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Response of Fabricated Germanium Optical Fibre Subjected to Low Dose Neutron-Gamma Irradiation

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ABSTRACT

The main purpose of this study is to establish the thermoluminescence response (TL) of fabricated 6% mol Ge-doped optical fibre towards a low dose neutron-gamma irradiation which includes dose linearity, fading signal, minimum detectable dose (MDD) and glow curve analysis. A cylindrical optical fibre with outer diameter of (604 µm and 483 µm) and flat optical fibres with outer dimension of 620 x 165 µm were employed in this study. All fibres were exposed with mixed neutron-gamma radiation that emitted from a ^{241}Am–Be radiation source located at Neutron Laboratory, Nuclear Science Building, Universiti Kebangsaan Malaysia for 5-, 7-, 14-, 21-, and 28 days. The source to the sample distance was set at 5 cm. For fading effect, the samples were kept at room temperature and read-out up to 71 days' post-irradiation. The glow curve and the minimum detectable dose were evaluated using the glow curve which was plotted using Microsoft Excel software and also corresponded with the formula found in Furetta et al. (2001). All the fabricated optical fibres showed a dose linearity response for a range of dose given at 30, 50, 101, 151 and 201 mGy. The minimum detectable dose for 604 µm and 483 µm cylindrical optical fibre was 0.25 mGy and 0.42 mGy. Meanwhile, for 620 µm flat optical fibre, the detectable dose was 1.13 mGy. At 71 days' post-irradiation, all the fibres showed less than 30% of signal fading. Moreover, single broad peak can be found for cylindrical fibre and double peak for flat fibre. These result show that fabricated Germanium optical fibre gives a good response to a low dose mixed gamma -neutron irradiation.

Keywords: Optical Fibre, Low Dose, Mixed Neutron-Gamma, Dosimetry.

1. INTRODUCTION

Thermoluminescence dosimeters (TLDs) are broadly used in radiation dosimetry field. The most commonly used is lithium fluoride or lithium borate which has good response to the dose and tissue equivalent. However, the drawback of using the material is that it is low in spatial resolution and not resistant to water [1]. In order to overcome the problem, optical fibres have been recently introduced as a potential new dosimeter due to their characteristics which are high spatial resolution, light, small and resistant to water [2].

Prior to introducing the optical fibers as a new dosimeter, the basic dosimetric characteristics such as dose linearity, thermoluminescence (TL) fading, reproducibility, glow curve, energy response, accuracy and precision were investigated. Optical fibres which are commercially available for optical communication have been widely reported as thermoluminescence dosimeter. The basic characteristics and thermoluminescence response of commercially

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Germanium (Ge) doped optical fibre to the different types of radiation sources such as gamma [2], photon [4], neutron [5], alpha [6], proton [7] and electron [8-9] have been reported. To date, none of the study related to this had ever studied the thermoluminescence response of fabricated Ge-optical fibre to neutron irradiations. In order to contribute to the body of knowledge in this field, the present work presents the preliminary experimental results to determine TL dose response, TL fading, minimum detectable dose (MDD) and analysis shape of glow curve for 6% Ge-doped fabricated optical fibre which was subjected to low dose mixed neutron-gamma irradiation.

With reference to the presently available neutron source, ^{241}Am-Be neutron is a mixture of americium oxide and beryllium metal. It emits gamma ray as well as neutron. Americium-241 will decay by alpha emission and interact with stable Beryllium-9 target materials which transform Beryllium-9 to Carbon-13. Carbon-13 then decay into Carbon-12 by emitting neutron. Finally, Carbon-12 can be left in an excited state with the emission of gamma-ray with predominant energy of 4.4 MeV or11 go to ground state. The maximum value of neutron energy is ~7 MeV [10]. The reaction of the neutron source can be written as below:

$$^{4}_{2}\alpha + ^{9}_{4}Be \rightarrow ^{12}_{6}C + ^{1}_{0}n$$

2. MATERIALS AND METHODS

2.1 Process of Fabrication of Ge-doped Cylindrical and Flat Optical Fibres

The fibres used were cylindrical optical fibre with outer diameter of (604 μm and 483 μm), and flat optical fibres with outer dimension of 620 x 165 μm. They were fabricated through the method of Modified Chemical Vapour Deposition (MCVD) at Photonics Laboratory, Faculty of Engineering, Multimedia University, Cyberjaya, Malaysia.

2.2 Sample Preparation

Table 1 Properties of fabricated optical fibre

Ge-Doped Concentration [% mol]	Shape of Fibre	Outer Dimension/ Diameter [μm]	Length of Fibre [mm]	Core Dimension/ Diameter [μm]	Core Volume [nm^3]
6	Cylindrical	483	6.0 ± 1.0	78.1	0.03
6	Cylindrical	604	6.0 ± 1.0	94.7	0.04
6	Flat	620 X 165	6.0 ± 1.0	459 x 3.54	0.01

The fibres then were cut into 6.0 ± 1.0 mm length by using diamond-cutter (Thorlabs, USA) to fit into the planchet area of the TLD reader. The fibres were then placed in a brass holder and covered with the aluminium foil for annealing. A vacuum tweezer (Dymax 5, UK) was used during the handling of the optical fibres to avoid scratches and contamination on the surface of optical fibre which can affect the TL signal. For annealing process, the brass holder containing the fibres were placed in an oven (Carbolite Gero Limited, UK) and heated at 400 degree celcius for one hour to erase any residual TL signal of the fibres. The fibres were retained in the oven for 16 hours to allow the fibres to reduce to its initial room temperature to avoid thermal stress. The fibres were encapsulated in a delrin capsule for irradiation. Properties of fibre used in this study are illustrated in Table 1.

2.3 Sample Irradiation

The sample inside the delrin capsule was glued on a cardboard, which then placed adjacent to a cylindrical piping where the neutron source was located. Irradiation was done by using neutron source with the dose rate 0.0173 mGy/hr at Neutron Laboratory, Nuclear Science Building, Universiti Kebangsaan Malaysia. All the samples inside the delrin capsule were placed at a distance of 5cm from the source. For linearity, all the fibres were irradiated in a range of dose 30 mGy to 201 mGy. For the fading effect, the samples were kept at the room temperature and the signal was read-out after 3, 4, 8, 9, 16, 23, 30, 36 and 71 days of storage period.

2.4 Sample Read-out

Table 2 Time-temperature profile set up for cylindrical and flat optical fibre

	Cylindrical Optical Fibre	**Flat Optical Fibres**
a) Preheat		
Temperature	80°C	120°C
Time	10 sec	10 sec
b) Acquire		
Maximum Temperature	400°C	400°C
Heating rate	30°C /sec	30°C /sec
Time	10 sec	10 sec
c) Anneal		
Temperature	400°C	400°C
Time	10 sec	10 sec

The TL signal from the fibres was obtained by using a Harshaw TLD Reader Model 3500 (Thermo Fisher Scientific, USA) and WinREM software located at Centre for Diagnostic Nuclear Imaging, Universiti Putra Malaysia in order to display the TL signal and the glow curve. Nitrogen gas, N_2 was applied as the heat transfer medium in order to suppress spurious light signals from triboluminescence and also to inhibit oxidation of the heating element[5]. The parameters of Time-Temperature Profile (TTP) used in the study are shown in Table 2.

3. RESULTS AND DISCUSSIONS

3.1 Dose linearity

Figure 1 below shows a dose response for all three types of fabricated optical fibres used in this study. All the samples show a good linearity with the range of dose given. Germanium doped flat fibre has a stronger TL response as compared to germanium doped cylindrical fibre. For the same shape of fibres such as cylindrical fibre, the largest core size of optical fibres produce a high TL response than the small core size. Each data points represents an average of minimum five measurement and normalized to the volume of each types of fibre used.

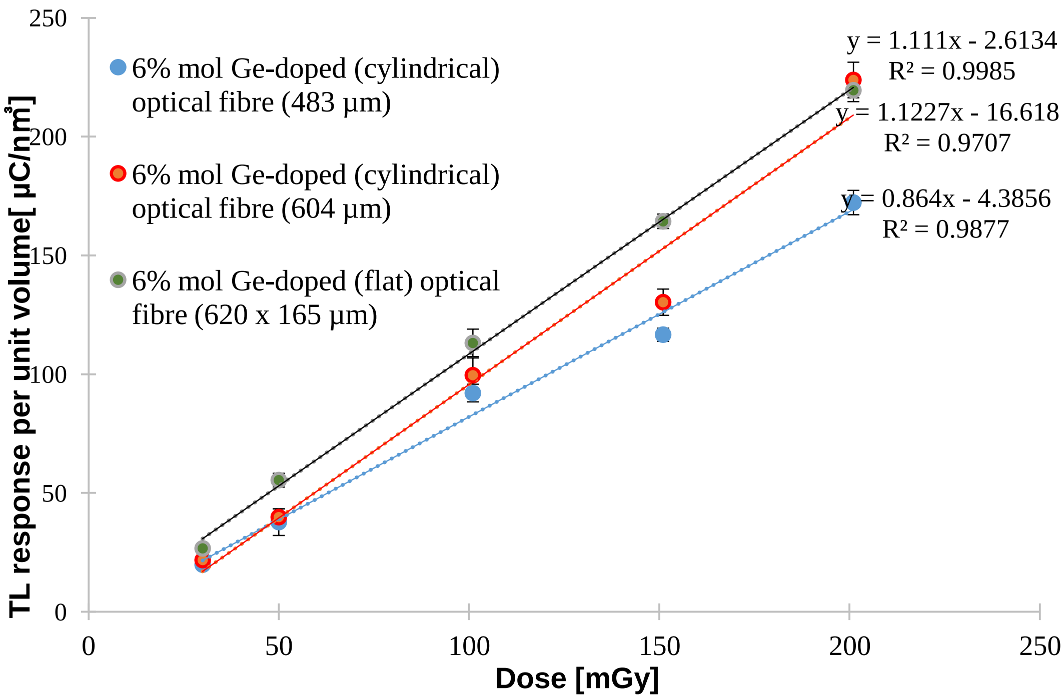

Figure 1. TL dose response of the fibres as a function of dose.

3.2 TL Fading

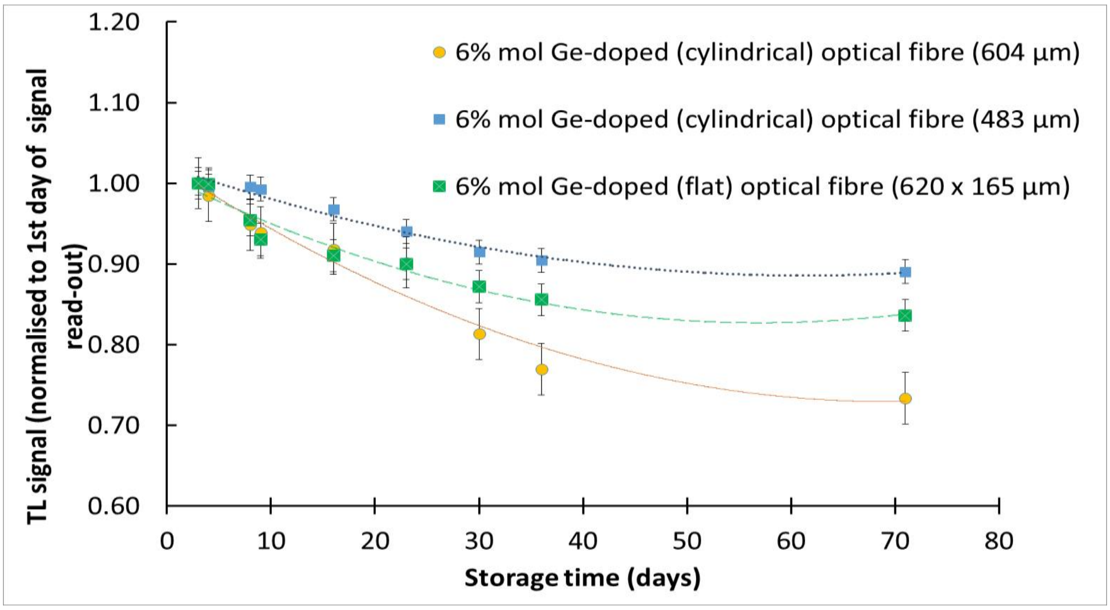

Figure 2. Fading of fibres over 71 days post irradiation.

Figure 2 shows a signal fading as a function of storage time. The fading rate is fitted using single/double exponential decay. Over 71 days post irradiation, cylindrical optical fibre with the largest core of 604 μm has the highest fading which is 26% as compared to the smallest core of 493μm with only 10%. Meanwhile, for the flat optical fibre, the loss of TL signal is 19.6%. Flat optical fibre has lowest TL signal loss as compared to 604 μm cylindrical optical fibre perhaps due to the new defects were introduced by forming the collapse walls in the flat fibre making the inner surface increase. This will introduce additional traps which is deeper [12].

3.3 Minimum Detectable Dose

Minimum detectable dose (MDD) is the smallest dose that has statistically significant difference from the background signal. MDD, D_0 can be obtained by using the formula in Eq. 1 and 2 from Furetta [11]:

$$D_0 = (B_{mean} + 2\sigma) F \quad (1)$$
$$F = 1/m \quad (2)$$

B_{mean} is the mean of the optical fibre that has not been irradiated in mGy and σ is the standard deviation of the mean background. Meanwhile, *F* is the TL system calibration factor for each type of the optical fibres expressed in $GynC^{-1}$, while *m* was the slope obtained from TL dose response for each TL. From this study, MDD value was found to be 0.42 mGy and 0.25 mGy for 483μm and 604 μm cylindrical fibre respectively. MDD for 620 μm flat fibre is 1.13 mGy.

3.4 Shape of Glow Curves

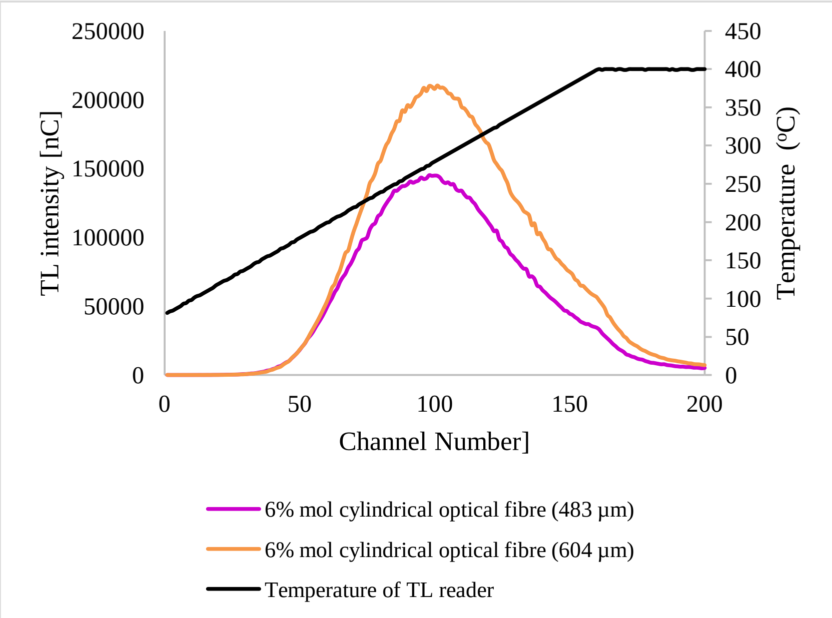

Figure 3. TL glow curves produced by cylindrical optical fibre (604 μm and 483 μm).

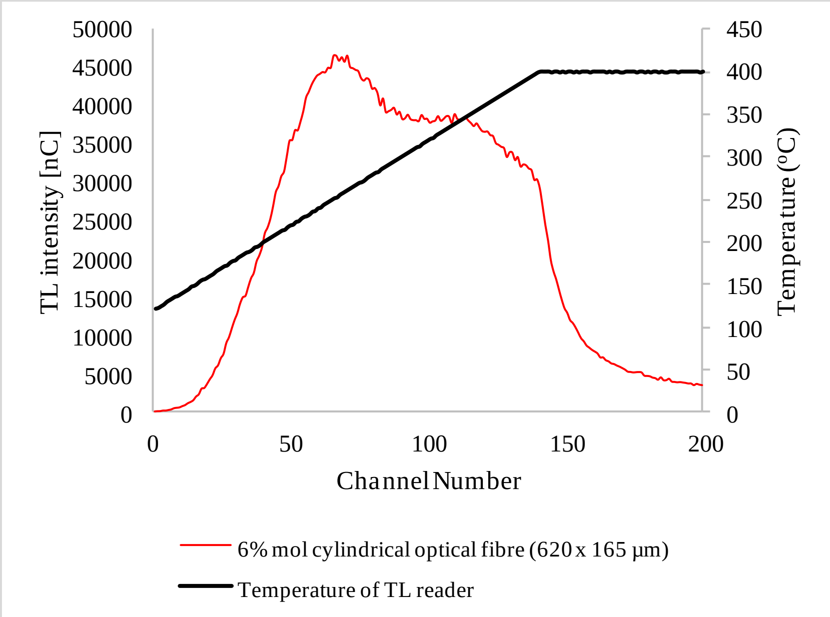

Figure 4. TL glow curve produced by flat fibre (620 x 165 μm).

TL glow curve is an intensity of luminescence as a function of temperature. The area under the curve represents the number of electron that is being released from the trap and is associated to the energy of radiation deposited in the fibre. High peak represents a maximum number of electron released from the trap [7]. Figures 3 and 4 display the shape of glow curves for the three types of fibres used in this study. Both cylindrical and flat optical fibres show a broad peak of the glow curve, which is the characteristic of amorphous media [3]. The cylindrical fibre glow curve for both 483 μm and 604 μm show a single peak at temperature 279 °C and 281 °C. Meanwhile, for flat fibre, it presents a double peak at temperature 251 °C and 339 °C respectively. These single and double peak behaviors are similar with the research finding by Safwan et al. (2017) [13]. The second peak of flat fibre indicates a deeper trap due to strain defect generation.

4. CONCLUSION

In conclusion, the preliminary results have shown that fabricated optical fibres (cylindrical and flat optical fibre) have a good response to low dose neutron-gamma irradiation. Future study will be carried out in order to characterize the thermoluminescence response to this mixed neutron-gamma irradiation by comparing with TLD 100, TLD 600 and TLD 700 which has been tested and established for a long period of time.

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