Dosimetric characteristics of fabricated silica fibre for postal radiotherapy dose audits

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Abstract. Present investigation aims to establish the dosimetric characteristics of a novel fabricated flat fibre TLD system for postal radiotherapy dose audits. Various thermoluminescence (TL) properties have been investigated for five sizes of 6 mol% Ge-doped optical fibres. Key dosimetric characteristics including reproducibility, linearity, fading and energy dependence have been established. Irradiations were carried out using a linear accelerator (linac) and a Cobalt-60 machine. For doses from 0.5 Gy up to 10 Gy, Ge-doped flat fibres exhibit linearity between TL yield and dose, reproducible to better than 8% standard deviation (SD) following repeat measurements (n = 3). For photons generated at potentials from 1.25 MeV to 10 MV an energy-dependent response is noted, with a coefficient of variation (CV) of less than 40% over the range of energies investigated. For 6.0 mm length flat fibres 100 µm thick x 350 µm wide, the TL fading loss following 30 days of storage at room temperature was < 8%. The Ge-doped flat fibre system represents a viable basis for use in postal radiotherapy dose audits, corrections being made for the various factors influencing the TL yield.

1. Introduction

From 1969 until present time, the International Atomic Energy Agency (IAEA) in collaboration with the World Health Organization (WHO) have utilised a conventional phosphor-based transfer dosimeter TLD system as a dose audit tool. This forms an independent quality audit for the dose delivered by external beam radiotherapy treatment machines [1]. The limitations of such dosimeters include potential hygroscopic problems and thermal fading [2]. This has stimulated studies of various alternative materials for medical radiation TL dosimeters [3]. A study [4] has suggested that one of the credible TL materials is silica dioxide (SiO_2) optical fibre. This is due to its good spatial resolution; ~ 0.1 mm [3], water and corrosion resistance as well as having low residual signal and modest cost [5].

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The main dosimetric characteristics of TLD of interest are linearity, reproducibility, energy dependence and fading. Previous study [5] has concluded that commercially available Ge-doped cylindrical cross-section silica optical fibres (~ 0.1 mm diameter) provide a good basis for medical radiation dosimetry at therapy levels. In present study use has been made of various sizes of fabricated flat fibres (of sub-mm cross-sectional dimension) doped with germanium (6 mol %), this doped medium exhibiting TL yield significantly greater than that of telecommunication fibres doped with Al, Nd, Yb, Er and Sm [3][6]. As such, there is the expectation that it can provide a sensitive system for therapy dose audit, approaching or perhaps exceeding that of TLD-100.

Prior to use for dose audit, there is a need to establish the characteristics of the fabricated dosimeter for accurate measurement and compliance to international codes of practice and the standard procedure used by the IAEA [7] and other agencies in postal dose audit programmes. This is the focus of present research.

2. Materials and methods

2.1. Sample fabrication

Various size of Ge-doped flat fibres were used in this study, the fibres comprising rectangular samples all of 6 ± 1 mm length, with thicknesses and widths of 60 x 180 µm, 85 x 270 µm, 100 x 350 µm, 165 x 620 µm and 200 x 750 µm. The fibres were produced using the modified chemical vapour deposition (MCVD) method, MCVD being carried out at the Multimedia University, with subsequent fibres production using the pulling-tower facilities of the Photonics Research Group, Department of Electrical Engineering, University of Malaya. Forming of the flat fibres was performed by applying a vacuum to the doped hollow silica preform during the fiber drawing process [8].

2.2. Preparation of Ge-doped flat fibres

The fibres were cleaned using methanol before cutting the fibres into their respective sizes using a S90R diamond cutter (Thorlabs, USA). The mass of each optical fibre dosimeter was obtained using an AB204-S electronic balance (Mettler Toledo, Canada) as shown in Table 1. The fibre mass was used to normalize the thermoluminescence (TL) signal, obtain TL yield per unit mass. In order to minimize surface abrasion of the fibre and deposition of dust or finger oil, vacuum tweezers (Dymax 5, Surrey, UK) were used to handle the optical fibres.

Table 1. Average mass of fibre.

Size of fibre (cladding + core)	Average mass of fibre (g)
60 x 180 µm	0.0035
85 x 270 µm	0.0044
100 x 350 µm	0.0053
165 x 620 µm	0.0097
200 x 750 µm	0.0109

2.3. Annealing

To erase any pre-irradiation TL signal (due for instance to tribological exposure) the optical fibres were annealed using a furnace (Carbolite, Derbyshire, UK). The fibres were placed in a brass holder and annealing was performed at a temperature of 400 °C for 1 hour, followed by a period of 8 hours of slow cooling to avoid thermal stress. After cooling, the fibres were placed inside a black light-tight container in order to minimize exposure to ambient light.

2.4. Sample irradiation

The irradiations were carried out using a Co-60 source located at the Secondary Standard Dosimetry Laboratory of the Nuclear Malaysia Agency and also using a University of Malaya Medical Centre Varian electron linac operated at 6 MV and 10 MV to deliver photon irradiations at commensurate energies. Five gelatine capsules were each loaded with four flat fibre dosimeters of 6.0 ± 1.0 mm

length, each capsule containing a particular cross-sectional set of fibres with thicknesses and widths as follows: 60 x 180 µm, 85 x 270 µm, 100 x 350 µm, 165 x 620 µm and 200 x 750 µm.

2.4.1. Linearity and energy dependence. The optical fibres were irradiated to doses in the range 0.5 Gy up to 10 Gy at a dose rate of 600 monitor unit (MU) per minute (for present conditions, 6 Gy per minute). During gamma irradiation using the Co-60 facility, the five different sizes of fibre were held in a polythene zipper bag placed at the surface of a Perspex (Polymethyl methacrylate, PMMA) phantom of dimensions (30 x 15 x 30) cm^3 with a source-to-surface distance (SSD) of 100 cm and a field size of 10 x 10 cm^2. For the 6 MV and 10 MV linac irradiations, the capsules were similarly held in a zipped storage bag and placed on a solid-water™ phantom, this time of dimensions (20 x 20 x 10) cm^3, to then be sandwiched with 1.5 cm bolus. The focus to surface distance (FSD) was 100 cm and a 10 x 10 cm^2 field size was used. Mean measured doses for each fibre group have been used to obtain a plot against delivered doses obtained from ion chamber measurements.

2.4.2. Reproducibility. For this, a total of four optical fibres were irradiated at dose rates of 0.0427 Gy min^{-1} and 600 cGy min^{-1} for Co-60 and the linac irradiations (6 MV and 10 MV photons) respectively, with doses ranging from 1 Gy to 2 Gy. Two repeat irradiations were made in order to assess the reproducibility of the flat fibres at the selected energy and dose.

2.4.3 Fading. Evaluation was made of the stability of TL signal over the period 1 to 30 days post irradiation. Irradiated flat fibres, dosed to 2 Gy, were read-out upon completion of the 1st, 6th, 16th and 22nd day post-irradiation.

2.5. Readout

The samples were read-out using a Harshaw 3500 TLD reader with a nitrogen gas atmosphere of 0.5 bars, used to suppress spurious light signals from triboluminesence and to reduce surface oxidation [9]. The following time-temperature profile was used during readout: preheat temperature of 180°C for 5 seconds; readout temperature of 400°C for 6 seconds and heating cycle rate of 35°C per second. An internal annealing temperature of 400°C was used for 10 seconds to remove any residual (deep traps) signal in the fibres.

3. Results and discussion

3.1. TL response

3.1.1. Linearity. The TL response of the fibres was found to be linear over the investigated dose range, as shown in Figures 1 to 3. Based on the coefficient of determination (R^2) of each flat fibre, the fibres of dimension 85 x 270 µm, 60 x 180 µm and 100 x 350 µm provided the best agreement between TL yield per unit mass and delivered dose for the Co-60 and 6 MV and 10 MV linac photons respectively. In line with expectation, based on sample mass, the least gradient corresponds to 60 x 180 µm for all photon energies delivered. For the thickest sample it is apparent that the additional attenuation of TL light transported through the medium suppresses any additional benefit of increased sample mass. The suppression becomes increasingly apparent with dose. This behaviour is a consistent feature that is observed in Figures 1 to 4.

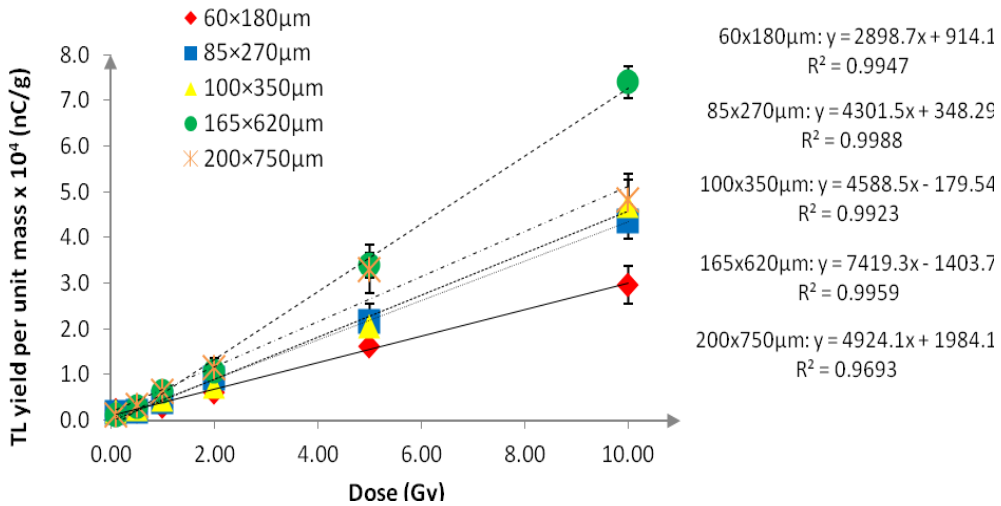

Figure 1. Linearity of the Ge-doped flat fibres for the 1.25 MeV mean energy of the Co-60 gamma beam irradiation.

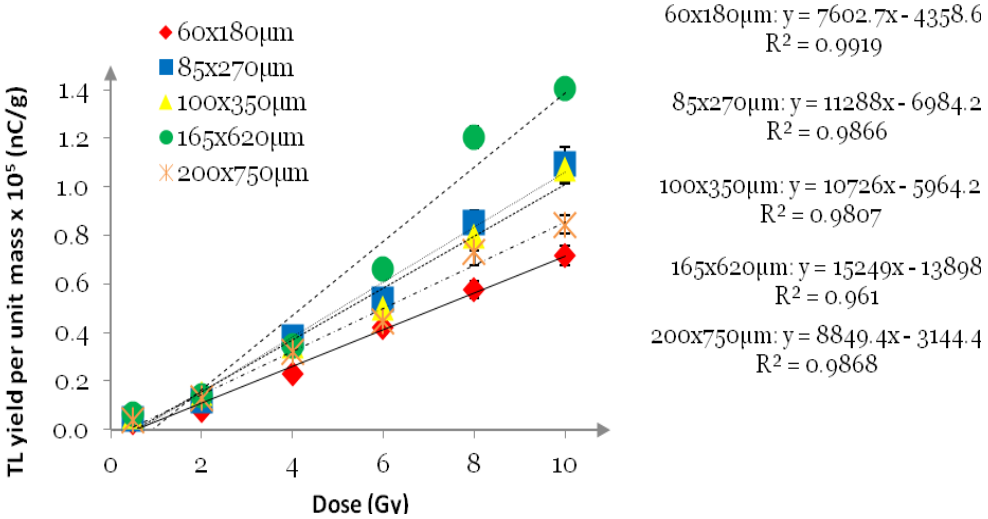

Figure 2. Linearity of the Ge-doped flat fibres for 6 MV photon beam irradiation.

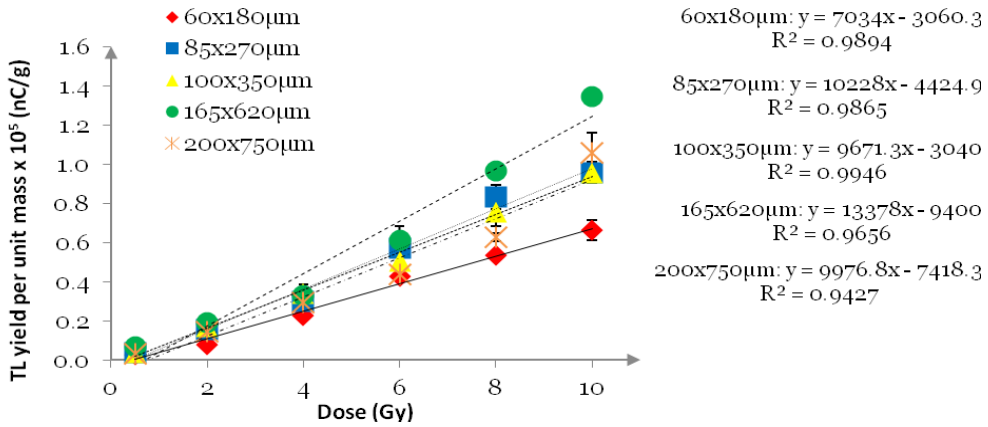

Figure 3. Linearity of the Ge-doped flat fibres for 10 MV photon beam irradiation.

3.1.2. Energy dependence. As shown in Figure 4, the Ge-doped flat fibres employed in this study exhibit increasing response at 6 MV compared to that obtained from Co-60 irradiation. However, the TL response obtained for the 10 MV photon beam is lower than that obtained at 6 MV, being in accord with [9] who observed the 9 µm commercial Ge-doped fibres response is decreased for 10 MV compared to 6 MV irradiations due to the mass energy absorption coefficient at 6 MV being higher than that for 10 MV. Overall, the results in this study reveal small energy dependence, with a coefficient of variation (CV) of less than 40% over the range of energies investigated.

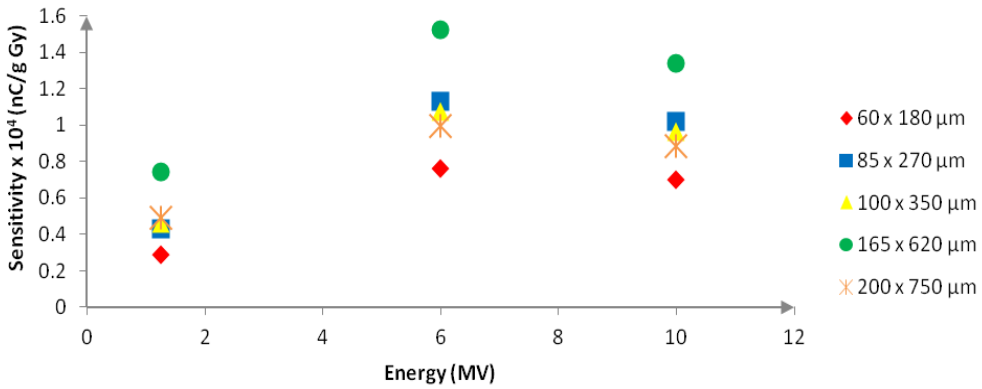

Figure 4. Energy responses of Ge-doped flat fibres following 1.25 MeV, 6 MV and 10 MV photon irradiations at a dose of 2 Gy.

3.1.3. Reproducibility. In this regard, the Ge-doped flat fibres were irradiated at a dose rate of 600 cGy min^{-1} for both 6 MV and 10 MV photons. Table 2 shows the mean TL yield per unit mass of each size of flat fibre for the corresponding doses and number of fibre samples read-out. The dose delivered was 1 Gy for Co-60 irradiations and 2 Gy for the linac irradiations. The standard deviation of these flat fibres in percentage terms was generally within 1.25 to 7.56%.

Table 2. Dose reproducibility of 1.25 MeV, 6 MV and 10 MV.

Size of flat fiber (µm)	Energy (source)	Dose (Gy)	No of fiber read	TL yield per unit mass (nC/g)		
				Mean	SD	SD in %
60 x 180	1.25 MeV	1	4	3857.58	106.39	2.76
	6 MV	2	4	5159.55	319.33	6.19
	10 MV	2	4	5080.00	301.26	5.93
85 x 270	1.25 MeV	1	4	3398.88	42.48	1.25
	6 MV	2	4	4783.85	212.98	4.45
	10 MV	2	4	6353.85	285.65	4.50
100 x 350	1.25 MeV	1	4	3897.58	151.74	3.89
	6 MV	2	4	7116.76	439.66	6.18
	10 MV	2	4	8294.78	288.18	3.47
165 x 620	1.25 MeV	1	4	18481.25	500.66	2.71
	6 MV	2	4	25427.08	1110.40	4.37
	10 MV	2	4	36333.33	919.13	2.53
200 x 750	1.25 MeV	1	4	7329.95	224.90	3.07
	6 MV	2	4	682.91	51.60	7.56
	10 MV	2	4	897.47	35.47	3.95

3.1.4. Fading. The loss of TL signal of irradiated flat fibres at 1st, 6th, 16th and 22th day post-irradiation is shown in Figure 5 and Figure 6 for 6 MV and 10 MV respectively. The line linking points are provided as a guide to the eye but not fit to each point. After 22 days, the largest signal loss was 51.11 %, suffered by the 200 x 750 µm fibre irradiated using 6 MV photons while the 165 x 620 µm fibre which been irradiated with 10 MV photon showed a signal loss of 44%. Conversely, the 100 x 350 µm fibre showed the least TL signal loss, at 6.55%, a matter worthy of continuing research in an effort to better understand the source of variation.

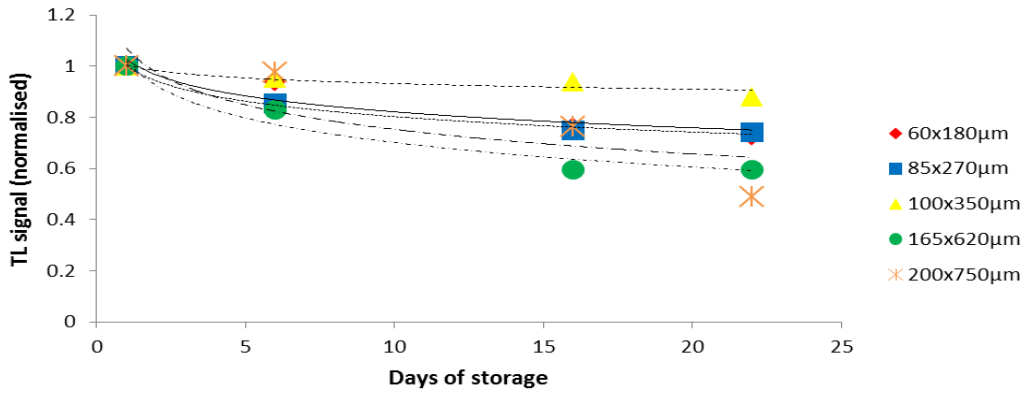

Figure 5. Decay fit to 4 measured fading values for 6 MV. Each data point corresponds to the average reading of 4 flat fibres.

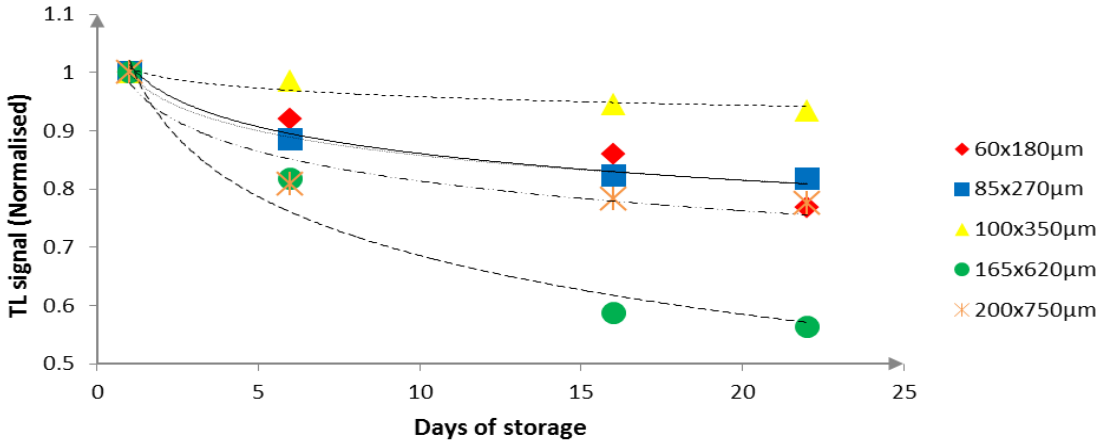

Figure 6. Decay fit to 4 measured fading values for 10 MV. Each data point corresponds to the average reading of 4 flat fibres.

4. Conclusion

The dosimetric characteristics of novel fabricated Ge-doped flat fibres have been established. Investigation reveals the 85 x 270 µm flat fibre to have the best performance, offering a viable system for postal radiotherapy dose audits, with corrections required for energy dependence, reproducibility and fading, suggesting the correction methods based on the Ge-doped audit system developed by Noor et al [9] need to be employed in order to calculate the absolute absorbed dose from Ge-doped optical fibres measurement for lower and higher energy photon.

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