Thermoluminescent response of single mode optical fibre to x-ray irradiation

S S Che Omar¹, S Hashim¹, S A Ibrahim¹, W M S Wan Hassan¹, G A Mahdiraji², N Md Isa³, M J Mad Isa³, M M Abd Jalil³ and A B Kadir⁴

¹ Department of Physics, Universiti Teknologi Malaysia, 81310 Skudai, Johor Darul Takzim, Malaysia
² Department of Electrical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
³ Department of Medical Physics, Malaysian Nuclear Agency Bangi, 43000 Kajang, Selangor, Malaysia
⁴ Secondary Standard Dosimetry Laboratory, Malaysian Nuclear Agency Bangi, 43000 Kajang, Selangor, Malaysia

E-mail: sitishwaiba@yahoo.com

Abstract. We present the characteristics of the thermoluminescence (TL) response of single mode optical fibre (SMF) subjected to 30 and 70 kV x-ray irradiation. The TL responses are compared with commercially available TLD-100 (rod types). The SMF and TLD-100 were irradiated with x-ray source by using X-rays Generator model Phillips MG 165 located at Malaysian Nuclear Agency. The SMF and TLD-100 show linear dose response subjected to 30 and 70 kV x-ray irradiation. The SMF shows TL response by 10 times and 8 times greater than TLD-100 for the above-mentioned energies. The TL sensitivity characteristics of SMF show promising results to be introduced as a TL dosimeter material. The SMF could be used in several applications in the fields of medicine, industry, and research purposes.

1. Introduction

Thermoluminescence (TL) can be defined as the emission of light from matter following the previous absorption from the radiation source of exciting light energy, x-rays, or any other ionizing radiation. As being reported by Rivera (2012), the importance of TL for radiation dosimetry is due to the fact that the amount of light emitted is proportional to the absorbed dose by the irradiated material, which requires sensitive detection and accurate measurements of ionizing radiation [1]. Many researchers have investigated the performance of commercially available optical fibres subjected to photon [2-4] and x-rays [5-8]. In this study, the TL materials used is a tailor-made optical fibre which being fabricated using Modified Chemical Vapour Deposition (MCVD). Single mode optical fibre (SMF) (unknown dopant) has a circular symmetry and was fabricated mainly from pure silica (SiO₂). The basic construction for SMF is illustrated in Figure 1.
The SMF usually has a core diameter between 8 to 10 µm and the cladding diameter is about 125 µm. These SMF have several advantages compared to commercial TLD-100, for instance, the fibres show high spatial resolution TL dosimetry (~ 100 - 120 µm), impervious to water (hygroscopic nature), flexibility and cheap relatively to be used in radiation dosimetry [3, 6].

According to The International Organization for Standardization, ISO (1999), it is recommended to use X-rays energies between 30 to 70 kV to treat tumours for diagnostics and industrial dosimetry purposes [9]. In this study, we have investigated the TL response of SMF at different x-ray energies (30 and 70 kV) and compare the TL response with the commercially available LiF:Mg, Ti (TLD-100).

2. Methodology

2.1. Material and preparation
Prior irradiation, a fibre stripper was used to remove the outer polymer coating of SMF. After removing the outer cladding, moist cotton was dipped into ethanol to clean the SMF and to avoid any presence of remnant polymer cladding. Then, the SMF was cut into approximate 0.5 ± 0.1 cm long pieces using optical fibre cleaver (Fujikura Ltd., Japan). To obtain the TL yield to be normalized per unit of mass, each of SMF (~ 0.25 ± 0.01 mg) and TLD-100 (rod) (~ 12.03 ± 0.01 mg) was measured using electronic balance (PAG Switzerland). The optical fibres were handling and grouping of the TL materials using vacuum tweezers (Dymax 5 – Charles Austen pump Ltd).

Annealing is the thermal treatment used to erase any irradiation history from the TL material, stabilizing the trap structure and restoring the dosimeter to initial conditions prior to irradiation. The annealing was performed with the optical fibres being kept in an oven set at 400 °C for a period of 1 hour, the optical fibres being retained in an alumina crucible during this time. Following the annealing cycle was the natural cooling down in the oven for 24 hours to avoid thermal stress; finally the optical fibres were equilibrated at room temperature. For the TLD-100, the annealing routine was to place these in a stainless steel plate and to anneal for 1 hour at 400 °C and subsequently 2 hours at 100 °C. After cooling, the TL materials were placed inside capsules and held within a light tight box in order to minimize exposure to potential high ambient light levels. Each capsule having at least five pieces fibre and the fibre stick on the wall of the capsule to make sure the fibre was irradiated uniformly.

2.2. Irradiation
In this study, after annealing, the sample of SMF and TLD-100 were exposed to the different energy of x-ray, which are 30 and 70 kV with a dose rate of 0.1869 mGy per second. As mentioned above, this study use x-ray energy of 30 and 70 kV to treat tumours for diagnostics and protection dosimetry.
purposes, respectively. The sample that irradiated to the both energies was obtained from the X-rays Generator model Phillips MG 165 placed at Malaysia Nuclear Agency (MNA), Bangi, Selangor. The X-ray machine has variable currents level up to 45 mA and a maximum voltage of 160 kV. The readout process was performed at Department of Medical Physics, Malaysian Nuclear Agency (MNA). The TL measurements were carried out using a Harshaw 3500 TL reader (USA) with following parameters: time temperature profile (TTP) was set at preheat temperature of 50 °C for 10s; heating rate at 25 °C s⁻¹ and acquisition time of 13.33 s. The maximum temperature that allowed in this reader is 300 °C remained for 20 s. The readings were taken under a gas flow of nitrogen. The nitrogen atmosphere was used to suppress possible spurious light signals from triboluminescence and also to reduce oxidation of the heating element.

3. Results and discussions

3.1. Glow curve

TL glow curve is defined as the plot of the amount of light emitted as a function of temperature [10]. In order to know the TL response of the SMF, this material was compared with the TL glow curve of TLD-100 (rod), using the same setup and read-out conditions. The comparison of glow curves is shown in Figure 2 and Figure 3. Figure 2 and Figure 3 illustrate the glow curve for energy of (a) 30 kV and (b) 70 kV for SMF and TLD-100 (rod) respectively.

![Figure 2. TL glow curves for SMF under (a) 30 kV and (b) 70 kV x-ray irradiations.](image1)

![Figure 3. TL glow curves for TLD-100 (rod) under (a) 30 kV and (b) 70 kV x-ray irradiations.](image2)
The obtained results show a well-defined TL glow curve for SMF and TLD-100. In terms of shape, the SMF have a broad peak that present the characteristic of the amorphous media, while TLD-100 show a narrow shape. The shape (area under the curve) of both sample represent the energy absorbs after irradiated whereas the highest temperature peak is used for calculations. The TL glow peak for energy of 30 kV was obtained at 222 °C for SMF and 297 °C for TLD-100. Meanwhile for energy of 70 kV, the SMF and TLD-100 was observed at 287 °C and 289 °C with dose of 10 mGy, respectively. The general structure of TL glow curve remains unchanged by repeating the cycles of annealing and irradiation at various doses. As shown in figure 2, the intensity recorded for SMF 30 kV is 1.010 nA show greater intensity compare to SMF 70 kV (0.921 nA). According to Portal (1981), the TLD-100 have five typical peaks at 65 °C, 120 °C, 160 °C, 195 °C and 210 °C [11].

3.2. TL sensitivity
In this study, the TL sensitivity is expressed as TL dose response per unit of mass of dosimeter and per unit of x-ray doses (TL. mg⁻¹.Gy⁻¹). Figures 4 and Figure 5 show the TL dose response of SMF subjected to 30 and 70 kV x-ray irradiations. The cross-comparison was made with TLD-100 for radiation doses up to 10 mGy.

In the first part of the experiment, the irradiation was performed at 30 kV for SMF and TLD-100 (rod) as shown in Figure 4.

![Figure 4. TL response against dose for SMF and TLD-100 (Rod).](image)

The TL sensitivity for SMF was 10 times greater than TLD-100 (rod) i.e. the slope were 3.0416 mg⁻¹.Gy⁻¹ and 0.3190 mg⁻¹.Gy⁻¹ for SMF and TLD-100 (rod) respectively. The linear coefficient, R² was found to be 0.9575 for SMF and 0.9886 for TLD-100. Each single dose was corresponding to the mean of the three reading. The error bars on the graph indicate values to one standard deviation, finding by calculation. The error bar for SMF and TLD-100 is in the range of 0.049-5.185 and 0.004-0.354, respectively. It means the error bar for TLD-100 was too small to be seen in the graph.

In the second series of the experiment, the same TL materials were exposed to 70 kV as shown in Figure 5.
The SMF shows significantly higher TL response is about 8 times more sensitive compared to that of TLD-100 (rod). The slope represents the TL sensitivity were $2.131 \text{ mg}^{-1} \cdot \text{Gy}^{-1}$ and $0.2712 \text{ mg}^{-1} \cdot \text{Gy}^{-1}$ for SMF and TLD-100 (rod), respectively. In terms of linear coefficient, the SMF shows $R^2 = 0.9943$ and $R^2 = 0.9962$ for TLD-100. As mentioned above, each single dose corresponds to the average of the three reading. The error bar for SMF and TLD-100 is in the range of 0.064-1.309 and 0.004-0.202, respectively. The error bar for TLD-100 also showed too small compare with SMF.

High energy x-ray photons will have a greater probability of penetrating the matter. In other words, the relatively low energy x-rays have a greater probability of being absorbed by the optical fibres [12, 13]. Therefore the lower the kV$_p$ and mean energy, there will be greater photons absorption from the x-ray beam by the fibres. This will contribute to the better TL response of 30 kV compared to 70 kV from SMF and TLD-100.

4. Conclusion

In this paper, we have investigated the performance of SMF subjected to 30 and 70 kV x-rays irradiation and compared to TLD-100(rod). From our result, we found that the SMF have 10 and 8 times more sensitive than TLD-100 (rod) will point to its use in radiodiagnostic purpose.

Acknowledgements

The authors would like to thank The Ministry of Education (MOE) HIR grant (A000007-50001) for funding the fiber pulling project and Universiti Teknologi Malaysia for providing financial assistance through Research University Grant Scheme (RUGS), under Program Saintis Negara. Project number (10J37).
References
[1] Rivera T 2012 Thermoluminescence in medical dosimetry Appl. Radiat. Isot. 71 30-34
[2] Hashim S, Al-Ahbabi S, Badley D A, Webb M, Jeynes C, Ramli A T and Wagian H 2009 The thermoluminescence response of doped SiO₂ optical fibres subjected to photon and electron irradiation Appl. Radiat. Isot. 67 423-427
[3] Wagiran H, Hossain I, Bradley D A, Yaakob A N H and Ramli T 2012 Thermoluminescence response of photon and electron irradiated Ge- and Al- doped SiO₂ optical fibres Chin. Phys. Lett. 29 (2) 027802(1)-027802(3)
[4] Badita E, Stancu E, Scarlat F, Vancea C and Scarisoreanu A 2013 Study of optical fibre as new radiation dosimeter Rom. Rep. Phys. 65 (4) 1438-1442
[5] Saeed M A, Fauzia N A, Hossain I, Ramli A T and Tahir B A 2012 Thermoluminescence response of Germanium-doped optical fibers to x-ray irradiation Chin. Phys. Lett. 29 (7) 078701(1)-078701(3)
[6] Abdul Rahman A T, Hugtenburg R P, Abdul Sani S F, Alalawi A I M, Issa F, Thomas R, Barry M A, Nisbet A and Bradley D A 2012 An investigation of the thermoluminescence of Ge-doped SiO₂ optical fibres for application in interface radiation dosimetry Appl. Radiat. Isot. 70 1436-41
[7] Bauk S, Alam M S and Alzoubi A S 2011 Precision of low-dose response of LiF:Mg, Ti dosimeters exposed to 80 kVp x-rays J. Phys. Sci. 22 (1) 125-130
[8] Girard S, Keurinck J, Ouerdane Y, Meunier J-P, Member IEEE, Member OSA and Boukenter A 2004 γ-rays and pulsed x-rays radiation response of Germanosilicate Single-Mode Optical Fibers: Inflence of cladding codopants J. Lightwave Technol. 22 (8) 1915-1922
[9] ISO 1999 The Int. Organization for Standardization X and Gamma Reference Radiation for Calibrating Dosimeters and Dose Rate Meters and for Determining Their Response as a Function of Photon Energy ISO 4037-3
[10] Pagonis V, Kitis G and Furetta C 2006 Numerical and Practical Exercise in Thermoluminescence (New York: Springer Science + Business Media)
[11] Portal G 1981 Preparation and Properties of Principal TL Products, In: Applied Thermoluminescence Dosimetry, ed M Oberhoffer and A Schermann (Bristol: Adam Hilger Ltd) pp 97-122
[12] Khan F M 2003 The Physics of Radiation Therapy (USA: Lippincott William & Wilkin)
[13] Knoll G F 2010 Radiation Detection and Measurement (USA: John Wiley & Sons)