpha and beta. X-rays, gamma rays, and neutrons are examples of uncharged particles (Cormier, 2020; Godwin et al., 2023).

Researchers in radiation include a number of fields like science, medicine and industry along with environment. Since ionizing and non-ionized radiations are distinct in their nature yet both represent critical technologies for various applications, gaining knowledge of the effectivity on biological systems as well as materials radiation upon the environment is highly valuable.

The biologic effects of ionizing radiation have been well studied in biology and help to understand the cellular injury caused by irradiation. (El-Faramawy et al., 2021a). Linear no-threshold (LNT) model, which is a commonly agreed approach have been questioned by new findings that underline the necessity for an advanced comprehensive methodology to assess health consequences in low dose radiations and potential adaptive responses respectively (Vinodkumar et al., 2024; Yılmaz and Akkuş, 2024). Radiation in Medicine Radiation is used often as a tool for treating cancer, and to diagnose it. Advancements in medical imaging technology strive to maximize radiation doses whilst maintaining diagnostic efficacy. In the case of radiation therapy, a pillar in cancer control since decades and still evolving involving tailored strategies integrating precision oncology along with advanced imaging for optimal therapeutic gains sans toxicity (G I Efenji et al., 2024).

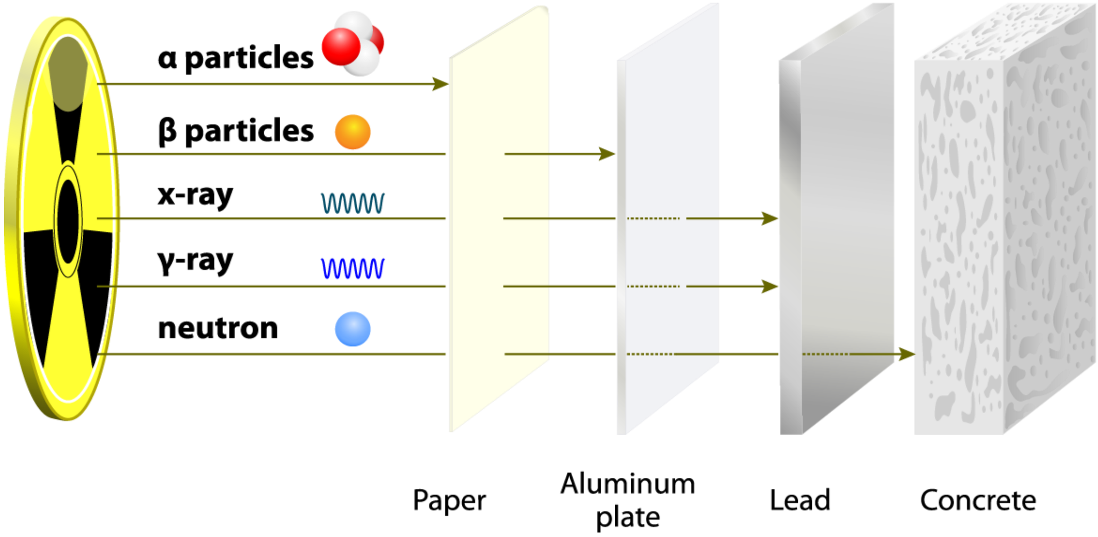

Figure 2.1 Basic Types of Radiation and Their Penetrating Power (Efenji, et al., 2024)

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2.1.1 X-Ray Production

X-rays have been used for over a century to image the inner workings of matter and organisms alike, aiding scientific inquiry, industrial applications as well as medical imaging. There have been ground-breaking advancements in the basic laws governing X-ray production that influence how efficient, safe and accurate an X-ray system will be used across different scenarios. Wilhelm Roentgen's 1895 discovery of X-rays provided the foundation for further research to understand and ultimately improve upon this process of producing X-ray. The early X-ray tubes were primitive, and nothing was known about phenomena related to the interactions of things with X-rays. Because researchers began to explore the physics of X-ray production, they also developed more advanced X-ray tubes and associated systems (Thomas et al., 2019).

At standard diagnostic X-ray energies (e.g., 80 kVp), the predominant interaction is the photoelectric effect, leading to the ejection of inner-shell electrons. The expelled electrons generate electron-hole pairs that may be confined in defect sites within the glass matrix, particularly those affected by dopant ions like Dy^{3+}. The energy accumulated in these traps is then emitted as light when heated, constituting the foundation of thermoluminescence (White et al., 2024).

Comprehending these interactions is essential for validating the choice of particular glass compositions and X-ray parameters employed in dosimetry research. The efficacy of charge trapping and subsequent luminescence is directly affected by the glass network architecture and the mechanisms of radiation interaction. Incorporating these characteristics will enhance the theoretical framework of the research by linking the physics of X-ray generation to the practical response of the dosimetric material, thus validating the material's appropriateness for precise radiation dosage measurement (Murthy, 2014).

Figure 2.2 highlights that the first step in creating X-rays is to subject a target material (often tungsten) to high energy electron bombardment. This interaction is responsible for two main types of X-ray production: Bremsstrahlung radiation and characteristic X-ray. Perhaps the single most important step in X-ray production was made with the advent of rotating anode x-ray tubes and so greatly increased power (and decreased exposure times). The objective of advancements in X-ray tube designs have been to strike a delicate balance between maximal radiation dosage reduction for both patients as well as operators with highest possible efficiency of generated X-rays. These technologies have advanced image quality and reduced dose, through innovations like digital radiography systems as well high frequency X-ray generators (Vallejo et al., 2020).

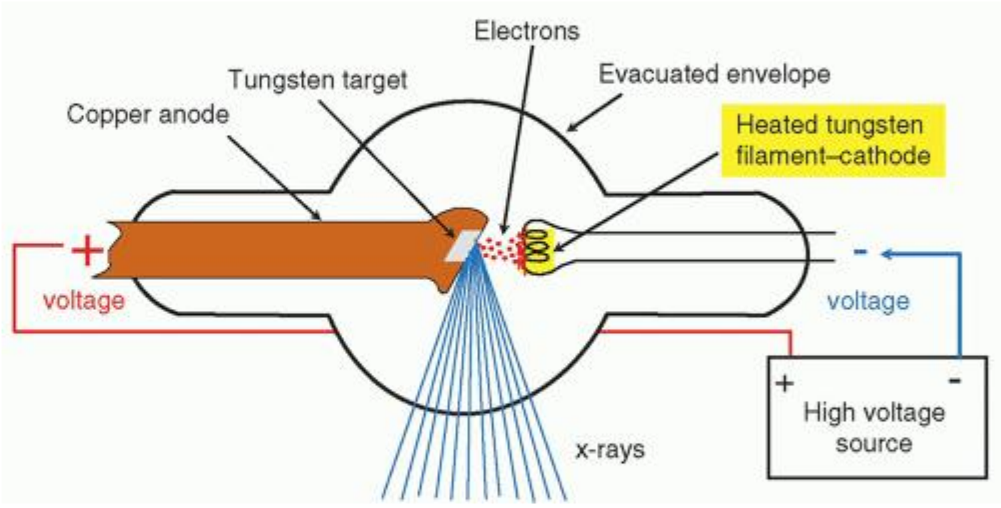

Figure 2.2 Schematic Diagram of X-ray Production

2.1.2 Types of Radiation

Overview of the four main types of ionising radiation (from Fig. 2: gamma, beta, neutron and alpha They all come with unique and different features) (Efenji, G. I., et al., 2022). Alpha radiation occurs when an unstable nucleus gives off two protons and two neutrons which is just a helium nucleus, the original atom transforms into another element due to fewer number of protons and neutron. They are heavier than other types of ionizing particle radiation. These are, however, useful in those devices that have a limited range (e.g., smoke detectors). Just a few inches of air, a piece of paper or even your skin will be enough to stop them (Bengisu, 2016).

An atom during its decay, releases a high-energy, fast-moving particle that can have either a positive or negative charge; this is beta radiation. The so-called "beta" particles are smaller and more energetic that alpha particles. There are two types of beta decay. A negatively charged particle leaves the nucleus, which is called as "beta minus decay". The negative beta particle, or electron (though it comes from the nucleus rather than the electron cloud that orbits around an atom. Since positively charged particles are called positrons, so kicking a positive out of the nucleus is beta plus decay or also known as emission. They have the same mass as electrons (Azorin, 2014).

Beta-minus decay occurs when an atom has more neutrons than protons. Stable Neutron goes transforms into Proton and electron. The proton remains in the nucleus, and an electron (beta minus particle), is emitted. This gains one proton and loses a neutron, so the atomic number of this atom increases by 1. There are always the same number of nucleons, so the mass number stays constant. This is beta plus decay or positron emission, and it happens when an atom has more protons than neutrons. An unstable proton changes to a neutron and in the process emits its excess energy as radiation. If the nucleus gains a neutron while losing a proton, one unit falls off from the atomic number and accordingly we get another element. Though, the individual masses of those nucleons are quite smaller and their increased energy makes a relatively minor change in mass occurring through that particular specific proton capture (Godwin et al., 2022; Mhareb et al., 2020).

Wattage high-energy waves like X-ray and gamma radiation can traverse great distances at the speed of light. Both have high penetration depth into matter. Lead, tumours and bone are all denser than flesh, so they block X-rays. As such, they are useful tool in diagnostic medicine. Along with insulation, which would enable the habitat to withstand repeated gamma ray flares at both human and higher-intensity energy levels. On top of endless applications in manufacturing, agriculture and pest control to name a few, gamma radiation can be focussed precisely on tumours causing destruction with quite accuracy. Just a few inches of lead can stop gamma rays (Wahab et al., 2020).

Ionising radiation, including X-rays and gamma rays, transfers energy via processes such as the photoelectric effect and Compton scattering, producing charge carriers within the glass. In borate-based glasses doped with Dy^{3+}, these carriers are captured and subsequently emitted as thermoluminescent light, which underpins radiation dosage assessment. Therefore, comprehending the various forms of radiation is essential for assessing the efficacy and sensitivity of these glasses in dosimetric applications.

2.2 Radiation Glass

For professionals who use dosimeters in their everyday jobs, the Radiation Glass appears to be a potential addition to the field of radiation safety. It strives to achieve a delicate balance between clarity and protection with its sturdy construction and stylish style (Vinodkumar et al., 2024; Wang et al., 2017). Radiation Glass is well-built, meaning it can withstand the rigours of various industries, including nuclear power and healthcare. The glass's minimal interference with dosimeter readings stems from its high-quality construction, and its frame ensures a snug and unnoticeable fit. The Radiation Glass excels at compatibility, supporting a broad range of dosimeter models and sizes. Due to its versatility, it's an excellent option for professionals who use various dosimeters in various circumstances (Godwin et al., 2023a; Mhareb et al., 2020).

The Radiation Glass cap takes the lead in terms of simplicity; Its light weight keeps the dosimeter unburdened, and installation or removal is easy. This is another benefit, as the clear instructions make it ideal for everyone from novices to experts

(Świontek et al., 2021).Radiation Glass is a good and commendable instrument for all those maintaining at radiation susceptible places. It is exciting in exploring the accuracy and safety owing to its friendly user interface, sleek design capability containment as well ultra-strong anti-radiation (Altunal et al., 2022). It is a reliable and useful tool for those who want to ensure that they are protected, as well as measuring radiation doses properly in the working place (although there still something could do about it). As always, prospective buyers should verify credentials and details to confirm the device is appropriate for their worksite and dosimeter requirements (Bulus et al., 2017; El-damrawi, 2021).

2.3 Glass Formation

Glass Formation has emerged as a novel method for enhancing radiation dosimeter performance, which is significant in the field of radiation safety. This new accessory may provide radiation protection while preserving the basic utility of dosimeters and adding one more layer for shielding. This new addition cause to the radiation protection parameter without loss any functional performance of dosimeters with a coating layer (Yılmaz and Akkuş, 2024, 2024). Perhaps the most striking lottery of contemporary design Glass Formation is remarkable for its simplicity and success as a concept. Its materials are selected for a facilitated trade-off between transparency and protection against radiation. This is necessary to ensure accurate dosimeter readings, which then will give us a boost in defence against dangerous radiation (Azorin, 2014; Wahab et al., 2020).

The compatibility with numerous dosimeter models is one of its key features and can be used by glass formation. The versatile attachment will allow professionals who use more than one dosimeter in a variety of working conditions to retain easy use with multiple devices. The design of glass formation care its translucency and transparency (Yılmaz and Akkuş, 2024), so any dosimeter accessory must take that into account. Dosimeter displays can be read very easily, since it is hard to distort the material. This is critical in ensuring that radiation dose estimates remain accurate (Sinclair and Pech-Canul, 2022).

One of the interesting inventions in radiation dosimeter accessories is glass formation. While it can be read by the dosimetry, a preferred choice for users due to its effectiveness nonetheless in radiation protection without affecting clearness or compatibility and blocking this material (Gul et al., 2024). While additional data on in-field performance, with user feedback provided to define its utility more completely Glass formation shows efficacy as a valuable resource for radiation sensitive experts. It is important for users to verify that glass formation works with their dosimeter models and workplace rules, reviewing the specifications and certifications provided by manufacturers (Azorín et al., 1993; Reddy, 2008).

The configuration of BO_3 and BO_4 units in borate glasses markedly affects the entrapment and recombination of charge carriers, hence directly impacting thermoluminescence intensity and stability. Dopants such as Dy^{3+} function as network modifiers by generating localised distortions or faults that create trapping centres within the matrix. These centres augment thermoluminescent characteristics by enhancing charge capture and prolonging recombination, essential for dose-dependent luminescence.

2.4 Glass Network

Glass formation is a very interesting advancement in radiation dosimeter peripherals. It is a clear choice with its ease of use, compatibility and significantly reduced radiation dose alone solution for those interested in bettering radiation safety without compromising dosimeter-reading accuracy as well (Gul et al., 2024). While further in-field testing and user feedback may help with a deeper understanding of how it works, Glass formation showed potential as resource for experts working within such radiation-sensitive environments. To check the specifications of your model and compatibility with workplace regulations, customers are encouraged to confirm that their dosimeters models accommodate glass formation (Gul et al., 2024; Munir, et al., 2024).

Glass is a material used as the medium of sensing in glass network dosimetry. Due to its natural stability, permanence and transparency for dosimeter applications glass is suitable. The glass sensors allow exact tracking of the radiation exposure over time, which provides further information when assessing possible health concerns and to ensure compliance with safety regulations (Reddy, 2008; S.W.S. McKeever, 1995). These Dosimeters Can Be Easily Fitted in an Extensive Network Enabling Data Collection and Real-Time Monitoring (Altunal et al., 2020). According to BK Medical, this link enables prompt transfer of data to centralised systems for an instantaneous response in the event of unexpected radiation exposure. That capability is indispensable in environments of high risk where swift action can mitigate the consequences, including nuclear power plants and hospitals (Bulus et al., 2017).

Glass network ideas also include advanced technology, such as Internet of Things (IoT) sensor capabilities that can improve dosimeter performance even more. By including sensors that track environmental data and radiation dose, dosimeters can provide researchers with a comprehensive view of the factors involved in radiation exposure. This integrated process facilitates the deployment of safety measures and strategic decision making (Murthy, 2014; Senyshyn et al., 2010).

2.4.1 Network Modifiers

The ability to capture low-level radiation events enhances the dosimeter's utility in diverse contexts, contributing significantly to safety and regulatory compliance (Sen et al., 2023). Accuracy is another critical dimension influenced by network modifiers. Through the fine-tuning of calibration processes, these modifiers ensure that dosimeter readings are not only sensitive but also highly accurate. This precision is indispensable for maintaining trust in the reliability of dosimeter data, especially in situations where radiation exposure must be monitored with the utmost precision for safety and compliance (Duragkar et al., 2019; Pekpak et al., 2014)

The highlighted area of network modifiers is represented by the connectivity features that make dosimeters gain greater functionality beyond a simple monitoring device and evolve into smart devices. Real-time communication and connectivity features for remote handling, data transmission and immediate alert on radiation occurrence (Thabit et al., 2023). Having this real-time capability can be an asset in the form of timely response to help mitigate risk. In addition, the inclusion of dosimeter data in broader safety systems improves overall radiation protection strategies (Duragkar et al., 2019; Jaidass et al., 2018).

Robust Network Modifiers are included to increase durability and longevity. The use of materials inherently resistant to this extreme environment in the construction of environmental-resistant dosimeters made it possible for these instruments to operate reliably under such challenging conditions. This is especially important when extended monitoring periods are required (Bengisu, 2016). Dosimeters further can be even more adaptable with network modifiers, tailoring them according to the radiation type and application. This flexibility allows dosimeters to be tailored for different industries and environments, which demonstrates their adaptability and utility in meeting specific needs (P. Seth et al., 2023; Thabit et al., 2023).

Improving on ordinary dosimeters, network modifiers built into the measurement device have advanced radiation monitoring abilities. Together, the myriad effects on sensitivity, accuracy, connectivity, durability and adaptability combine to dramatically elevate dosimeters that incorporate these modifiers into a position of technological leadership supporting both individuals and environments from any danger potentially posed by radiation exposure. While that provides a great step in forward, the development of network modifiers within dosimeters as technology progresses promises additional improvement to radiation monitoring and safety (El-Adawy et al., 2010).

2.4.2 Intermediate Modifier

One important advance in radiation monitoring technology is the attaching of so-called intermediate modifiers to dosimeters, which closely orchestrate moderate improvements among all areas. These different moderators, which fit between more advanced technologies and basic dosimeter components contribute to the overall efficacy of radiation monitoring devices (Stanković Petrović et al., 2021). One of the important applications for intermediate modifiers is taking inner quo capability sensitive dosimeters. This intermediate level can be achieved by adding some specialized materials or technology to the dosimeters which could help to detect lower exposure of radiation. This is critical in all cases requiring radiation detection, as it detects the smallest changes that can be expected and ensures a wider range of detected radiation levels (Ahmad et al., 2020).

Accuracy is also another area that intermediate modifiers have a positive effect on. Calibration of dosimeters with these modifiers improves the certainty that measurements are relevant, reliable and sensitive. Such improved accuracy is especially important for robustness in applications where adherence to high H&S standards simply has no alternative (Hamzah et al., 2017; Stanković Petrović et al., 2021).

Intermediate modifiers often lead of two material and technology evolutions that divide mainstream dosimeter elements from futuristic concepts. By taking this compromise approach, incremental improvements are achievable without having to restart from scratch on a dosimeter design. Applying these modifiers will facilitate a smoother move from traditional dosimetry methods to modern technology, making it more accessible and feasible for more applications (Saidu et al., 2015).

Intermediate modifiers for modifying the network also create an impact on connectivity and communication function at some extent, but not like that of advanced ones. More efficiently equipped dosimeters with intermediate enhancements will be able to transfer data effectively which would, in turn facilitate more effective radiation exposure monitoring and analysis (Sundararaman et al., 2020). But these intermediate features combine to make for an easier-to-use and more integrated dosimetry system than their advanced counterparts. Longevity & durability benefits are often attributed to combining of intermediate modifiers. These additives make the dosimeters more tough and allow them to withstand challenging environments and long-term service (Rivera, 2012).

2.4.3 Modifier and Dopants

The Sensitivity, Stability and Responsivity characteristics of these materials are determined by their composition with required modifiers and dopants additionally.

Choice of detector material plays a very important role in radiation dosimetry, as the performance of dosimeter becomes dependent on it. Additionally, the sensitivity of dosimeter properties has been investigated over time with a view to optimize responses using various additives and dopants (Saidu et al., 2018).

Additives can be added to dosimeter materials, for the purpose of changing in chemical and physical properties or improving their ionising radiation response. Inorganic salts, organic chemicals and nanoparticles are usually applied as modifiers. Organic compounds such as plasticizers are most used to broadens the applicability of materials, further increasing their elasticity (Murthy, 2014).

Additionally, several previous studies have published about the use of inorganic salts as thermoluminescent dosemeter (TLD) modifier such as: lithium fluoride (LiF) and lithium borate ($Li_2B_4O_7$). Even with the most modern narrow band gap semiconductor detectors, defect engineering still plays a huge role in the final radiation sensitivity of this material. In addition, the energy response of the dosimeter may be affected by the selection of modifiers and therefore it is essential to tailor this material for radiation types (Ezra et al., 2024). The uniqueness of nanoparticles has made them popular as modifiers. Examples are the metal oxide nanoparticles titanium dioxide (TiO_2) and zinc oxide (ZnO), which exhibited a potential to increase their sensitivity in solid dosimeter materials. Supposing that one of the things which these nanoparticles do is essentially act as electron traps, they find that this should increase luminescence from radiation (Pekpak et al., 2014).

Dopants are substances added in a small quantity to dosimeter materials, giving them certain optical or electrical properties. Many dosimeter materials are doped with dopants to enhance performance, particularly when used in conjunction with scintillation detectors. Example of this type are cerium and europium; these Dopants are often added to scintillation dosimeters as emitters for managing clear response in the LM. When the dust is exposed to ionising radiation, these rare-earth elements efficiently pass on energy and produce light by creating energy levels in the dosimeter material. The dosimeter has a non-linear temperature response across dose and this may potentially be corrected for with suitable fitting coefficients this was however not considered in the current work (Huy et al., 2009).

One of the recent developments is in doping of quantum dot materials with dosimeters. The size-dependent optoelectronic properties conferred by quantum dots enable tuneable responses to different radiation intensities. This should pave a way to fabricate extremely sensitive dosimeters along with on-like capabilities through the doping of quantum dots. While dosimeter material modification/ doping has come a long way, there are still unresolved issues. The ever-present struggle of linearity versus energy independence and sensitivity is another difficult tightrope to walk. Moreover, the incorporation of altered and doped dosimeters is hinged on environmental consideration or maintenance with aging for such devices (El-damrawi, 2021).

Some advanced nanomaterials including 2D materials as well as nano composite may be considered for use in the future studies also to act dopants and modifiers. Moreover, improvement of computer modelling, and simulation methods can expect to optimise dosimeter performance even before experimental testing. According to the study, modifiers and dopants are critical in determining radiation dosimeter performance. Continuous investigations are required to surmount the difficulties and introduce new dosimeter materials working according to demand of modern