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Assessment of Ge-doped optical fibres subjected to x-ray irradiation

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Abstract. We have reported the thermoluminescence (TL) response of five different diameters ~120, 241, 362, 483, and 604 µm of 6 mol percent Ge-doped optical fibres. The perfomance of the Ge-doped optical fibre are compared with commercially available TLD-100 chips (LiF:Mg,Ti) in terms of their sensitivity and minimum detectable dose (MDD). The irradiation was performed using X-ray machine (Model ISO 'Narrow Spectrum Series') provided by the Malaysian Nuclear Agency (MNA) at 60 kV X-ray irradiation in low doses ranging from 1-10 mGy. The results show the linear TL dose response from the fibres up to 10 mGy. The smallest diameter of 120 µm optical fibre shows the highest TL dose response compared to above mentioned fibres. The minimum detectable dose (MDD) is 0.82, 0.20, 0.14, 0.08, and 0.13 mGy for Ge-doped with diameters of 120, 241, 362, 483 and 604 µm. All TL materials show the MDD value within the delivered dose 0.01-1.00 mGy subjected to x-ray irradiation. The Ge-doped fibre with diameter of 483 µm was matched the MDD value of TLD-100 chips that equivalent to 0.08 mGy at the same irradiation. We have observed that among the five different diameters of optical fibre, 120 µm shows the best results and its better response than TLD-100 chips (by a factor of 5). The linear response at low dose levels makes this optical fibre most suitable for medical application.

1. Introduction

Thermoluminescence (TL) is well established technique of radiation dosimetry that allows the measurement of radiation dose to extremely low dose levels that are used in a various types of applications; medical, personal, environmental and industry. The determination of exposure of doses delivered to personnel working in the field of ionizing radiation fields is called Thermoluminescence Dosimetry (TLD). TLD is a basic for radiation protection which is to know the exact amount of absorbed dose delivered for optimization. Therefore, the study of new TL materials is important to improve the precision of the radiation measurement in specific applications.

The selection of the TL material type to be used in any application depends on the specific requirements of application. For example, improper use of TL materials in medical applications may lead to unacceptable bias and large uncertainties in the dose estimation [2]. Recently, a number of studies were investigated in Ge-doped optical fibre as new TL materials that have good linear response. It has been established to have potential in radiation dosimetry [3, 4]. To provide a good potential of TL material should be not only considered on radiation parameter such as energy, dose rate and dose response but also the type of fibres [5]. Up to now, optical fibres were studied to measure dose response for radiation dosimetry, in order to overcome spatial resolution that limited to a capability of ~ few mm existing in-vivo dosimetry system [3]. However, TL performance also influence by additional dopant to TL material which can greatly enhance the sensitivity of optical fibres to radiation by providing an increased number of traps. In additions, new defects and absorption bands can appear [4]. Besides, one advantage of optical fibre dosimeters is that they are impervious to water and in some instances, it then becomes possible to locate the optical fibre within a particular tissue of interest [6]. Measurement of the absorbed dose in tissue exposed to radiation, requires that the TL material has energy absorption characteristics nearly same as that of human tissue, i.e. to be tissue-equivalent. Nowadays, very few TL material are nearly tissue equivalent, however LiF are the famous tissue-equivalent detector that it equal to Z_{eff} = 7.4 for soft tissue. In this study was determined dosimetric characteristics for lithium borate, $Li_2B_4O_7$:Cu, in which obtained the effective atomic number of 7.8 which is closest energy absorption characteristics to tissue of all investigated TLDs in this work [7]. According to Furetta, the main dosimetric TL characteristics include glow curve, annealing procedure, TL sensitivity, dose response, precision of TL measurements, reproducibility, energy response, fading characteristics and minimum detectable dose. Its shows TLD are nearly to tissue equivalence to photon radiation, high sensitivity, very simple glow curve with a single well defined peak, low fading, excellent reproducibility and very wide linearity range [8].

In fact, Modified Chemical Vapor Deposition (MCVD) is the commonly method that is used to fabricate optical fibre began at Bell Laboratories. This process became rather widely practiced because it is simple, requires a minimum of equipment, and produces quality fibres. Subsequently, this process was developed to create new fibres design possibilities. MCVD process has an ability to precisely control index and spacing within the fiber core provided for efficient manufacture and so the process exists in spite of its limitations in deposition rate and total quantity of silica deposited. This is because of better control over refractive index profile and superior process flexibility [9].

In this paper, we present the experimental results to determine the TL sensitivity and minimum detectable dose (MDD) 6 mole percent of Ge-doped optical fibre with five different fibre diameters subjected to X-ray spectrum at low doses range. The purpose of this study is to investigate the suitability of optical fibres as a new TLD produced by X-ray irradiation. This results will be compared with standard dosimetry as a radiation dosimeter (LiF:Mg,Ti).

2. Materials and Methods

2.1 Sample preparation

The studied optical fibres and its original preform have been produced by the manufacturer through the MCVD process at University of Malaya (UM). The aim of this process is to design and produce tailored fibres, characterized in terms of radiation response and dependence on production parameters also examining the production possibilities. These allow for tailor-made fibres, producing enhanced TL yield per unit dose [10]. In this study, five different diameters of 6 mole percent Ge-doped optical fibres were used to comparing the TL dose response. The five diameters are ~120, 241, 362, 483, and 604 µm will be taken in this experiment. For comparison, the TLD-100 chips form is used in this research that has the dimension of 3.2 mm x 3.2 mm x 0.9 mm. In preparation the samples, optical fibre was cleaned using a cotton cloth dampened with small amount of methyl alcohol and the fibre was cut into 5.0 ± 0.1 mm long pieces using optical fibre cleaver (Fujikura, Japan). Then, the mass of fibres were recorded using an analytical balance BSA224S-CW (Germany) that are approximately 0.057, 0.625, 0.933, 2.3 and 2.7 ± 0.05 mg for ~120, 241, 362, 483, and 604 µm respectively. While, 23.76 ± 0.05 mg is the mass for TLD-100 chips. Vacuum tweezers were used for easy handling and grouping of fibres [3].

2.2 Annealing
Before exposure the 6 mole percent of Ge-doped optical fibres to the X-ray radiation they were placed in alumina crucible which was kept in an annealing oven. The fibres were annealed at 300°C for a period of 1 hour in order to erase all possible remaining information. During an annealing, about 24 hours is taken for cooling down inside the oven to avoid thermal crashes. The fibres were equilibrated at room temperature in the end of annealing process [11]. While, for TLD-100 chips, annealing were placed on a annealing plate for 1 hour at 400 °C and 2 hours at 100 °C. After annealing, the samples were storage inside dark plastic container to minimize environmental exposure such as humidity, temperature and visible light.

2.3 Irradiation
The materials were irradiated at 60 kV X-ray Tube that mostly used in medical diagnostic application. The irradiation was performed based on ISO 4037 'Narrow Spectrum Series' provided by Malaysian Nuclear Agency (MNA) with dose range 1 – 10 mGy. The optical fibres were placed on the surface of Solid Water phantom™. The phantom with outer dimensions 30 cm x 30 cm x 15 cm with PMMA walls (front wall 2.5 mm thick, other walls 10 mm thick) filled with water and known as the ISO water slab phantom. The fibres were positioned at the centre of radiation field and perpendicular to the beam axis with a fixed voltage at 60 kV. The slab phantom has a rectangular box shape with 15 cm x 15 cm and positioned at irradiation distance of 2 m. Filters according to ISO 4037–1 were used to produce the spectra of the radiation qualities of the ISO narrow spectrum series which were used 0.24 mm Cu and additional filter of 4.0 mm Al and 0.60 mm Cu. Hence, the total thickness of filtration used is 4.84 mm [12]. The dose rate of 12.444 mGy s^{-1} were using for delivered the dose. The fibres were handled carefully and were encapsulated in the gelatin capsules.

2.3 TL measurements
Post irradiation, the fibres were left for 24 hours to control thermal fading before readout. TL measurements were readout being performed using instrument Harshaw 3500 TL reader (Ohio, USA) and WinREMS software for displaying TL glow curve and TL response values at Malaysian Nuclear Agency (MNA). In this study, the time temperature profile (TTP) was set at preheat temperature of 50 °C for 8 s; acquisition temperature 300 °C for 13.33 s; heating rate cycle of 25 °C per second. Finally, an annealing temperature of 300 °C for 10 s was applied to sweep out any residual signal. All TL measurements were made in a nitrogen atmosphere in order to reduce the thermal noise resulting from the heating planchet of the TL reader. The TL yield obtained was then normalized to unit mass of the particular TL medium.

3. Results and Discussions

3.1 TL Dose response and Sensitivity
The dose response of fibre was analyzed in a fixed energy at 60 kV and different diameters of optical fibres. Figure 1 shows that the TL responses of optical fibre with five different diameters for low doses in the range of 1 to 10 mGy were exposed to X-ray radiation. All samples display a linear TL response for low doses in the range of 1 to 10 mGy. Assuming a linear fit, the change in TL yield per unit absorbed dose (in other words the slope) is 3.03, 1.51, 1.39, 1.34 and 1.31 TL.$mg^{-1}Gy^{-1}$ for 120, 241, 362, 483, and 604 µm respectively as shown in figure 1.

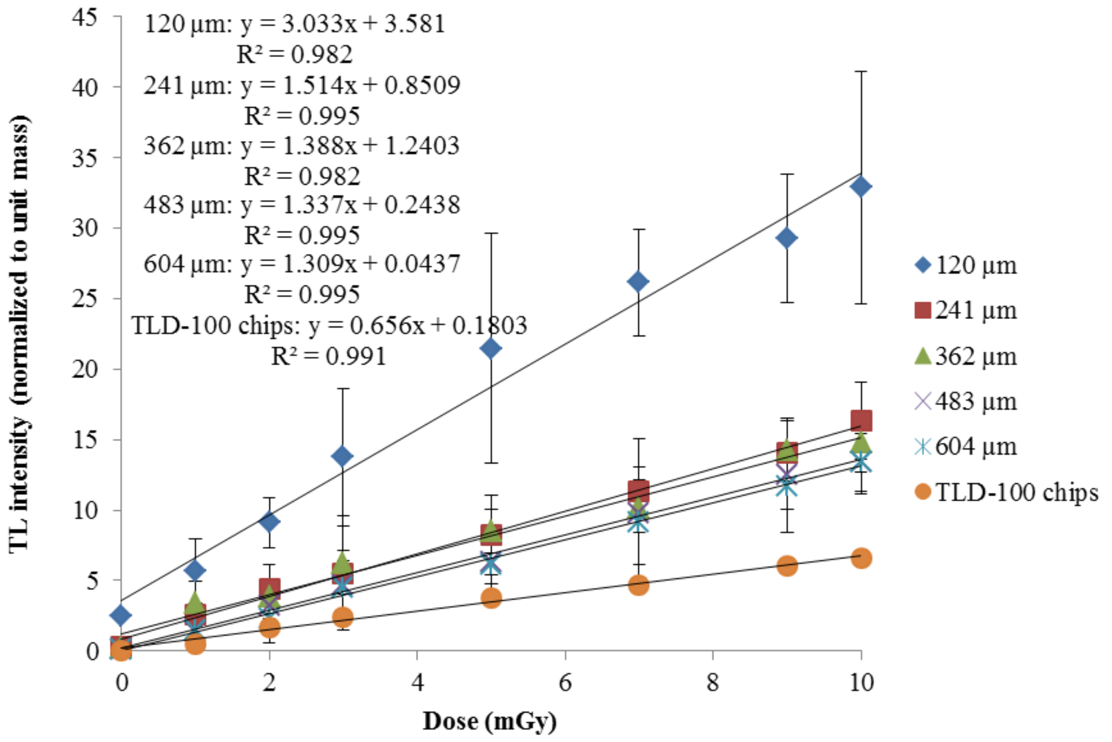

Figure 1 TL dose response of five different diameters optical

From the Figure 1, TL measurement presents a linear response over the dose range studied; however, for smallest diameter is slightly highest dose response and most sensitive followed by increasing diameters values. The variations values of these five different diameters were compared and clearly seen that they are approximately close to each other except for smallest diameter which has large gap than other fibres. The error bars represents the standard error of the mean, which for a fibre with 120 µm diameter is found to be in the range of 1.798-8.254. The finding indicates that at 3, 5 and 10 mGy the error bar was too large because it no longer precise. To conclude, the TL dose response increases with the smaller diameter. According to Bradley [12], the fibres performance of an irradiated optical fibre is influenced by the physical characteristic of the fibres include their spatial resolution of ~120µm, their water impervious nature giving the potential on interstitial and intercavitary measurement and the production of fibre through MCVD process that introduces dopant at selected concentrations.

In order to validating the results, the TL dose responses presented were compared with the TL response of TLD-100 chips as shown in Figure 1. As clearly seen that the all the fibres present higher response compared to TLD-100 chips which have TL response 0.66 TL.mg^{-1}Gy^{-1}. The dose response of 120 µm diameter show high response than TLD-100 chips by a factor of 5. This shows that the optical fibres are more preferable than TLD-100 chips in measurement of low dose. The implications were performed that the same irradiation of the 6 mole percent of GeO_2 optical fibre also influenced by parameter of radiation at lower energies. These X-ray measurements at least perform improvement to provide better and accurate dosimetry suitable for radiation protection of workers.

3.2 Sensitivity

In Figure 2 present the five different optical fibres of their sensitivity that were compared with TLD-100 chips in terms of TL.Gy^{-1}.mg^{-1}.

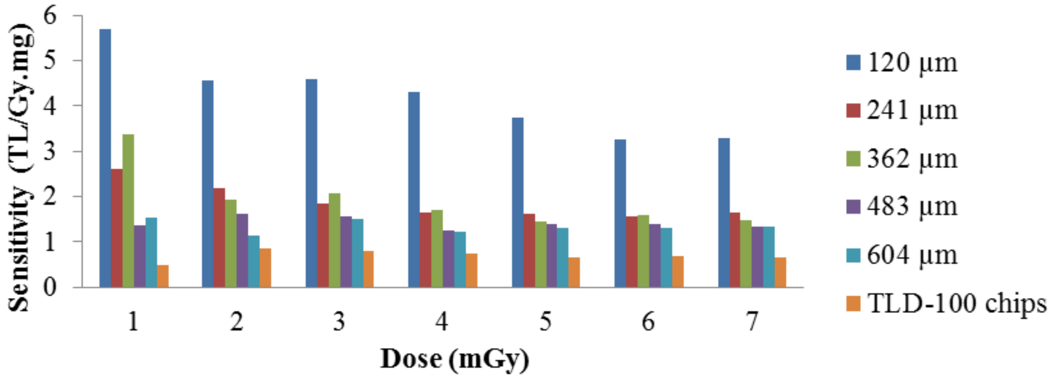

Figure 2 The sensitivities of different diameter sizes of optical fibres with TLD-100 chips.

In terms of sensitivity, the results illustriate a superior sensitivity of 120 µm than higher diameters fibres (TL dose response per dose). These results are also better sensitivities than TLD-100 chips. The relative sensitivities were determined to be 11.60, 5.36, 5.75, 5.70, 5.61, 4.83, and 5.00 for 120, 241, 362, 483, and 604 µm respectively with respect to TLD-100 chips. High spatial resolution diameter size of 120 µm was observed to be the highest sensitivity. The difference in the sensitivity at the higher dose is due to the low optical signal at these doses, giving a high signal-to-noise ratio. To conclude, 120 µm is suitable used for medical diagnostic application as the dose applied.

3.3 Minimum Detectable Dose

$$D_o = (B\ mean + 2\sigma)\ F \qquad (1)$$
$$F = 1/m \qquad (2)$$

Minimum Detectable Dose (MDD) is the smallest dose in response statically significant different from a background signal. Here, MDD were calculated using equation 1 which B_{mean} is the mean of TL signal obtained from the samples annealed but then not irradiated in mGy, 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 $GynC^{-1}$, which *m* were the slope obtained from TL dose response for each TL materials shown in equation 2 [14]. In the present study, MDD value was found to be 0.82 mGy, 0.20 mGy, 0.14 mGy, 0.08 mGy, 0.13 mGy, and 0.08 mGy for 120, 241, 362, 483, 604 µm, and TLD-100 chips respectively.

The MDD for all the samples include TLD-100 chips shows that it still quite well and far below 1 mGy (lowest delivered dose) using threshold dose. The Ge-doped fibre with diameter of 483 µm was matched the MDD value of TLD-100 chips that equivalent to 0.08 mGy at the same irradiation.. These values show a good detection of fibre at low doses range in X-ray. During the experimental of MDD, it is important the relation among high TL sensitivity, TL dosimeter material and the type of TLD reader used for obtaining a low detection dose.

4. Conclusions

The results of 6 mole percent of Ge-doped optical fibres with five different diameters are very promising for dosimetry applications. The Ge-doped optical fibres and TLD-100 chips exhibit good dose response up to 10 mGy irradiation. The sensitivity of five different diameters has been observed to be slightly higher than TLD-100 chips. Among the five different optical fibres, the fibre with 483 µm core diameter and TLD-100 chips have the lowest MDD i.e. 0.08 mGy. In future, our group has great intention to investigate the performance of Ge-doped optical fibres with different Ge concentration.

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References
[1] Kortov V 2007 *Radiat. Meas.* **42** 576-581.
[2] Moscovitch M and Horowitz Y S 2007 *Radiat. Meas.* **41** S71-77.
[3] Hashim S, Al-Ahbabi S, Bradley D A, Webb M, Jeynes C, Ramli A T, Wagiran H 2009 *Appl. Radiat. Isot* **67** 423-427.
[4] Yaakob N H, Wagiran H, Hossain Md I, Ramli A T, Bradley D A, and Ali H 2011 *Appl. Radiat. Isot.* **69** 1189–1192.
[5] Bradley D A, Abdullah Y A, and Amin Y M 2001 *Radiat. Phys. and Chem.* **61** 409-410.
[6] Yusoff A L, Hugtenburg R P, and Bradley D A 2005 *Radiat. Phys. and Chem.* **74** 459-481.
[7] Miljanic S, Ranogajec-Komor M, Knezevic Z and Vekic B 2002 *Radiat. Prot. Dosim.* **100** 437-442.
[8] Furetta C, Prokic M, Salamon R, and Kitis G 2000 *Appl. Radiat. Isot.* **50** 243-250.
[9] MacChesney M 2000 *IEEE Journal of Quantum Electronics* **6** 1305-1306.
[10] Bradley D A, Abdul Sania S F, Alalawia A I, Jafaria S M, M. Noor N, Hairul Azhar A R, Mahdiraji G A, Tamchek N, Ghosh S, Paul M C, Alzimam K S, Nisbet A, Maah M J 2014 *Radiat. Phys. and Chem.* In Press, Corrected Proof.
[11] Hashim S, Bradley D A, Saripan M I, Ramli A T, and Wagiran H 2010 *Appl. Radiat. Isot*. **68** 700–703.
[12] ISO 4037–1 International Standard 1997 Part 1: Radiation Characteristics and Production Methods.
[13] Bradley D A, Hugtenburg R P, Nisbet A, Abdul Rahman A T, Fatma Issa, Mohd Noor N, and Alalawi A 2012 *Appl. Radiat. Isot*. **71** 2-11.
[14] Khan F M, 2003. *The Physics of Radiation Therapy* (SA: Lippincott Williams & Wilkins).