EFFECT OF PHOTON IRRADIATION ON THE THERMOLUMINESCENCE RESPONSE OF OPTICAL FIBRES

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Specially dedicated this work

To my dear parents

Hj. Mohamad Sharif bin Abdul Rahman

Hjh. Absah binti Long

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

To my siblings and lovely sister

Nurul Aeni binti Mohamad Sharif

For their endless laughs and tears

To my friends

For their love, understanding and support through my endeavour

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ABSTRACT

Studies on silica glass (SiO_2) optical fibre as thermoluminescent materials for medical radiation dosimetry have been conducted by several research groups. This study focuses on the thermoluminescence (TL) response, linearity, sensitivity, dose response, fading, reproducibility and minimum detectable dose of 12 optical fibres sample namely Ge (A) Batch 1, 2 and 3, Ge (B), Multi Photonic Crystal Fibre (MPCF, 220 µm), Multi Photonic Crystal Fibre (MPCF, 2 mm), photonic crystal fibres (PCF), Dummy Flat Fibre (DFF), Flat fiber, Photosensitive Flat Fibre (PFF), Erbium (Er) and Aluminium/ Thulium (Al + Tm) doped optical fibre. A comparison was performed with TLD-100 (chips) to obtain the best TL response among the samples. Irradiation were performed with 6 and 10 MV photons covering the dose range of 1 Gy to 4 Gy by using linear accelerator machine Elekta Synergy^{TM} at Pantai Hospital, Kuala Lumpur and Varian Model 2100C linear accelerator at University Malaya Medical Centre (UMMC). The comparisons of TL response with different model linear accelerators involved in this research were also performed. The results show that the highest sensitivity was obtained by using TLD-100, followed by PFF, Flat, Ge (A) Batch 1, MPCF (2 mm), Ge (A) Batch 3, Ge (A) Batch 2, DFF, Al+Tm, Ge (B), Er, MPCF (220 µm) and PCF. The fading of 5 optical fibres Ge (A) Batch 1, PFF, Er, Flat Fibre and PCF were determined and the loss of the TL signal for these TL materials were 10%, 29%, 30%, 30% and 43%, respectively. The dopant concentrations of Ge (A) Batch 1, Ge (B) and Er were found to be in the range of 0.03-0.72 mol % while the Z_{eff} was in the range of 11.9-17.1. These TL materials have great potential to be introduced as new radiation dosimeters.

ABSTRAK

Kajian mengenai serabut optik kaca silica (SiO_2) sebagai bahan luminesens terma bagi dosimeter sinaran perubatan telah dijalankan oleh beberapa kumpulan penyelidik. Kajian ini tertumpu kepada sambutan luminesens terma, kelinearan, kepekaan, sambutan dos, kepudaran, kebolehulangan dan dos minimum dikesan bagi 12 jenis sampel gentian optik SiO_2 iaitu Ge (A) kumpulan 1, 2 dan 3, Ge (B), 'Multi Photonic Crystal Fibre' (MPCF, 220 µm), 'Multi Photonic Crystal Fibre' (MPCF, 2 mm), 'photonic crystal fibres' (PCF), 'Dummy Flat Fibre' (DFF), 'Flat fiber', 'Photosensitive Flat Fibre' (PFF), 'Erbium' (Er) dan 'Aluminium/ Thulium' (Al + Tm). Perbandingan terhadap TLD-100 (cip) juga dilakukan untuk mengetahui sampel yang paling baik sambutan luminesens terma. Penyinaran telah dilakukan dengan foton 6 dan 10 MV pada julat dos 1-4 Gy dari sumber pemecut linear Elekta Synergy™ di Hospital Pantai, Kuala Lumpur dan pemecut linear Varian Model 2100C di Pusat Perubatan Universiti Malaya (PPUM). Perbandingan sambutan luminesens terma dengan menggunakan model pemecut linear yang berbeza juga telah dilakukan. Keputusan menunjukkan kepekaan luminesens terma yang paling tinggi diperoleh menggunakan TLD-100, diikuti oleh PFF, 'flat fiber', Ge (A) kumpulan 1, MPCF (2 mm), Ge (A) kumpulan 3, Ge (A) kumpulan 2, DFF, Al+Tm, Ge (B), Er, MPCF (220 µm) dan PCF. Kepudaran bagi 5 gentian optik iaitu Ge (A) Kumpulan 1, PFF, Er, Flat Fibre dan PCF telah ditentukan dan isyarat luminesens terma yang hilang masing-masing adalah 10%, 29%, 30%, 30% dan 43%. Kepekatan dopan ditemui adalah dalam julat 0.03-0.72 mol % manakala Z_{eff} dalam julat 11.9-17.1. Bahan luminesens terma ini mempunyai potensi yang baik untuk diperkenalkan sebagai dosimeter sinaran yang baharu.

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LIST OF SYMBOLS

Z_{eff}	The effective atomic number
SiO_2	Silicon dioxide
LiF	Lithium fluoride
E	Activation energy
p	Probability of escaping by the trap
T	Temperature
s	Frequency factor
k	Boltzmann's constant
σ	The standard deviation
N_2	Nitrogen
F (D)	Linearity index
D	Absorbed dose
R^2	Regression coefficient
S_d	Relative sensitivity
F_{dm}	Sensitivity achieve from proposed dosimeter
$F_{d(TLD-100)}$	Sensitivity of standard dosimeter
B_{mean}	Mean TL background
F	TL system calibration factor
m	slope of graph

LIST OF ABBREVIATIONS

TLD	Thermoluminescence dosimeters
TL	Thermoluminescence
SEM	Scanning electron microscope
LINAC	Linear accelerator
IMRT	Intensity-modulated radiation therapy
TPS	Treatment planning system
MCVD	Modified Chemical Vapour Deposition
PCVD	Plasma-activated Chemical-Vapour Deposition
OVD	Outside-Vapour Deposition
VAD	Vapour-axial Deposition
EDX	Energy Dispersive X-ray Analysis
EDS	Energy Dispersive X-ray Spectrometry
SSD	Source-Surface Distance
MU	Monitor Unit
TPR	Tissue Phantom Ratio
PDD	Percentage depth dose
FSD	Focal-spot Skin Distance
FESEM	Field Emission Electron Microscopy

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CHAPTER 1

INTRODUCTION

1.1 Overview

Radiotherapy is one of the modalities that use high energy X-rays, gamma rays or electrons to deliver ionizing radiation. It is a treatment that kills the malignant tumor in the patient body (Davies, 2008). A malignant tumor is an abnormal cell and potentially unlimited growth. A radiotherapy treatment can be divided into two parts which are external and internal beam therapy. For external beam therapy, the cancer cells are treated by machine outside the patient body and for internal therapy, radiation is put inside to the patient body, in or near to the cancer cell.

Due to ionizing radiation can cause harmful effects such as deterministic or stochastic effects, safety and radiation protection should be emphasized to maximize the radiation dose to cancer cells and at the same time to minimize damage and injury to healthy cells (Bartesaghi et al., 2007). Dosimeter is one of the important tools in radiotherapy treatment to detect the amount of absorbed radiation dose to the patient body.

Thermoluminescence (TL) is one of the individual dosimeter that is commonly used in radiation dosimetry and the detector that are most often used for *in vivo* dosimetry purposes (Wagiran et al., 2011). *In vivo* dosimetry is important because it helps to reduce the risk of serious accidents and also to ensure that the treatment carried out as planned in addition to the requirement of the law. It is because it able to determine the accurate dose delivered to the patient body. TL detector must also be similar to the equivalent tissue to facilitate the application of radiation dosimeter, especially in clinical applications and radiation therapy. Dosimeter material should approach the atomic composition of biological tissue of human body, (Z_{eff} = 7.42) for the measurement of absorbed dose X-rays and gamma irradiation (Furetta et al., 2001).

Phenomena of TL have long been used in radiotherapy. First application of these phenomena as dosimetry was introduced by Daniel et al in 1953 (Jung et. al, 2004). As an improvement and a better understanding of the nature of the material in order to develop new TL materials, many researches work have been carried out. Personal, environment and clinical dosimetry is examples of TLD application technique (Bos, 2001). Dosimeter material or phosphors that are usually used in the TLD dosimeter is calcium fluoride, calcium sulfate, lithium borate, lithium fluoride and potassium sulfate (Lancaster, 1969). The TLD material based on LiF phosphor is known as TLD-100. Lithium fluoride, LiF, doped with magnesium and titanium which denoted by LiF: Mg, Ti are used widely today (Yaacob et al., 2011).

Although TL dosimetry is a well-established technique and is widely used in radiation dosimetry especially for application in radiotherapy, there are some limitations of it such as poor spatial resolution and hygroscopic problem. Therefore, many research in silica glass (SiO_2) optical fiber as TL materials are carried out to overcome these limitations. The use of SiO_2 in radiation dosimetry is very helpful because their transmission signal loss is low (Chen and Jaluria, 2009). Present or addition dopant in silica also can offer advantages in radiation dosimetry as it can increase the radiation sensitivity of the silica by providing a high number of traps. In addition, new defects and absorption bands can appear (Yaakob et al., 2011).

1.2 Background of the Problem

Ionizing radiation is energy in the form of waves or particles that will able to ionize the matter when passes through it. Ionizing radiation can be divided into two categories which are indirect radiation and direct radiation. X-ray, gamma ray and neutron are the examples of the indirect radiation which first produce charge particles before the charge particles ionized the matter. Meanwhile, alpha and beta particles are direct radiation which this particles will ionize the matter directly (Wondergem, 2010).

Exposure to the ionizing radiation can contribute to acute and chronic effect based on their absorbed dose level, which determines the severity of the effect; expose volume size, which indicates external whole or partial body exposure, or localize exposure and the nature of radiation (N´enot, 2009). Acute effect is the effect of ionizing radiation that occurs when large dose delivered at short period. Meanwhile, small amount of dose received over a long period of time is called chronic effect.

Recently, ionizing radiation is broadly used in medical field like in diagnosis, treatment and sterilization. Radiotherapy is one of the modalities in medical that use ionizing radiation to kill cancer cells. When using radiation to treat cancer cell, the healthy cells will also be injured. Therefore, the amount of absorbed dose in patients is important to avoid the side effects of radiation to the patient. As precaution step in order to avoid any affect that occur while exposure to ionizing radiation, one tool which is called dosimetry is to detect amount of absorbed dose in the patient body.

TL is one of the individual dosimeter that is widely used in radiation dosimetry. Previously, film badges were widely used as radiation detectors before the development of TLD dosimeter. TLD replaced the film badge in radiation dosimeter because of the weakness and deficiencies of the film badge system. Examples of film dosimeter weaknesses are that it cannot be exposed to light before being processed, cannot reflect the actual readings at low photon energy, does not give an immediate reading and false image will be formed under pressure, heat and chemicals on the film (Wagiran, 1997).

Recently, a lot of researches on silica were developed due to its potential as individual dosimeters. It is because silica glass (SiO_2) optical fibre help to overcome the limitation existed on the TL dosimeter. The advantage of silica is that it is able to improve positional sensitivity, typically ~200µm. In addition, silica is impervious to water because it forms a glass in the fibre-preforming process. Therefore, it is suitable for usage in intercavitary and interstitial measurements (Hashim, 2009).

1.3 Problem Statement

The TLD phosphors that are widely used in medical field are LiF:Mg, Ti, LiF:Mg, Cu, P and $Li_2B_4O_7$:Mn. However, these well-established phosphors have some drawbacks including being hygroscopic and poor spatial resolution-up to a few mm (Hashim, 2006). With these restrictions in mind, novel TLD materials are currently identified based on doped SiO_2 optical fibres, which offer characteristics that provide good potential for broadening the applicability of TLD.

Many researches about silica have not clearly give the information on the most appropriate material that is suitable to be used as dosimeter. It is because not all material can be used as effective radiation detector. Many criteria must be concerned and analyzed in identify the suitable and appropriate material which is able to become a good phosphor in radiation detector especially in term of personal dosimeter. The type of fibre and radiation parameters will determine the TL performance of irradiated optical fibre.

The linearity, sensitivity, dose response, energy response, fading, reproducibility and minimum detectable dose of optical fibres must be determined to know the performance of TL response of each fibre. The TL results are compared with those of the commercially available TLD-100 (Yaacob et al., 2011).

The comparison of TL response between different type of flat fibre which is photosensitive flat fibre, flat fibre and dummy flat fibre must be determined. Moreover, the TL response of multi photonic crystals fibre (MPCF) that have different diameter at their core should also be carried out and compared with TLD-100 (chips). The comparison of the type of flat fibre and MPCF with TLD-100 (chips) are carried out to study their potential as new TL dosimetry in radiation therapy application.

In addition, the percentage of dopant added to the optical fibres must be determined because the exact amount of dopant added to these fibres is not specified by the manufacturers. The analyses of the dopant concentration percentage are to be determined by using Scanning Electron Microscopy (SEM). In this research, the dopant concentration for Ge (A), Ge (B) doped optical fibre and Erbium (Er) will be explored.

1.4 Research Objectives

The objectives of the research are as follows:

1) To study the dosimetric properties which are linearity and sensitivity with respect to dose response, energy response, TL glow curve, fading, reproducibility and minimum detectable dose of optical fibres and TLD-100 subjected to photon irradiation.

2) To compare the TL response between single mode optical fibre, multiphotonic crystal fibres (MPCF) with different diameter of their core and also type of flat fibre.

3) To determine the dopant concentration and effective atomic number, Z_{eff}, of the Ge (A), Ge (B) and Erbium (Er) doped optical fibre using Scanning Electron Microscopy (SEM).

1.5 Significance of Research

i. Able to overcome the limitations that exist in the TLD-100 which are hygroscopic and poor spatial resolution.

ii. Apply optical doped fibre as TL material to improve individual dosimetry and can save the cost of this dosimetry because the optical fibre SiO_2 is more economical.

iii. Able to improve positional sensitivity, typically ~ 200μm and optical fibre can use in intercavitary and interstitial measurements since the fibres are impervious to water.

1.6 Scope of Study

In this research, the 12 types of optical fibres which are MPCF (220 μm), MPCF (2 mm), Ge (A) Batch 1, 2 and 3, Ge (B), photonic crystal fibres (PCF), Flat fiber, Dummy Flat Fibre (DFF), Photosensitive Flat Fibre (PFF), Erbium (Er) and Al + Tm were investigated to obtain their dosimetric properties which are effective atomic number, energy response, linearity and sensitivity with respect to dose response, TL glow curve, reproducibility and minimum detectable dose of each optical fiber. The difference between Ge (A) and Ge (B) is their dopant concentration. In this study, 3 batches of Ge (A) are study which the batch is referring to the time these fibres received from the supplier. Harshaw TLD 3500 is use to read TL response of the optical fibres which are already exposed with photon beam. The glow curves for each sample are obtained and the results are compared with TLD-100 (chips).

The determination of the fading effect of the samples has been performed by using 6 MV photon irradiation at dose 1 Gy. Readings of TL yield were obtained on 14 consecutive days following the time of irradiation. The reproducibility of the samples characteristic also were examined. The fading characteristics of 5 TL materials which are Ge (A) Batch 1, Er, Photonic crytals fibre, Photosensitive Flat Fibre and Flat fibre are studied.

The irradiation on the core of the optical fibre has been conducted at dose levels ranging from 1–4 Gy by using a linear accelerator Elekta Synergy^{TM} (LINAC) at Department of Radiotherapy and Oncology, Pantai Hospital, Kuala Lumpur and Varian Model 2100C linear accelerator at Clinical Oncology Unit, University Malaya Medical Centre (MMUC). All samples were irradiated in solid water phantom with 6 and 10 MV photon energy. The TL results obtained are compared with TLD-100.

This research has also been carried out to determine dopant concentration and effective atomic number, Z_{eff} for Ge (A) Batch 1, Ge (B) and Er doped optical fibre. Scanning electron microscope (SEM) is used in this research to obtain the effective atomic number by measuring the composition of the elements present.

The present chapter has provided an introduction to the problems associated with TL and significance of the optical fibre in this study. The physics behind the thermoluminescence and review of the existing literature regarding the subject is described in Chapter 2. The methods of preparing sample, irradiation process and analyzing the TL glow curves will be described theoretically in Chapter 3. In chapter 4, the range of thermoluminescence studies and 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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APPENDIX

Titles of Paper Presentation (International/Local)

1. N.A.M. Sharif, S.N. Buang, S.S.C. Omar, S.A. Ibrahim, S. Hashim, S. Zakariah, A.T.A. Rahman, N. M. Ung and G.A. Mahdiraji. "Thermoluminescence Response of Ge-Doped SiO_2 Optical Fibres Subjected To 6 MV Photon Irradiations." 8th National Seminar on Medical Physics. Sunway Hotel, Seberang Jaya, Penang, 19 Dec 2012.

2. S.A. Ibrahim, N.A.M. Sharif, S.N. Buang, S.S.C. Omar, S. Hashim, M.I. Saripan, N.M. Noor, N. M. Ung and G.A. Mahdiraji. "The Thermoluminescence Response of Multi Photonic Crystal Fibres (MPCF) Subjected To 6 MV Photon Irradiations." 8th National Seminar on Medical Physics. Sunway Hotel, Seberang Jaya, Penang, 19 Dec 2012.

3. S.S.C. Omar, S. Hashim, S.A. Ibrahim, S.N. Buang, N.A.M. Sharif, W. M. S. Wan Hassan, N. M. Ung and G.A. Mahdiraji and M. I. Saripan. "The Thermoluminescence Response of Multi Photonic Crystal Fibres (MPCF) Subjected To 12 MeV Photon Irradiations." 8th National Seminar on Medical Physics. Sunway Hotel, Seberang Jaya, Penang, 19 Dec 2012.

4. S.N. Buang, S. Hashim, N.A.M. Sharif, S.S.C. Omar, S.A. Ibrahim, S. Zakariah, A.T.A. Rahman, G.A. Mahdiraji and N. M. Ung. "Thermoluminescence Response of Ge-Doped SiO_2 Optical Fibres Subjected To Electron Irradiation." 8th National Seminar on Medical Physics. Sunway Hotel, Seberang Jaya, Penang, 19 Dec 2012.