



## Different Germanium Dopant Concentration and the Thermoluminescence Characteristics of Flat Ge-Doped Optical Fibres

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### ABSTRACT

The influence of elevated germanium concentration on the thermoluminescence characteristics of a novel form of fabricated flat optical fibre was examined. All the samples were irradiated with two nominal photon energies (6 MV and 10 MV) and 1.25 MeV gamma energy. Flat fibres with 10 mol % Ge concentration provided the superior TL yield compared against that of 6 and 8 mol % Ge-doped optical fibres for both 6 MV and 10 MV energy. Interpretation of the results has been aided by study of the glow curves, revealing in particular new generation of defects in the flat fibres due to strain-generation at the collapsed surfaces. The strain represent deep-energy defects.

*Keywords:* Dosimetric characteristics, flat fibre, glow curves

### Article history:

Received: 16 June 2016

Accepted: 20 December 2016

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### INTRODUCTION

Optical fibres are widely known in the global communications industry and have been extensively used for worldwide broadband communication such as the internet. Recent developments in optical fibre technology have led to a renewed interest in passive dosimetry

applications. The interest concerns in particular the introduction of commercially available telecommunication doped amorphous silicon dioxide ( $\text{SiO}_2$ ) fibres as a thermoluminescent dosimeter (TLD), specifically because in radiation dosimetry the optical fibres offer good spatial resolution and for certain dopants concentrations there is sufficient thermoluminescent (TL) yield to serve the associated sensitivity needs (Bradley et al., 2012).

Prior to the use of any radiation dosimeter in daily clinical applications, the characteristics of the dosimeters first need to be established, including reproducibility, linearity, dose-rate and energy dependence, and for TLDs the fading effect of superficial traps. Depending on the use and characteristics of the optical fibres, the medium can be added to or modified, including change in the concentration of the dopant element in order to alter the radiation response of the fibre. Previous studies have primarily concentrated on the more usual germanium (Ge) doped cylindrical fibre shapes, showing promising dosimetric characteristic in thermoluminescence dosimetry especially in respect of radiotherapy photon beams (Hashim et al., 2009; Hashim et al., 2010; Noor et al., 2010; Abdul Rahman et al., 2011; Abdul Rahman et al., 2012; Noor et al., 2012; Noor et al., 2014).

Recent studies on Ge-doped fibres by Alawiah et al. (2013), Alawiah et al. (2015), Bradley et al. (2015) and Mahdiraji et al. (2015) have focused on the development of a new tailor-made flat fibre. Analysis and discussion of flat fibre performance have been presented in respect of several energy and dose ranges, from diagnostic applications (Ramli et al., 2015), to radiotherapy photon beams (Fadzil et al., 2014) to high dose irradiation (Noor et al., 2015). Research on the subject has been mostly restricted to limited comparisons of different sizes of optical fibre. To-date little attention has been paid to study the effect of different dopant concentration on the thermoluminescence performance of the optical fibre, with systematic understanding of how the dopant concentration contributes to TL intensity still lacking. The purpose of this paper is to study the influence of elevated concentration of Ge-doped flat fibres on the thermoluminescence's characteristics.

## **MATERIALS AND METHOD**

### **Fabrication and designation of the fibre**

The manufacturing of an optical fibre involves: (i) preform fabrication and; (ii) the drawing process. The preform is a glass rod hollow-tube structure with diameter of  $22 \pm 2$  mm. A commercially used method based on the standard modified chemical vapour deposition (MCVD) technique was employed in fabricating the preform. This technique involved chemical vapour reaction at temperature ranging from  $1600^\circ\text{C}$  to  $2000^\circ\text{C}$ , mixing the silica tetrachloride ( $\text{SiCl}_4$ ) with germanium tetrachloride ( $\text{GeCl}_4$ ) and oxygen ( $\text{O}_2$ ) during passage through a rotating silica glass tube (F300). These three compounds were deposited inside the inner layer of F300 and produced several layers of the core. The percentage of dopant concentration was determined by the dopant flow rate during the MCVD process. This process was carried out using facilities at the Photonics Laboratory, Faculty of Engineering, Multimedia University, Cyberjaya, Malaysia. Three Ge-doped silica dioxide optical fibres preforms with different germanium dopants concentration (6, 8 and 10 mol %) were fabricated for this study. An overview of the preform fabrication process is represented in Figure 1.

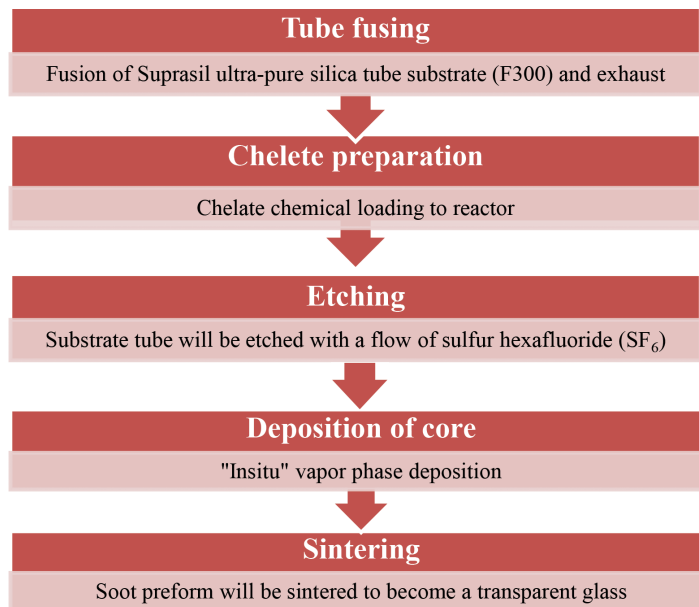


Figure 1. Preform fabrication flow chart in MCVD process.

The optical fibres then were cut and cleaned using methanol to eliminate carbon deposition. The actual flat fibre dimensions (Figure 2) and their weights are presented in Table 1 for the three Ge concentrations.

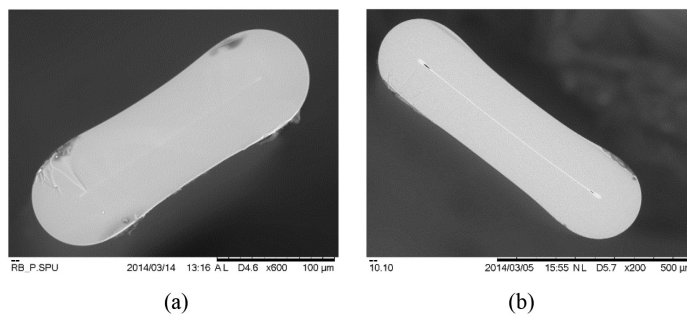


Figure 2. Scanning Electron Microscope image of a small (a) and large (b) dimension of Ge-doped flat fibres.

Table 1  
The flat fibre sizes and mass for the three Ge concentrations

Size		6% mole	8% mole	10% mole
Small	Size (µm)	270 ±5 x 80 ±2	255 ±5 x 50 ±2	270 ±4 x 80 ±2
	Mass (mg)	1.29 ±0.08	1.12 ±0.30	1.22 ±0.03
Large	Size (µm)	780 ±10 x 190 ±5	760 ±7 x 150 ±4	750 ±6 x 230 ±3
	Mass (mg)	3.39 ±0.16	1.90 ±0.13	3.54 ±0.28

### Irradiation and Readout

The fibres were exposed to x-rays generated at 6 MV and 10 MV, with a dose rate of 600 MU/min and doses ranging from 0.5 Gy up to 10 Gy using a Varian Clinac Linear Accelerator located at the University Malaya Medical Centre (UMMC). A source to surface distance (SSD) of 100 cm was employed, with a field size of 20 × 20 cm<sup>2</sup>. After the irradiation, the TL intensity of the Ge-doped fibres was obtained using a Harshaw 3500 TLD reader. The selected time-temperature profile (TTP) of the reader is shown in Table 2.

Table 2  
*Time-temperature profile setup for flat fibre TL assessment*

Time-temperature profile parameters	
Preheat temperature	80 °C
Acquires ramp rate	30 °C s <sup>-1</sup>
Acquisition time	13 seconds
Maximum temperature	400 °C

### Glow Curve

The shape of the glow curves obtained as a result of heating the thermoluminescent materials is important in determining the nature and TL properties of the material and also key to the media forming a suitable dosimeter. In particular, the glow curves reflect the nature of the trap parameters. The glow curve analysis was carried out herein by plotting the glow curve using Microsoft Excel software, yielding features such as the temperature at which the highest peak intensity is obtained.

## RESULTS AND DISCUSSION

Here, there is increasingly complex interplay between defect generation at the collapsed fibre internal interface (so-called strain defects), the detected luminescence yield and the overlaying cladding thickness. In regard to the overall TL yield, that from the smaller dimension flat fibres doped with 6 mol % Ge is observed to produce greater TL signal intensities (Figure 3 and 4). Conversely, the TL yield of the larger dimension flat fibres shows 10% mol fibre produce greater response compared with 6 and 8 mol % fibres, both for 6 MV and 10 MV irradiations respectively (Figure 5 and 6).

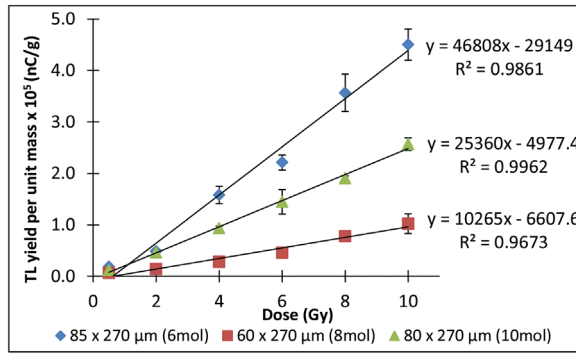


Figure 3. The TL yield of the smaller dimension flat fibres doped with 6, 8 and 10 (mol %) Ge subjected to 6 MV photon irradiation.

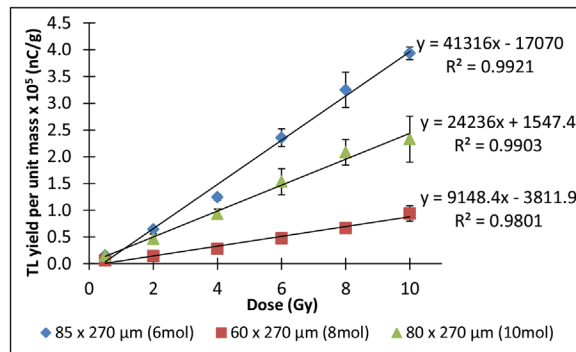


Figure 4. The TL yield of the smaller dimension flat fibres doped with 6, 8 and 10 (mol %) Ge subjected to 10 MV photon irradiation.

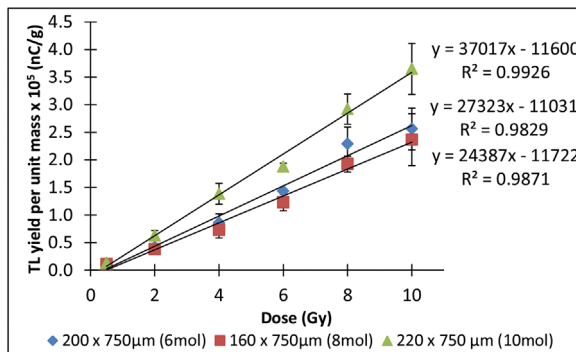


Figure 5. The TL yield of the larger dimension flat fibres doped with 6, 8 and 10 (mol %) Ge subjected to 6 MV photon irradiation.

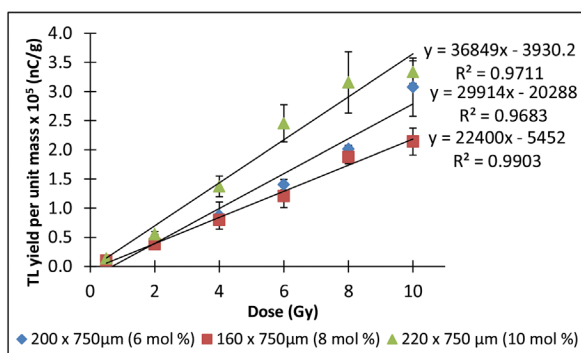


Figure 6. The TL yield of the larger dimension flat fibres doped with 6, 8 and 10 (mol %) Ge subjected to 10 MV photon irradiation.

A better understanding of the more complex situation is to be obtained from glow curve analysis, the flat fibres being represented by a two-peaks system, the first prominent peak observed for temperatures ranging from 201 °C to 253 °C while the second peak appears at temperatures ranging from 362 °C to 390 °C (Figure 7(a) and (b)), indicative of a deeper traps system resulting from strain defects generation. Glow curve peak parameters of flat fibre for the three Ge concentrations including temperature, channel and TL intensity were obtained as shown in Table 3.

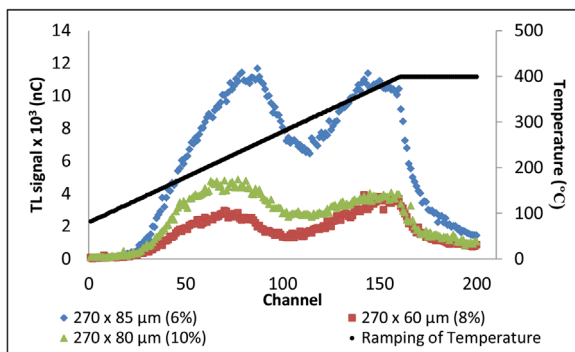


Figure 7(a). Flat fibre (small dimension) TL glow curves for the three different dopant concentrations (6, 8, 10 mol %) following 2 Gy Co-60 irradiation.

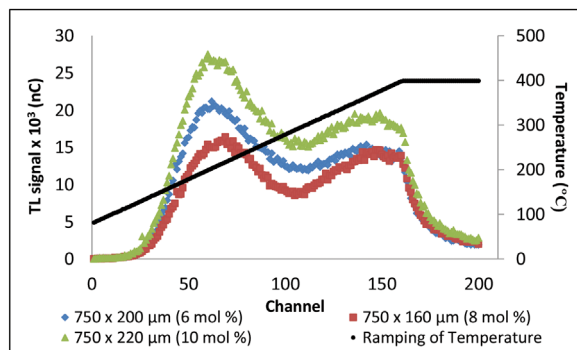


Figure 7(b). Flat fibre (largest dimension) TL glow curves for the three different dopant concentrations (6, 8, 10 mol %) following 2 Gy Co-60 irradiation.

Table 3  
*Glow curve peak parameters of flat fibre for the three Ge concentrations*

Flat fibres (small)	First peak			Second peak		
	Temperature (°C)	Channel number	TL signal (nC)	Temperature (°C)	Channel number	TL signal (nC)
270 x 85 $\mu\text{m}$ (6% mol)	253	87	11679	366	144	11386
270 x 60 $\mu\text{m}$ (8% mol)	221	70	2944	378	150	3805
270 x 80 $\mu\text{m}$ (10% mol)	233	77	4865	390	156	4057

Flat fibres (large)	First peak			Second peak		
	Temperature (°C)	Channel number	TL signal (nC)	Temperature (°C)	Channel number	TL signal (nC)
750 x 200 $\mu\text{m}$ (6% mol)	203	62	21168	362	142	15381
750 x 160 $\mu\text{m}$ (8% mol)	217	69	16383	372	147	14666
750 x 220 $\mu\text{m}$ (10% mol)	201	61	26886	376	149	19624

## CONCLUSIONS

The present study was designed to determine the effect of germanium dopant concentration on TL intensity of flat fibres with the intention of developing new TL dosimeters with optimum performance for radiotherapy dosimetry applications. The evidence from this study suggests that the response in the flat fibres is assisted by strain defects generation, representative of deep-energy defect levels. The findings of this study have a number of important implications for future practices in radiotherapy dosimetry, to be preceded by more detailed investigations of the factors influencing TL yield.

## ACKNOWLEDGEMENTS

This research is supported by Malaysia Fundamental Research Grant Scheme (FRGS) no: 5524789; University of Malaya High Impact Research Grants (UM-HIR) no UM.C/625/1/HIR/33; Universiti Putra Malaysia Geran Putra Incentive Putra Siswazah (UPM-GP-IPS) no 9433970 and A000007-50001 from the Ministry of Education Malaysia. Use of irradiation facilities at the Malaysian Nuclear Agency and University of Malaya Medical Centre are acknowledged. We are indebted to the staff of Telekom Malaysia Research & Development Sdn Bhd, Cyberjaya and the Pulling-Tower Laboratory, University of Malaya for their technical assistance during the sample fabrication and pulling process.

## REFERENCES

- Alawiah, A., Intan, A. M., Bauk, S., Rashid, H. A. A., Yusoff, Z., Mokhtar, M. R., ... Tamchek, N. (2013). Thermoluminescence characteristics of flat optical fiber in radiation dosimetry under different electron irradiation conditions. In *Proc. SPIE* (Vol. 8775, p. 87750S).
- Alawiah, A., Bauk, S., Rashid, H. A. A., Gieszczyk, W., Hashim, S., Mahdiraji, G. A., ... Bradley, D. A. (2015). Potential application of pure silica optical flat fibers for radiation therapy dosimetry. *Radiation Physics and Chemistry*, *106*, 73-76.
- Bradley, D. A., Hugtenburg, R. P., Nisbet, A., Rahman, A. T. A., Issa, F., Noor, N. M., & Alalawi, A. (2012). Review of doped silica glass optical fibre: their TL properties and potential applications in radiation therapy dosimetry. *Applied Radiation and Isotopes*, *71*, 2-11.
- Bradley, D. A., Mahdiraji, G. A., Ghomesian, M., Dermosesian, E., Adikan, F. R. M., Rashid, H. A., & Maah, M. J. (2015). Enhancing the radiation dose detection sensitivity of optical fibres. *Applied Radiation and Isotopes*, *100*, 43-49.
- Fadzil, M. A., Ramli, N. N. H., Jusoh, M. A., Kadni, T., Bradley, D. A., Ung, N. M., ... Noor, N. M. (2014). Dosimetric characteristics of fabricated silica fibre for postal radiotherapy dose audits. In *Journal of Physics: Conference Series* (Vol. 546, No. 1, p. 012010). IOP Publishing.
- Hashim, S., Al-Ahbab, S., Bradley, D. A., Webb, M., Jeynes, C., Ramli, A. T., & Wagiran, H. (2009). The thermoluminescence response of doped SiO<sub>2</sub> optical fibres subjected to photon and electron irradiations. *Applied Radiation and Isotopes*, *67*(3), 423-427.
- Hashim, S., Bradley, D. A., Saripan, M. I., Ramli, A. T., & Wagiran, H. (2010). The thermoluminescence response of doped SiO<sub>2</sub> optical fibres subjected to fast neutrons. *Applied Radiation and Isotopes*, *68*(4), 700-703.
- Mahdiraji, G. A., Adikan, F. R. M., & Bradley, D. A. (2015). Collapsed optical fiber: A novel method for improving thermoluminescence response of optical fiber. *Journal of Luminescence*, *161*, 442-447.
- Noor, N. M., Hussein, M., Bradley, D. A., & Nisbet, A. (2010). The potential of Ge-doped optical fibre TL dosimetry for 3D verification of high energy IMRT photon beams. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, *619*(1), 157-162.
- Noor, N. M., Shukor, N. A., Hussein, M., Nisbet, A., & Bradley, D. A. (2012). Comparison of the TL fading characteristics of Ge-doped optical fibres and LiF dosimeters. *Applied Radiation and Isotopes*, *70*(7), 1384-1387.
- Noor, N. M., Hussein, M., Kadni, T., Bradley, D. A., & Nisbet, A. (2014). Characterization of Ge-doped optical fibres for MV radiotherapy dosimetry. *Radiation Physics and Chemistry*, *98*, 33-41.
- Noor, N. M., Jusoh, M. A., Razis, A. A., Alawiah, A., & Bradley, D. A. (2015). Flat Ge-doped optical fibres for food irradiation dosimetry. *National Physics Conference 2014 (PERFIK 2014)* (p. 100007): AIP Publishing.
- Rahman, A. A., Nisbet, A., & Bradley, D. A. (2011). Dose-rate and the reciprocity law: TL response of Ge-doped SiO<sub>2</sub> optical fibers at therapeutic radiation doses. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, *652*(1), 891-895.



- Rahman, A. A., Hugtenburg, R. P., Sani, S. F. A., Alalawi, A. I. M., Issa, F., Thomas, R., ... Bradley, D. A. (2012). An investigation of the thermoluminescence of Ge-doped SiO<sub>2</sub> optical fibres for application in interface radiation dosimetry. *Applied Radiation and Isotopes*, *70*(7), 1436-1441.
- Ramli, N. N. H., Salleh, H., Mahdiraji, G. A., Zulkifli, M. I., Hashim, S., Bradley, D. A., & Noor, N. M. (2015). Characterization of amorphous thermoluminescence dosimeters for patient dose measurement in X-ray diagnostic procedures. *Radiation Physics and Chemistry*, *116*, 130-134.

