PHOTON ENERGY RESPONSE OF SILICON DIOXIDE FIBRE OPTIC AND TLD 100 USING MONTE CARLO SIMULATION

HAZILA BINTI ASNI

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Charming and beloved mother, Halimah Jumaat

Encouraging and ambitious father, Asni Md Taib

Supportive and harmonious brothers, Hazlan, Hazli & Hazril

Generous and adorable in-laws, Kak Sam & Shida

Exuberant, talkative and energetic niece, Sofea Hani

Glorious and fabulous families of Majidi, Kempas & Jengka

Love of my life, the one that always listen to my story and be there for me

My wonderful husband, Ahmad Fadzil Mohamed

I dedicated this works for all of you...with lots of love

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ABSTRACT

Even though there are other methods in detecting and measuring radiation, thermoluminescence (TL) is still the main choice in many areas of ionizing radiation dosimetry. This fact leads to the countless investigation of other materials to be used as TL phosphor. Recent material being recognised and investigated as a TL phosphor is silicon dioxide fibre optic. This study focuses on the energy response of silicon dioxide fibre optics and TLD 100 subjected to photon irradiation. The TL responses for photon energies, ranging from 20 keV to 20 MeV, were investigated as energy absorbed in the TL materials. The simulation was performed using Monte Carlo N-Particle transport code version 5 (MCNP5). The input parameters included in this study are geometry specification, source information, material information and tallies. Tally F6 was used to obtain average fraction of energy deposited by TL materials in the simulation. Comparisons of energy responses were made between calculated, simulation and previous experiment. For TLD 100, calculation results show an over responses at below 100 keV while the simulation and experiment results shows over response at below 150 keV. In terms of energy dependence, TLD 100 has a relatively flat response since its response lies within ANSI acceptable range. Unlike TLD 100, fibre optic had a limited range of flat response. A flat response can only be seen at energy range of 200 keV to 10 MeV. Although simulation results exhibit similar pattern of energy responses, the values are slightly higher when compared to calculated and experiment results, especially at lower energy (< 100 keV). The effect of different dopant concentrations on the energy responses were also analysed and discussed. Result from simulation shows no apparent effect of different dopant concentration on the energy response.

ABSTRAK

Walaupun terdapat pelbagai kaedah dalam pengesanan dan pengukuran sinaran, dosimetri termocahaya (TLD) masih menjadi pilihan utama dalam bidang dosimetri sinaran mengion. Kenyataan ini mendorong banyak penyelidikan dilakukan untuk mencari bahan yang sesuai menjadi fosfor termocahaya. Di antara bahan baru yang telah dikenali berpotensi untuk digunakan sebagai TLD ialah serabut optik silikon dioksida terdop. Kajian ini menumpukan kepada sambutan tenaga serabut optik silikon dioksida dan TLD 100 terhadap foton. Sambutan luminesens cahaya bagi pelbagai tenaga, dalam julat 20 keV hingga 20 MeV, dikaji sebagai tenaga terserap di dalam bahan luminesens. Kajian ini dijalankan menggunakan simulasi komputer *Monte Carlo N-particle, versi 5 (MCNP5).* Terdapat beberapa parameter dimasukkan ke dalam simulasi seperti spesifikasi geometri, maklumat berkenaan sumber sinaran, maklumat bahan serta *tallies*. *Tally F6* digunakan bagi mendapatkan jumlah pecahan purata tenaga yang diserap oleh bahan TL dosimeter dalam simulasi ini. Perbandingan sambutan tenaga dibuat antara keputusan simulasi dengan keputusan kiraan dan eksperimen. Bagi TLD 100, keputusan pengiraan menunjukkan *"over response"* pada tenaga 100 keV ke bawah, manakala keputusan simulasi dan eksperimen menunjukkan *"over response"* pada tenaga 150 keV ke bawah. Dalam terma kebergantungan tenaga, TLD 100 mempunyai sambutan tenaga yang malar kerana semua sambutan tenaga berada dalam julat yang diterima ANSI. Tidak seperti TLD 100, serabut optik mempunyai julat sambutan tenaga malar yang terhad. Sambutan malar hanya dapat dilihat dalam julat tenaga 200 keV hingga 10 MeV sahaja. Walaupun keputusan simulasi menunjukkan corak sambutan tenaga yang serupa, nilainya sedikit tinggi apabila dibandingkan dengan pengiraan dan eksperimen, terutamanya pada tenaga rendah (<100 keV). Kesan perbezaan kepekatan bahan terdop dalam serabut optik terhadap sambutan tenaga juga dikaji. Keputusan daripada simulasi menunjukkan tiada kesan yang besar terhadap sambutan tenaga bagi kepekatan bahan terdop yang berbeza-beza.

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LIST OF SYMBOLS

E	Energy
k	Boltzmann's constant
p	Probability of escaping by the trap
T	Temperature
Z_{eff},	The effective atomic number
SiO_2	Silicon dioxide
Z	Atomic number of the atom
w_i	Fraction of that element
η	The efficiency of the thermoluminescence emission
m	Mass
Gy	Gray
LiF	Lithium fluoride
Ti	Titanium
ppm	Part per million
$f(E)$	Average fraction of energy deposited in TL material
ϕ	Photon fluence
$\eta(E)$	TL efficiency
$(\mu_{en}/\rho)_{air(E)}$	The mass energy absorption coefficient for air
$S_E\,(E)$	Photon energy response
$(RER)_E$	Relative Energy Response
$\left({}^{\mu_{en}}/_{\rho}\right)_m$	Mass energy absorption coefficient of the material
$\left({}^{\mu_{en}}/_{\rho}\right)_{ref}$	Mass energy absorption coefficient of the reference material
^{60}Co	Cobalt-60 source
$CaSO_4$	Calcium Sulphate

LIST OF ABBREVIATIONS

TLD	Thermoluminescence dosimeters
TL	Thermoluminescence
PMT	Photomultiplier
PMMA	Polymethylmethacrylate
SEM	Scanning electron microscope
MCNP5	Monte Carlo N-particle code, Version 5
EGS	Electron-gamma shower computer code
EGSnrc	Electron-gamma shower computer code (maintained by NRC)
NRC	National Research Council of Canada
GEANT4	Geometry and Tracking computer code
TTB	Thick Target Bremsstrahlung
SDEF	Source specification data card
EPDL	Evaluated photon data libraries
ENDF	Evaluated nuclear data files
ACE	A Compact ENDF
SB	Source bias
SD	Source definition
SI	Source information
SP	Source probability
FOM	Figure of Merit
Vised	Visual Editor
NPS	Number of particles
IMP:P	Photon importance
ANSI	American National Standard Institute

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Over the last decade, the investigation of thermoluminescence and other thermoluminescence dosimetry has expanded enormously. Many phosphor materials have been studied, become commercially available and have been applied to many areas of ionizing radiation dosimetry including personal, environmental, clinical, charged particle and neutron dosimetry.

In the late 1940s, Daniels and his co-workers had concluded in their investigation that lithium fluoride (LiF) from Harshaw Chemical Company was most suitable to use in measuring ionizing radiation exposure [McKinlay, 1981]. Later in studies of LiF in 1960, Harshaw incorporated titanium and others elements in the LiF to produce a phosphor with a high TL sensitivity. This material is the basis of what is now generally regarded as the ‘standard’ TL phosphor: Harshaw TLD 100. TLD 100 was often being used as comparison material in investigating others TLD [McKinlay, 1981].

More recently studies in thermoluminescence are in investigating and developing the commercial SiO_2 fibre optic as a TL material. The fibre optic has several characteristics such as respond monotonically to gamma photon radiation and in some dose regions it responds linearly, carries a low residual TL signal, can be reused several times and low degree of fading. As claimed by Espinosa *et. al.* [2006]

fibre optics could be very attractive for used in variety of radiation dosimetry applications due to its small size, flexibility, low cost and commercially available.

TL performance of an irradiated fibre optic is depends on the type of fibre and by the radiation parameters [Hashim, 2009]. Different impurities in the fibre could give different outcome in the fibre optic performance as TL material. Abdulla *et al* [2001a] has carried out a TL study on commercially available ge-doped silica based fibre optic in dose range of 1-1230 Gy. It was found that fibre optic was response linearly from 1 to 120 Gy and has fast fading rate (2% within 6 hours and 6% within 30 days). Besides germanium, Abdulla *et al* [2001b] also studied on commercially available erbium doped fibre optic. Dose ranges investigated was 2 to 400 Gy, linear dose response was found at up to 250 Gy. Despite its wider range in linear dose response, erbium doped fibre optic had rapid rate of fading compared to germanium doped. As reported, nearly 30% of TL signals being lost after the first 24 hours and a total loss of 58.6% of TL signal were reported after 20 days storage at room temperature.

Hashim [2009] carried out work also on commercially available germanium doped fibre optic compared mainly to aluminium doped fibre optic. This TL dosimeter irradiated by a broad range of sources, from low energy photons to megavoltage, through to neutrons and charged particles (from β-sources, accelerated electrons and α-particles). Germanium doped fibre optic was found to have linear dose response until at least 4 Gy for 6 MV photons, and up to 3.5 Gy for 6-, 9- and 12 MeV electrons irradiation. Besides photon and electron irradiations, a linear dose response was also observed for 2.5 MeV protons irradiations. Exposure to 0.18 Gy of the ^{90}Sr / ^{90}Y β-ray source; it was found that germanium doped fibre had higher TL response compared to the Al-doped fibres. Germanium doped fibre was also prove to have strong TL response to fast neutron irradiation, whereas for aluminium doped fibres the TL response was practically negligible.

If a TL material is to be used for any dosimetric applications in the field of photon radiation, one of the main characteristics that must be known is its energy response. The energy response is a measure of an energy absorbed in TL material used in comparison to the energy absorbed in a material taken as the reference, when irradiated at the same exposure. Normally air is used as a reference material in dosimetry. Energy response is not easily measured, but its theoretical value is very helpful in selecting a particular TL material for any special application. [Oberhofer *et al*, 1981]. Other than energy response, the absorbed dose response was also one of the thermoluminescence characteristics that can be examined. It is very useful for a phosphor to have a linear TL-absorbed dose response over measurement and calibration ranges of absorbed dose [McKinlay, 1981].

Nowadays, other than carried out by experiment, the response studies also could be done by simulation. One of the famous simulation methods is Monte Carlo simulation. Monte Carlo simulation is a stochastic technique which is based on random numbers and probability statistics. This simulation is one of the most important tools to study particle transport and interaction with matter as well as radiation protection and dosimetry. Various Monte Carlo simulation programs are available for different user needs. For instance, Monte Carlo N-Particle (MCNP), Geometry and Tracking computer code (GEANT4) and Electron- Gamma Shower computer code (EGSnrc).

Monte Carlo N-Particle version 5 (MCNP5) will be used for this research. MCNP5 is a general purpose Monte Carlo n-particle transport code that is continuous-energy, generalized-geometry, time-dependent code, and can be used for single or coupled neutron/photon/electron transport.

1.2 STATEMENT OF PROBLEM

There are several studies showing the useful of fibre optic as TL material [Houstan,*et.al*, 2002; Abdulla, 2003; Espinosa *et.al*, 2006; Hashim, 2009] in terms of TL sensitivity, fading and dose response. This study will give more attention to the fibre optic energy response as from the review; none of these studies discuss enough about energy response of TL dosimeter. Energy response has been studied by Abdulla [2003] and Safitri [2006]. However, their studies on energy response of TL dosimeter only limited to accelerated photons and electrons from linear accelerator, which means only energy more than 1 MeV were applied. On the other hand, this studied will applied energy of 20 keV until up to 20 MeV which cover from environmental dosimetry energy ranges to clinical applications. With the aim to understand the dependency of fibre optic response on broad energy ranges, studying this energy ranges is essential as this study may provide a basis for energy correction method needed for fibre optic later.

Previous studies in thermoluminescence were carried out mainly by experiment. However this research tries alternative approach which is Monte Carlo simulation, specifically MCNP5. It is a common but not widely used method in thermoluminescence dosimetry area. With the aim to prove the capability of MCNP5, this research investigates the energy response of TLD 100 and commercially available SiO_2 fibre optic at energy ranges of 20 keV to 20 MeV.

1.3 RESEARCH OBJECTIVES

The objectives of this research are as follows:

i. To simulate the response of TLD 100 to various energy of photon using MCNP5 simulation.
ii. To simulate the response of commercial germanium doped SiO_2 fibre optic to various energy of photon using MCNP5 simulation.
iii. To study the effect of different dopant concentration in SiO_2 fibre optic on energy response using MCNP5 simulation.

1.4 STATEMENT OF HYPOTESIS

Over-response (when the ratio of the amount TL from a dose of a test radiation to the TL from the same amount of ^{60}Co source is greater than 1.0) in the 150 keV ranges for TLD 100 has been well documented [McKinlay, 1981,; McKeever *et al*, 1995; Glennie, 2003; Davis, 2003; Hranitzky *et al*, 2006]. It is hypothesize that simulation response of TLD 100 will have similar response as measured by experiment as well as calculated.

Energy response of fibre optic will also be comparing with calculated and experiment response measured by Abdulla [2003]. It is expected that fibre optic response by simulation depict similar response with experiment and calculation. Abdulla [2003] studies shows over response at energy 100 keV and lower, and like most of TL material energy response has a flat energy response at high energy (greater than 100 keV).

1.5 SCOPE OF RESEARCH

These studies will applied Monte Carlo N Particle code version 5 (MCNP5). MCNP was chosen because of the simplicity and ease when using the code compared to the other codes. Many of the published papers perform Monte Carlo simulation using EGS code in the area of thermoluminescence dosimetry. Thus, the lack of published literature referencing MCNP shows that there is a need for more research to be conduct with MCNP.

Energy response of fibre optic will be compare with calculated response and experiment response as measured by Abdulla [2003]. Even though there is various type of fibre optic with different dopant available, germanium doped fibre optic was chose as investigated material because of its usefulness in terms of sensitivity and dose response was proved by Abdulla [2003] and Hashim [2009]. Since only one type of fibre optic was used in this research, any fibre optic mention was referred to germanium doped fibre optic hereafter.

Other than germanium doped fibre optic, as a standard material, TLD 100 will be used as a comparison material. TLD 100 was chose as its information on its energy response were extensively studied by several group [Davis, 2003; Glennie, 2003 and Hranitzky *et. Al*, 2006]. For more specific comparison, studies by Glennie [2003] were chose as its thesis provided complete and comprehensible setting of the experiment as well as result of energy response. The experiment set up by Glennie will be a reference for simulation setup of this research later. Energy response of TLD 100 from simulation studies will also be compared with result of TLD 100 energy response from Glennie [2003].

1.6 SIGNIFICANCE OF THE RESEARCH

This research will give an insight of commercial SiO_2 fibre optic for a candidate as a TL material in terms of its energy response. The fibre optic can be widely used not only for clinical dosimetry but also for environmental and personal dosimetry.

This research utilized MCNP5 simulation in order to study the energy response with the aim to promote the usage of computer simulation as well as provide basic knowledge in MCNP5 application. Moreover, by using MCNP5 simulation; it is much easier to study the relationship between response and TL material. Hopefully this research will contribute to the knowledge that can create new experts in thermoluminescence area as well as Monte Carlo area.