THERMOLUMINESCENCE CHARACTERISTICS OF SILICON OPTICAL FIBRE DOPED WITH YTTERBIUM AND YTTERBIUM – TERBIUM AS PHOTON DOSIMETER.

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ABSTRACT

The study of SiO_2 commercial optical fiber explores the useful thermoluminescence (TL) properties and reveals its potential as a TL dosimeter. The present work describes the TL dose response, reproducibility, fading and minimum detectable dose of SiO_2: Yb and SiO_2: Yb, Tb optical fibers as compared to TLD-100. The optical fibers were placed in a solid phantom and irradiated with 6 and 10 MV X-rays using LINAC Primus MC 3339 and 1.25 MeV gamma ray from gamma cell. Scanning electron microscopy analysis was performed to determine the dopant concentration and the effective atomic number, Z_{eff}. The dopant concentration of Yb for SiO_2: Yb optical fiber was found ranging between 0.23 – 0.35 mol% and for SiO_2: Yb, Tb; the dopant concentration of Yb and Tb were in the range of 0.03 – 1.46 mol% and 0.12 – 0.39 mol% respectively. The Z_{eff} value for SiO_2: Yb and SiO_2: Yb, Tb were 11.19 and 12.27 respectively, which is higher than that of soft tissue (7.42), but close to bone (11.6 – 13.8). In term of TL dose response and sensitivity, SiO_2: Yb, Tb optical fiber demonstrated better results than SiO_2: Yb optical fiber, but both TL materials were still inferior when compared to TLD-100. SiO_2: Yb, Tb optical fiber had the lowest percentage lost in fading of about 5.83%, 15.65% and 18.55% for day 7, 21 and 28 respectively, compared to SiO_2: Yb optical fiber which has higher fading of about 55.17% and 95.87% for day 14 and 30 respectively. SiO_2: Yb, Tb optical fiber shows good reproducibility results compared to SiO_2: Yb optical fiber. The minimum detectable dose of SiO_2: Yb and SiO_2: Yb, Tb optical fibers were 333 mGy and 19 mGy respectively. In general, it can be concluded that SiO_2: Yb, Tb optical fiber is a much better optical fiber to be developed as a new TL dosimeter compared to SiO_2: Yb optical fiber.

ABSTRAK

Kajian gentian optik komersial SiO_2 meneroka ciri luminesens terma (TL) berguna dan keupayaan sebagai dosimeter TL. Kajian ini membincangkan sambutan dos luminesens terma, kebolehulangan, kepudaran dan dos pengesanan minimum gentian optik SiO_2: Yb dan SiO_2: Yb, Tb dan berbanding TLD-100. Gentian optik diletakkan di dalam fantom pepejal dan disinarkan dengan sinar-X 6 dan 10 MV menggunakan LINAC Primus MC 3339 dan sinar gama 1.25 MeV dari sel gama. Analisis mikroskop pengimbas elektron (SEM) dilakukan bagi menentukan kepekatan dopan dan nombor atom berkesan, Z_{eff}. Kepekatan dopan Yb bagi gentian optik SiO_2 ialah dalam julat 0.23 – 0.35 mol% dan kepekatan dopan Yb dan Tb bagi SiO_2 : Yb, Tb masing-masing ialah 0.03 – 1.46 mol% dan 0.12 – 0.39 mol%. Nilai Z_{eff} bagi gentian optik SiO_2 : Yb dan SiO_2 : Yb, Tb masing-masing ialah 11.19 dan 12.27, iaitu lebih tinggi daripada nilai tisu lembut (7.42), tetapi hampir dengan tulang (11.6 – 13.8). Dari aspek sambutan luminesens terma, SiO_2 : Yb, Tb memberi keputusan yang lebih baik berbanding SiO_2 : Yb, tetapi kedua-dua bahan masih tidak dapat menandingi TLD-100. Gentian optik SiO_2 : Yb, Tb mempunyai peratus kepudaran yang lebih rendah iaitu 5.83%, 15.65% dan 18.55% masing-masing pada hari ke-7, 21 dan 28 berbanding dengan SiO_2 : Yb yang mempunyai peratus kepudaran yang lebih tinggi sebanyak 55.17% dan 95.17% pada hari ke-14 dan 30. Hasil kajian menunjukkan gentian optik SiO_2 : Yb, Tb menunjukkan keputusan sifat kebolehulangan yang lebih baik berbanding gentian optik SiO_2 : Yb. Dos pengesanan minimum bagi gentian optik SiO_2 : Yb dan SiO_2 : Yb, Tb masing-masing ialah 333 mGy dan 19 mGy. Secara umum dapat disimpulkan bahawa gentian optik SiO_2 : Yb, Tb adalah lebih sesuai untuk dimajukan sebagai dosimeter TL berbanding gentian optik SiO_2 : Yb.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

Z_{eff}	The effective atomic number
γ	Gamma
β	Beta
µ	Micro
Gy	Gray
ŋ	The efficiency of the thermoluminescence emission
m	Mass
ε	Ratio between the energy
D	Absorbed dose
M	TL signal
k	Boltzmann's constant
F_c	The inverse of the calibration factor
$(\mu_{en}/\rho)_i$	The mass energy absorption coefficient
W_i	The fraction of that element
S	TL signal
k	Kilo
s	Second
ºC	Degree Celsius
pC	PikoCoulomb
nC	NanoCoulomb
a_n	Weight fraction contribution
Z_n	The atomic number of the element-*n*
mg	Milligram

F(*d*)	Dose response at dose D
D_o	The response at the lowest dose
B	TL background signal
σ_B	The standard deviation
F	The calibration factor
MV	Megavoltz
MeV	Mega electron voltz
keV	Kilo electron voltz
R	Regression coeffiecient

LIST OF ABBREVIATIONS

TLD	Thermoluminescence dosimetry
TL	Thermoluminescence
SEM	Scanning electron microscope
LINAC	Linear accelerator
MOS	Metal oxide semiconductor
CRN	Continuous random network
ODC	Oxygen deficient centers
EPR	Electron paramagnetic resonance
NBOHC	Non bridging oxygen hole center
UV	Ultra violet
POR	Peroxy radical
STH	Self-trapped hole
RE	Rare earth
CT	Computed tomography
PMMA	Polymethylmethacrylate
SSD	Source-surface distance
MU	Monitor unit
PMT	Photomultiplier tube

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

In radiotherapy and radio diagnosis, in order to map dose in tissues, there exist a need for highly sensitivity in vivo dosimetry systems of high spatial resolution, commercially available thermoluminescence dosimeters (TLDs) being limited to a capability of few millimeters. The spatial resolution and dynamic range required of a dosimeter to accurately evaluate the radiotherapy dose distribution of such complex three-dimensional geometries, especially at the micro spatial resolution scale, is becoming more challenging. Major advantages in using optical fibers or optical fibers sensors for radiation detection and monitoring are: real-time interrogation capabilities, possibility to design spatially resolved solutions and in-vivo investigation (Sporea *et al.* 2012).

The foundation of thermoluminescence (TL) theory appear to be due to Randall and Wilkins (1945) and by Garlick and Gibson (1948) (Mckeever *et al.* 1988), providing expressions for the shape of a glow peak in terms of temperature, heating rate, and the characteristic of the trap. LiF has been developed commercially by Harshaw Chemical Company and made available as TLD 100, TLD 100H, TLD 600 and TLD 700 depending on the quantity of Li present. The Li concentration determines how the element will respond to neutrons, and an activator is required for the material to be thermoluminescent. The effective atomic number of LiF (Z_{eff} = 8.04) is close enough to the value of Z_{eff} for tissue make it almost tissue equivalent.

Studies of potential radiation therapy applications of the optical fiber TL dosimetric system have been undertaken by several groups. Since then, much research has been carried out for a better understanding and improvement of the material characteristics as well as to develop new TL materials. As stated by Espinosa *et al.* (2006), that optical fibers could be very attractive for using in a variety of radiation dosimetry applications due to its small size, flexibility, low cost and commercially available. Abdulla *et al.* (2001) has carried out a TL study on commercially available Ge-doped silica based fiber optic in the dose range from 1 to 120 Gy and has fast fading rate (2% within 6 hours and 6% within 30 days).

Hashim *et al.* (2009) work was also based on commercially available Ge-doped optical fiber and compared to aluminum doped optical fiber. The TL dosimeters were exposed by a wide range of sources, from low energy photons to megavoltage, through neutrons and charged particles. The results showed that Ge-doped optical fiber had linear dose response until at least 4 Gy for 6 MV photons, and up to 3.5 Gy for 6, 9and 12 MeV electrons irradiation. A linear dose response was found for 2.5 MeV protons irradiations.

Another study from Hashim *et al.* (2010) was done by using oxygen atoms as a dope to pure SiO_2 optical fibers by using ion implantation technique. The O_2- , Ge- and Al- doped optical fibers were exposed to 6 MV photons and separately to 6, 9 and 12 MeV electrons. The results show the superior TL response to be that of the Ge-doped optical fibers followed by the O_2-doped fibers and lastly Al-doped fibers.

Encouraging results from such studies have paved the way in development of the fiber radiation dosimeters specifically TL dosimetric characterization and properties such as the glow curves parameters, energy dependence, relative energy response and dose rate effect.

In many TLD applications, the main purpose is to determine the dose absorbed in human tissue. For this reason, it is desirable that the TLD has an energy response equal to that human tissue. In composite materials, for photon interactions the atomic number cannot be represented uniquely across the entire energy region, as in the case of elements, by a single number known as effective atomic number, Z_{eff} (Shivaramu *et al.* 2000). It is very useful in medical radiation dosimetry for the calculation of dose in radiation therapy and medical imaging. TL materials with Z_{eff} = 7.42 or near this number are called tissue equivalent.

1.2 Objectives of the Research

The objectives of this study are:

a) To determine the Z_{eff} of Ytterbium, Yb and Ytterbium-Terbium, Yb-Tb doped SiO_2 and compare them with Z_{eff} of tissue and bone.
b) To determine the dose response (dose linearity and sensitivity) and energy response and compare them with LiF: Mg, Ti.

c) To determine the fading, reproducibility and minimum detectable dose of Yb and Yb-Tb doped SiO_2 optical fiber.

1.3 Statement of the Problem

Among the wide choice of radiation dosimeters that can be used for application in radiotherapy, brachytherapy, diagnosis radiology and radiation protection of the patient, thermoluminescence dosimetry (TLD) now become the well-established technique for radiation detection. But it also has several restrictions including being hygroscopic and having relatively poor spatial resolution – up to few millimeters.

In in-vivo dosimetry, the radiotherapist faces problem to set the exposure in real-time to ensure that the proper dose is delivered to the desired region. Because, it only provides integrated dose information after some time of irradiation of patient. Other limitations of TLD are poor dose reproducibility, limited dynamic range and sensitivity and in certain cases nonlinear response. This study intended to investigate the alternative dosimetric material base on SiO_2 optical fiber as a TL dosimeter.

Recently, several research groups have started to use SiO_2 optical fibers as a radiation dosimeter to measure the absorbed dose by patients, in particular overcoming the spatial resolution limitations of existing TL dosimeter system (Yaakob et al., 2011) and for certain dopant and dopants concentrations, sufficient TL yield to serve the associated sensitivity needs (Wagiran et al., 2012). However, the manufacturers did not specify the amount of dopant added in the optical fiber. Therefore, in this research, the concentration of dopant for Tb-Yb and Yb-doped SiO_2 optical fiber will also be determined.

In regard to the potential of Ytterbium, Yb and Ytterbium-Terbium, Yb-Tb doped optical fiber for therapeutic dosimetry application, studies have been carried out to investigate the TL response of this candidate dosimeter for various types of radiation beam. It is important to investigate the possible linear dose response between the absorbed dose and the TL intensity over a wide range of dose as well as the energy response of the dosimeters.

1.4 Scope of the Research

This study may provide a basis for applying TL phenomena in several dosimetric situations. Their general characteristics such as linearity, energy response, reproducibility, fading, sensitivity and atomic effective number, may provide information to introduce Yb-Tb and Yb-doped SiO_2 optical fiber as a new TL material. This dosimeter may be suitable for many types of application particularly in radiation therapy.

The irradiation of the core of the optical fiber exposed at dose level ranging from 0.5 – 4.0 Gy of X-ray irradiation using Primus MLC 3339 linear accelerator machine (LINAC) at 6 and 10 MV X-ray beams and 1.0 – 10.0 Gy for 1.25 MeV gamma rays using Cobalt-60. The determination of fading effect of Tb-Yb and Yb-doped optical fiber has been done using 6 MV X-ray irradiation at 4.0 Gy. Readings of TL yield are obtained on 30 days following the time of exposure, and the reproducibility characteristic were examined using 6 MV X-ray with dose 4 Gy produced by LINAC.

This study has also been carried out to determine dopant concentration and effective atomic number, with Z_{eff} for Tb-Yb and Yb-doped optical fiber using a scanning electron microscope (SEM). By using SEM, the composition of the elements present in the fiber and the effective atomic number was determined.

1.5 Significance of the Research

The ability to manufacture silica fibers of relatively small diameter provides the possibility of producing a thermoluminescence dosimeter offering high spatial resolution. It is a further expectation that such fibers will provide radiation measurements close to that of an ideal Bragg-Grayy cavity. This is important in the accurate evaluation of absorbed radiation dose, being a critical consideration for non-tissue equivalent probes such as doped silica glass.

There are a lot of advantages of doped silica glass fiber dosimeters. For example, unlike conventional TLDs, the fibers are impervious to water; it then becomes possible to locate the fiber dosimeter within a particular tissue of interest. With the flexibility of silica glass fibers, this further suggests the possible use of fibers in a variety of vascular procedures that involve appreciable radiation doses, in particular, in intra-coronary artery brachytherapy.

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