THERMOLUMINESCENCE RESPONSE OF DOPED SILICON DIOXIDE OPTICAL FIBRES SUBJECTED TO ELECTRON IRRADIATION

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I dedicate this work

To my beloved parent

Buang bin Hj. Pelet

Salmi binti Hj. Kasimon

Whose love, kindness, patience and prayer have brought me this far

To my dear siblings

For their love, understanding and support through my endeavour

To my friends

Whose presence fills my life with joy and cheerful

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ABSTRACT

This study was focused on the suitability of commercial optical fibres as a new thermoluminescence dosimeter (TLD). The materials doped to silicon dioxide (SiO_2) were germanium type A (Ge (A)) of first, second and third batch, germanium type B (Ge (B)), erbium (Er), aluminium and thulium (Al + Tm), photonic crystal fibre (PCF) of first and second batch, and multi photonic crystal fibres (MPCF). The MPCF came with different range of core diameter of 220 µm (MPCF 220 µm) and 2 mm (MPCF 2 mm). The study also used pure glasses such as photosensitive flat fibre (PFF), flat fibre (FF) and dummy flat fibre (DFF). A comparison of the thermoluminescence (TL) response of electron irradiation concerning sensitivity, linearity, energy dependence, fading signal, reproducibility, minimum detectable dose (MDD) and effective atomic number, Z_{eff} parameters as well as cross-comparison with that of TL dosimeter i.e TLD-100 (LiF:Mg,Ti) rods were investigated. Scanning electron microscopy (SEM) was used to determine the dopant concentration in each doped optical fibres. The irradiation was performed using 6 MeV electrons for doses ranging from 1 – 4 Gy at Pantai Hospital and University of Malaya Medical Centre separately according to the batch. All the optical fibres produced linear dose-TL responses for dose range of 1 – 4 Gy. TLD-100 produced greater TL sensitivity followed by PFF, FF, Ge (A), MPCF 2 mm, DFF, Al + Tm, Er, MPCF 220 µm, Ge (B) and PCF with their relative sensitivity of 0.2, 0.15, 0.08, 0.04, 0.02, 0.01, 0.005, 0.004, 0.003 and 0.002 respectively compared to TLD-100. Ge (A) showed 7% signal loss followed by PFF, Er, FF and PCF with 15%, 26%, 28% and 33% signal loss respectively after 14 days of irradiation. Reproducibility of Ge (A), Ge (B), Er, PCF, MPCF 2 mm and MPCF 220 µm were poor due to high degree of fading. The lowest MDD obtained from TLD-100, followed by FF, Ge (A) 1st batch, Ge (A) 3rd batch and PFF with their MDD of 0.13, 0.9, 4.0, 5.2 and 5.4 mGy respectively. The Z_{eff} for Ge (B), Ge (A) and Er doped to SiO_2 optical fibres were 11.88, 12.95 and 20.69 respectively. Several attractive features offered by these fibres point to its use in radiation therapy.

ABSTRAK

Kajian ini memberi tumpuan kepada kesesuaian gentian optik komersial sebagai dosimeter luminesens terma (TLD). Gentian optik yang didopkan kepada silikon dioksida (SiO_2) ialah germanium jenis A (Ge (A)) kumpulan pertama, kedua dan ketiga, germanium jenis B (Ge (B)), erbium (Er), aluminium + tulium (Al + Tm), "photonic crystal fibre" (PCF) kumpulan pertama dan kedua, dan "multi photonic crystal fibre" (MPCF). MPCF terdiri daripada teras diameter yang berbeza iaitu 220 μm (MPCF 220 μm) dan 2 mm (MPCF 2 mm). Kajian ini juga menggunakan kaca tulen iaitu "photosensitive flat fibre" (PFF), "flat fibre" (FF) dan "dummy flat fibre" (DFF). Perbandingan sambutan luminesens terma (TL) dilakukan terhadap sinaran elektron mengenai kepekaan, kelinearan, pergantungan tenaga, isyarat pudar, kebolehulangan, dos minimum terkesan (MDD) dan nombor atom berkesan, Z_{eff} begitu juga perbandingan silang dengan dosimeter rod TLD-100 (LiF:Mg,Ti) turut dikaji. Mikroskopi pengimbas elektron (SEM) digunakan untuk menentukan kepekatan dopan dalam setiap gentian optik. Penyinaran telah dilakukan menggunakan 6 MeV untuk dos elektron dalam julat 1 – 4 Gy di Hospital Pantai dan Pusat Perubatan Universiti Malaya secara berasingan mengikut kumpulan. Semua gentian optik menghasilkan tindak balas dos linear-sambutan TL untuk julat dos 1 – 4 Gy. TLD-100 menghasilkan sambutan TL yang lebih peka diikuti oleh PFF, FF, Ge (A), MPCF 2 mm, DFF, Al + Tm, Er, MPCF 220 μm, Ge (B) dan PCF dengan kepekaan relatif masing-masing adalah 0.2, 0.15, 0.08, 0.04, 0.02, 0.01, 0.005, 0.004, 0.003 dan 0.002 berbanding dengan TLD-100. Ge (A) menunjukkan isyarat pudar sebanyak 7% diikuti dengan PFF, Er, FF dan PCF dengan masing-masing isyarat pudar adalah15%, 26%, 28% dan 33% selepas 14 hari penyinaran. Kebolehulangan Ge (A), Ge (B), Er, PCF, MPCF 2 mm dan MPCF 220 μm adalah rendah kerana darjah kepudaran yang tinggi. Nilai MDD terendah diperoleh daripada TLD-100, diikuti dengan FF, Ge (A) kumpulan pertama, Ge (A) kumpulan ketiga dan PFF dengan MDD masing-masing adalah 0.13, 0.9, 4.0, 5.2 dan 5.4 mGy. Z_{eff} bagi Ge (B), Ge (A) dan Er yang didopkan kepada gentian optik silikon dioksida masing-masing adalah 11.88, 12.95 dan 20.69. Beberapa ciri menarik yang ditawarkan oleh gentian ini membawa kepada penggunaan dalam terapi sinaran.

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LIST OF SYMBOLS

E_o	Electron original energy
T	Lifetime
Z	Atomic number of the atom
θ	Small scattering angle
E_l	Electron energy of the elastic scattering
S_Δ	The linear stopping power
e	The electronic charge
LiF	Lithium fluoride
$CaSO_4$	Calcium sulphate
B_{mean}	The mean TL background signal
σ	The standard deviation
F	TL system calibration factor
D_o	Threshold dose
N_2	Nitrogen gas
SiO_2	Silicon dioxide
MU	Monitor Units
Z_{eff}	The effective atomic number
S_d	Relative sensitivity

LIST OF ABBREVIATIONS

TLD	Thermoluminescence dosimetry
ICRP	International Commission of Radiological Protection
TL	Thermoluminescence
LET	Linear energy transfer
MCVD	Modified Chemical Vapour Deposition
LINAC	Linear accelerator
SEM	Scanning electron microscope
ALARA	As low as reasonable acievable
PCS	Plastic clad silica
MU	Monitor unit
PDD	Percentage depth dose
FSD	Field source distance
PMT	Photomultiplier

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CHAPTER 1

INTRODUCTION

1.1 Overview

As part of cancer therapy, every year 2.5 million people around the world are treated with ionizing radiation which is radiation therapy. A predictable fraction of the cancer cells die when high energy is applied in the deterministic regime. In spite of that, radiation can also act as a carcinogen (cancer-causing agent) which will cause radiation sickness. In addition to destroy the cancer cells, radiation therapy can also destroy the healthy tissue near the cancer cells when exposed to high energy. Dose that is delivered to the healthy tissue possibly creates an enhanced risk of cancer at some time later (Suzanne, 2003).

For that, radiation energy that is deposited in human tissue should be measured. A specific dosimetric system is chosen for the planned measurement of absorbed dose. In radiotherapy, *in vivo* dosimetry is required in order to measure of actual dose delivered to internal organs with a high level of accuracy. Apart of ensuring the critical organ is delivered with the prescribed dose, it is also necessary to limit the dose burden from damaging of the surrounding normal tissue as low as possible (Khalil, 2006).

In this work, thermoluminescence dosimetry (TLD) is used for radiotherapy application. TLD is found widespread in *in vivo* dosimetry, probably because of its high thermoluminescence (TL) output. One of the characteristic needed in a dosimeter is that one must have closeness of its effective atomic number, Z_{eff} to that of tissue (Z_{eff} = 7.4). Only lithium fluoride in the form of LiF: Mg: Ti from all the phosphors available so far has found widespread application in electron dosimetry. It fills the characteristic needed in dosimetry system as its Z_{eff} is 8.2 (Klevenhagen, 1985, Greening, 1981, Attix, 1986). Different TL materials have different TL response. Lithium borate, $Li_2B_4O_7$ has a better tissue equivalency, Z_{eff} being 7.4 but its sensitivity is only one tenth to the LiF with respect to electron irradiation (Klevenhagen, 1985). A material such as $CaSO_4$ although having high sensitivity for TLD has not been used as much in medical dosimetry as its atomic number was far from human tissue with respect to photons irradiation (Greening, 1981).

As an improvement and a better understanding of the nature of the material in order to develop new TL materials, many researchers has investigated the potential use of silica glass (SiO_2) optical fiber as TL materials. Applications of SiO_2 optical fibre such as the measurement of absorbed dose for *in vivo* radiation therapy and diagnostics was reported by Aznar, 2002. The optical fibre also demonstrated high flexibility, easy handling and low cost compared with the other TL materials (Espinosa, 2006).

1.2 Background of the problems

The potential for health hazards will occur if ionizing radiation is not properly used or contained. When doses of radiation exceed certain level acute health effects such as skin burns or acute radiation syndrome can occur. Cancer will also occur when someone is exposed to low doses of ionizing radiation in longer term. Tissue or organ damage depends on the dose, type of radiation received and sensitivity of different tissues and organs.

In order to prevent our health from being threatened by radiation hazard, first we have to make sure the dose received is in the standard level. For this purpose, we use a device called radiation dosimeter that is capable of providing a reading of absorbed dose deposited in matter by ionizing radiation (Attix, 1986). Radiation dosimeters must exhibit several desirable characteristics in order to be useful. The desirable dosimeter properties such as accuracy and precision, linearity with dose, dose rate dependence, energy response, directional dependence and spatial resolution must be taking into account (Podgorsak, 2005). There are many types of integrating dosimeters such as TLD, photographic dosimetry, chemical dosimetry and calorimetric dosimetry (Attix, 1986). This work will focus on the TLD as it has been widely applied in areas such as environmental monitoring of ionizing radiation, personal dose monitoring, diagnostic radiology and radiation oncology.

TLD is one of the methods widely used to measure ionizing radiation. TLD is based on the capability of the material itself to keep the energy trapped as it been radiated and release the energy in the form of light as it been heated. The amount of energy trapped and energy released after heated depend on the absorbed dose by the TLD (Wagiran, 1997).

1.3 Statement of the problems

While TLDs are widely used for *in vivo* dosimetry, the problem is that they are unable to store dose information permanently. Heating the TLD can erase the stored information. In addition, annealing procedures are required to restore the original sensitivity after being irradiated. This is because the sensitivity is unstable after receiving a large dose of radiation. Additional limitations of TLDs include their high sensitivity to light especially UV, sunlight or fluorescence light. Poor response due to environmental factor like humidity also is one of its limitations.

For optical fibre provided by Universiti Malaya (UM), the manufacturer did not specified about the percentage dopant consist in each doped SiO_2 optical fibres. Scanning Electron Microscopy (SEM) is required to determine its dopant concentration. The image of cross section area of optical fibres can be obtained by using SEM. In this research, Er, Ge (A) and Ge (B) doped optical fibres were investigated.

Different dosimeters made in UM from a given batch of optical fibres showed a distribution of dopant uniformity. After being cut into 0.5 cm, the dopant concentration in each optical fibres still unknown. Thus, the TL yields were sometimes produced different average sensitivities. To overcome this problem several optical fibres for each material; at least five fibres are necessary for acceptable accuracy and precision.

1.4 Research objectives

This study embarks on the following objectives:

i) To investigate the TL response of linearity, sensitivity, dose response, energy response, fading, the reproducibility and minimum detectable dose of doped optical fibres subjected to electron irradiation.

ii) To compare the TL response of doped SiO_2 optical fibres with TLD-100.

iii) To determine the dopant concentration and effective atomic number (Z_{eff}) for doped SiO_2 optical fibres using a scanning electron microscope (SEM).

1.5 Statement of the hypothesis

For many applications, this study has hypothesized that the TLD-100 rods and SiO_2 doped optical fibre have a high sensitivity, which means both high efficiency of the high emission and low threshold dose. The relationship between the TL signal and dose applied is assumed to have a linear relation. In other words, a proportionality factor will always be included or implied in the considerations of response to dose.

Furthermore, TLDs are expected to have long term stability of the stored dosimetric information at the room temperature concerning thermal and optical fading. It is very important to get dosimeter with low fading. The greatest stability of signals on the electron traps is the preferred dosimeter either in medical or environmental fields.

Moreover, it is preferred to get dosimeter with plan or fixed response for a wide range of energies. For precise dosimetric purposes, the proposed TLD should get a constant response over wide incident energy. To be used in radiotherapy application, TLD is expected to have close value of effective atomic mass with the biological tissue. The ideal dosimeter is the mixture that have effective atomic number equal or close to the composition of human biological tissues of 7.4. The dosimeter with effective atomic number far from this composition is demanding for calibration and conversion factor.

Minimum detectable dose determination is another important factor in determining the required dosimetric material that is appropriate. This lower dose or signal of an irradiated TLD is almost the same as the noise or background signal. Another official definition is "the dose which gives three times the standard deviation of the zero doses reading of the dosimeter" (Furetta *et al*., 2001).

All these TL characteristics, plus the small size SiO_2 optical fibre, the high flexibility, easy handling and low cost compared with other TL materials make the commercial optical fibre a very promising TL material for use in research, medicine, industry, reactor physics and a variety of other applications (Espinosa *et al.,* 2006). This research is expected to have the way for the introduction of optical fibre as a new TL material in dosimetry.

1.6 Scopes of the research

This study may provide a basis for employing TL phenomena in various dosimetric situations. Their general characteristics which include TL response, linearity, sensitivity, dose response, fading, reproducibility, minimum detectable dose, glow curve analysis and effective atomic mass, may provide ten types of doped SiO_2 optical fibres. It consists of two types of Germanium (Ge) doped fibres named Ge (A) and Ge (B). Other material of TLDs investigated were Erbium (Er), Photosensitive Flat Fibre (PFF), Flat Fibre (FF), Dummy Flat Fibre (DFF), Aluminium+Thullium (Al+Tm), Photonic Crystal Fibre (PCF). PCF also came with different core diameter. They are 220 µm (MPCF 220 µm) and 2 mm (MPCF 2 mm). This dosimeter may be suitable for a variety of applications particularly in radiation therapy. The TL responses of these TLDs were then compared to the well known, TLD-100 rod.

The irradiation on the core of the optical fibre has been conducted at dose levels ranging from 1 to 4 Gy of electron ionizing radiation source by using a linear accelerator Elekta Synergy machine (LINAC) at Pantai Hospital and Varian Clinac 2100C at UMMC. These dosimeters were irradiated to 6, 9 and 12 MeV of electron beams. The TL results obtained are compared with the commercially available TL material, TLD-100 rod.

The determination of the fading effect of all doped optical fibre has been perform using 6 MeV of electron irradiation for 1 – 4 Gy dose applied. Readings of TL yield are obtained on 14 consecutive days following the time of irradiation, while the reproducibility characteristic were examined using 6 MeV electron with dose 1 Gy produced by LINAC.

This research is also carried out to determine dopant concentration and Z_{eff} for doped optical fibre using SEM. By using SEM, the Z_{eff} can be obtained by measuring the composition of the elements present. In this study, the sample used is Ge (A), Ge (B) and Er optical fibres only, due to unavailability of SEM equipment. Thus, study for the rest of doped optical fibres is not executed in this study.

1.7 Organization of thesis

This chapter provides an introduction to the problems associated with TL and offers review of the existing literature regarding the subject. The physics behind the TL theory is described in Chapter 2. The methods of material preparation and analyzing the TL response will be described theoretically in Chapter 3. In chapter 4, the results obtained are presented and discussed in detail. Chapter 5 summarizes the findings of this investigation, and provides an outlook for future study in this area.

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