THE THERMOLUMINESCENCE RESPONSE OF Ge-DOPED OPTICAL FIBRES TO X-RAY PHOTON IRRADIATION

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ABSTRACT

Thermoluminescence dosimetry (TLD) is useful in medical application to determine dose received by patient in cancer treatment. The interest is to introduce optical fibres as a new thermoluminescence (TL) material. This paper presents preliminary results on the TL response reproducibility with various doses and fading of Ge-doped optical fibres to X-ray photon irradiation. The optical fibres investigated were typical single-mode fibres, with a core diameter of 130 μm. Prior to X-ray photon irradiation, the calibration of diagnostic X-ray machine doses was made using ionization chamber. Dose rate of 58.31 mGy s^{-1} was delivered to the Ge-doped optical fibre using 49.8 kV_p and 986 μA current setting. During irradiation, a retort stand was used to hold the plastic container in order to get uniform exposure. TL response of Ge-doped optical fibre following X-ray irradiations was found to be linear in medical radiotheraphy dose range up to 10 Gy. In fading studies, a total of 30 samples of Ge-doped optical fibres were simultaneously irradiated, first to 2 Gy of X-rays and then subsequently to 10 Gy of X-ray dose. The performance of Ge-doped optical fibres was then compared against the currently available TL material i.e. TLD-700 (LiF:Mg,Ti). The average reading from five repeated measurements on both types of TL material were recorded on a daily basis over a period of six days. After irradiation, and until readout, the samples were kept in the lightproof container at a room temperature. Six days after irradiation, the Ge-doped optical fibre exposed to 2 Gy showed a 26.2 % loss of signal compared to the yield obtained 24 hours after irradiation, while at 10 Gy the fibre showed a loss of 19.7 %. Conversely, for TLD-700 the respective values were 75.9% and 36.1 %.

Keywords: Ge-doped optical fibre; TL (thermoluminescence); X-ray photon; Fading.

INTRODUCTION

Ionizing radiation is used for diagnostic and therapeutic purposes in medicine. This covers a wide range of various radiation doses and most of applications utilize photons either in the form of X-rays (diagnostic radiology, radiotherapy) or gamma rays (nuclear medicine, radiotherapy).

TLD is used in medicine to determine patient dose arising from diagnostic X-ray procedures and radiotherapy treatments. TL signal occurs when part of the energy absorbed by the material is emitted as a photon when being heated. The spectrum of light emitted is called glow curve. It consists of one or several peaks. The glow curve peaks parameters such as position, shape and intensity are used for TL material characterization

Recently, some research groups started to use SiO_2 optical fibres as a radiation dosimeter to measure absorbed dose to patients for *in vivo* dosimetry [1]. Some other research groups have been working to develop optically stimulated luminescence methodology for use with doped optical fibre material with possible use as dosemeter material [2]. While other groups are working on *in situ* measurement of radiation-induced optical absorption in silica core fibres exposed to fission from nuclear reactors [3]. The optical fibre material has been used directly as nuclear track detector for fission fragments [4], Investigation has been performed on commercially available germanium-doped SiO_2

optical fibres in terms of their response to photons in the therapeutic energy and dose range [5], and currently the use of commercial optical fibre as TLD material is also being conducted [6].

These on-going researches will pave the way to introduce the SiO_2 optical fibres as a new TL material in variety of applications.

MATERIALS AND METHODS

Material and preparation

The Ge-doped optical fibre has a core diameter of 130 μm. The protective polymer layer of the optical fibre was removed by using a fibre stripper. A moist cotton cloth dipped into ethanol was used to clean the Ge-doped optical fibre core. Subsequently, the fibre was cut to the length of 0.8 ± 0.1 cm by using an optical fibre cleaver. The mass of each fibre is 0.21 ± 0.01 mg. It was measured using an electronic balance to allow TL yield to be normalized to unit mass. For fading studies, TLD-700 (LiF:Mg,Ti), comprising 99.99% ^{7}Li, and in the form of a disc of diameter 4.6 mm and 0.63 mm thickness was used as a standard against which the Ge-doped fibre response was compared.

For routine storage, handling and in some cases for irradiation purposes, each sample of the optical fibre was placed inside an opaque plastic container. When not in use, the optical fibres were kept in a lightproof container.

Annealing

Annealing is the thermal treatment used to erase any irradiation memory from the dosimetric material. The high temperature anneal is required to clear the dosimetric traps of residual signal which may cause unwanted background reading during subsequent use of the dosimeters. The low temperature anneal is required to stabilize and aggregate low temperature traps in order to enhance the sensitivity of the main dosimetry traps and to reduce losses of radiation-induced signal due to thermal or optical fading during use. Annealing was performed at 400 °C for a period of 1 hour, the fibres being retained in an alumina container during this period. To avoid thermal stress following the annealing cycle, the fibres were left inside the furnace for 18 hours to finally equilibriate at temperature of 40 °C [7]. After cooling, the fibres were placed inside the opaque plastic container in order to minimize exposure to the potentially high ambient light levels.

Readout parameters

During readout the following parameters were used: preheat temperature 160 °C for 10 s; readout temperature of 300 °C for 25 s; heating cycle rate of 25 °C s^{-1}.

Exposure to radiation

Irradiation of Ge-doped optical fibre were performed by using 49.8 kV_p and 986 μA current diagnostic X-ray machine. The dose rate of 58.31 mGy s^{-1} was obtained after calibrating the X-ray machine using ionization chamber. By varying the exposure time, from 10 seconds up to 6 minutes, the dose response ranging from 0 to 10 Gy were observed, Figure 1.

Instrumentation

A Solaro TL reader (Vinten TLD, Reading, UK) TL was used under a N_2 atmosphere.

Elemental mappings

The Faculty of Mechanical Engineering, Universiti Teknologi Malaysia hosts the Scanning Electron Microscope (SEM) facility based on GEMINI technology (Zeiss, Germany).

SEM technique was used to determine the effective atomic number of the Ge-doped optical fibres by measuring the composition of the elements present. The optical fibres were attached to the surface area of a stainless steel sample holder. To minimize the electrostatic effect, the samples were placed into sputtering machine for gold coating procedures. Then, the optical fibre samples were ready for scanning purposes. The scanning process was performed to the surface and the cross-sectional area.

INCAEnergy software (Oxford Instruments, U.K) was used to identify the elements present in the optical fibres. The X-ray spectrum was obtained from the X-rays being emitted from the samples. The software automatically identifies the peaks in the spectrum and the elements in the sample. Elemental presence can also be detected manually if the optical fibres composition was known. The quantity of the element is calculated automatically.

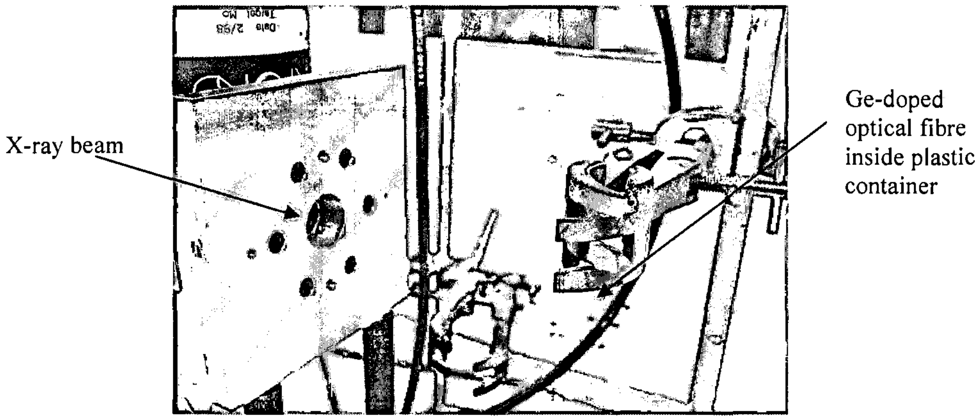

Figure 1: Irradiation of Ge-doped optical fibre using 49.8 kV_p and 986 μA current diagnostic X-ray. The calibration was performed before irradiating the fibres by using ionization chamber in order to estimate the dose rate produced by the X-ray machine. During irradiation, the retort stand was used to hold the plastic container in order to get uniform exposure.

RESULTS AND DISCUSSION

Effective atomic number, Z_{eff}

Z_{eff} is the atomic number of an element with which photons interact in the same way as the given composite material. Since photoelectric effect is highly Z dependent, Z_{eff} is considered for photoelectric effects. Z_{eff} was calculated using Mayneord equation [8],

$$Z_{eff} = (a_1 Z_1^{2.94} + a_2 Z_2^{2.94} + a_3 Z_3^{2.94} + ... + a_n Z_n^{2.94})^{1/2.94} \quad (1)$$

where $a_1, a_2, a_3, ... a_n$ are the fractional contributions of each element of Ge-doped fibres to the total number of electrons in the mixture. From SEM analysis, with the presence of silica, oxygen and germanium, the value of Z_{eff} is 12.39.

The TL response of Ge-doped optical fibre following X-ray irradiations was found to be linear in the medical radiotherapy dose range up to 10 Gy as can be seen in Figure 2.

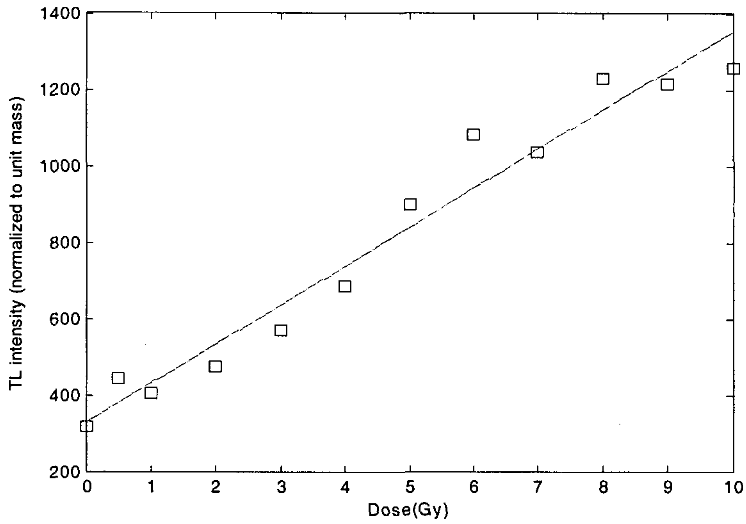

Figure 2: TL response of Ge-doped optical fibre for X-ray irradiation. Dose response linearity is observed up to at least 10 Gy.

TL glow curve

The Ge-doped optical fibre and TLD-700 performance was compared after irradiation to the 2 Gy and 10 Gy X-rays photon irradiation. The TLD materials were irradiated for 34 seconds for 2 Gy and 172 seconds for 10 Gy irradiation respectively followed by readout process. The glow curves (light intensity as a function of temperature) were obtained at a heating rate of 25°C s^{-1}.

The classic form of response for crystalline TL phosphor is obtained, the more shallow traps being preferentially emptied as the material is heated (a good example is the localized trapping whose corresponding peak in light yield intensity is located at ~ 200°C), light yield subsequently falling off as these traps are depleted. As heating continues, the electrons in deeper traps are released, resulting in additional peaks, in this particular case producing a peak value corresponding to a temperature of ~300°C. Usually the highest peak is used for calculations. The area under the curve represents the radiation energy deposited [9]. After the readout is complete, the TLD is annealed at a high temperature. This process essentially zeroes the TL material by releasing all trapped electrons. The TLD is then ready for reuse.

The readout temperature obtained from the TLD reader is limited to a maximum of 400°C. As can be seen in the Figure 3, Ge-doped optical fibre has a broad peak whereas TLD-700 has two narrow peaks at 200 °C and 300 °C. If the dose level is changed, the general structure of the TL curve remains the same. Repeated cycle of annealing and irradiation at various dose produced the same glow curve shape. It is intended to use an automatic TLD reader to verify this result.

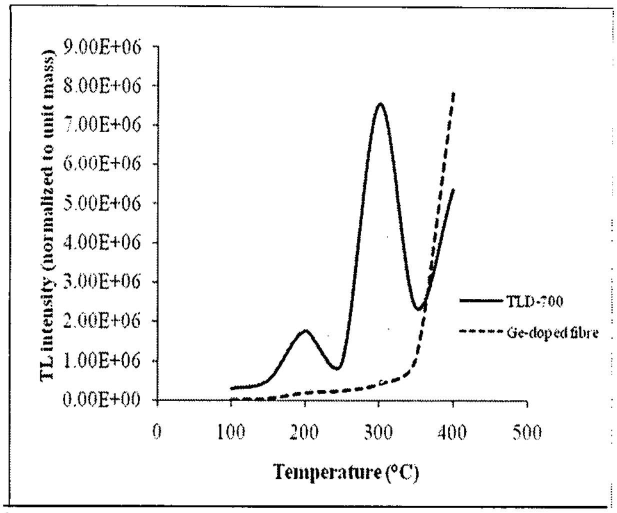

Figure 3: The glow curves of TLD-700 and Ge-doped optical fibre for 10 Gy of X-rays irradiation. The TLD materials were irradiated for periods of 172 seconds for dose of 10 Gy.

Fading

Fading is defined as a loss of stored thermoluminescent signal after irradiation. All TL materials suffer from fading of the stored signal to some extent. Fading depends largely on the depth of the traps and the storage temperature. It is also affected by the heat treatment applied during annealing and readout procedures [10].

30 samples were simultaneously irradiated with the dose of 2 Gy and 10 Gy. The performance of Ge-doped optical fibres was compared respectively with TLD-700. The average reading from five repeated measurements was obtained each day. The TL measurements were continued up to six days period. After the irradiation, the samples were kept in a lightproof container at room temperature. Six days after irradiation, the Ge-doped optical fibre dosed to 10 Gy showed a loss of signal of 19.7 % compared to the yield obtained 24 hours after irradiation as can be seen in Figure 4, while at 2 Gy irradiations the Ge-doped optical fibre showed a loss of 26.2 %. Conversely, for TLD-700 the respective values were 36.1 % as in Figure 5 and 75.9 %.

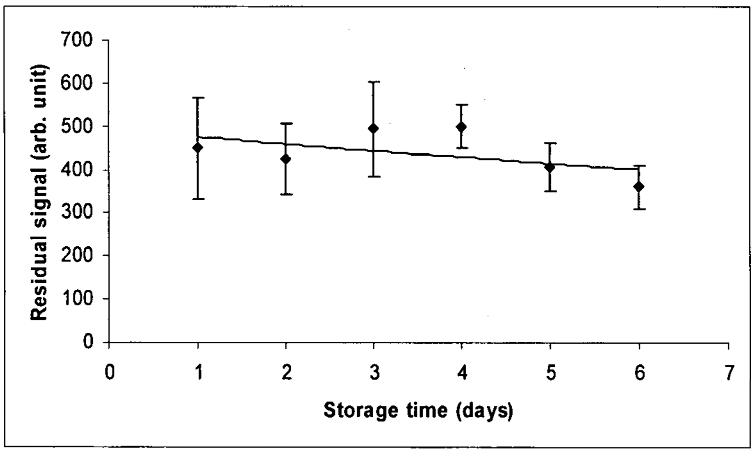

Figure 4: Fading of signal at 19.7 % for Ge-doped optical fibres, irradiated to X-ray dose of 10 Gy.

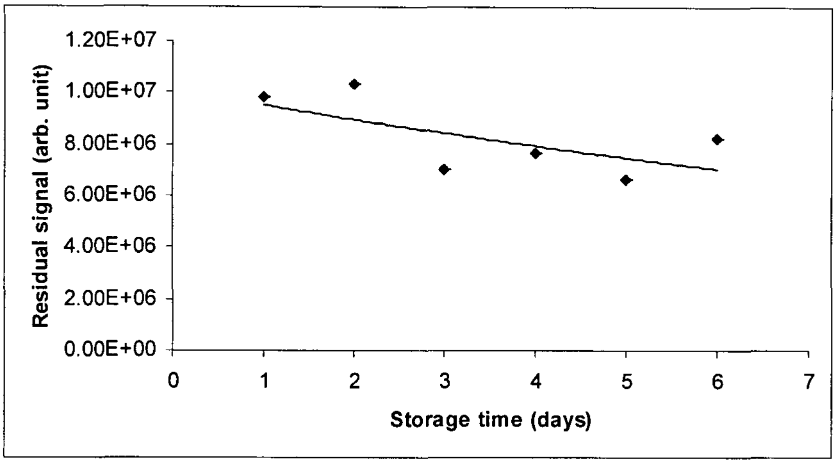

Figure 5: Fading of signal at 36.1 % for TLD-700, irradiated to X-ray dose of 10 Gy

CONCLUSION

The Ge-doped optical fibres studied here exhibit a linear response up to 10 Gy when subjected to X-ray photon irradiation. The Z_{eff} of Ge-doped optical fibre is 12.39. This study provides important parameters for introducing doped SiO_2 optical fibres as a TL dosemeter suitable in various applications. The intention of this group is to continue the studies using variously doped SiO_2 optical fibres subjected to X-rays and electrons produced by linear accelerators.

ACKNOWLEDGEMENTS

The authors would like to thank Academy of Sciences Malaysia for providing a SAGA grant and to Universiti Teknologi Malaysia for supporting a research studentship.

REFERENCES

[1] Aznar, M., Polf, J., Akselrod, M., Andersen, C., Back, S., Boetter-Jensen, L., Mattsson, S., McKeever, S. and Medin, J. (2002). *Real-time optical fibre dosimetry in radiotherapy.* Available on http://www.aapm.org/meetings/02AM/pdf/76262 0413.pdf.

[2] Houston, A.L, Justus, B.L., Falkenstein, P.L., Miller, R.W., Ning, H. and Altemus, R. (2002). *Optically stimulated luminescence glass optical fibre dosemeter.* Radiat. Prot. Dosim. **101**, 23-26.

[3] Brichard, B., Borgermans, P., Fernandez, A., Lammens, K. and Decreton, M. (2000). *Radiation effects in silica optical fibre expose to intense mixed neutron-gamma radiation field.* Available on http://www.sckcen.be/sckcen_en/people/affernandez/pdf/BB_TNS01.pdf

[4] Espinosa, G., Golzarri, J.I., Vazquez, C. and Fragoso, R (2003). *Measurement of nano-size etched pits in SiO_2 optical fibre conduit using AFM.* Radiat. Meas. **36**, 175-178.

[5] Youssef, A.A., Amin, Y.M. and Bradley, D.A. (2001). *The thermoluminescence response of Ge-doped optical fibre subjected to photon irradiation.* Radiation Physics and Chemistry. **61**, 409-410.
[6] Espinosa, G., Golzarri, J.I., Bogard, J. and Garcia-Macedo, J. *Commercial optical fibre as TLD material.* Radiat. Prot. Dosim. **18**, 1-4 (2006).
[7] Espinosa, G. (2005). *Thermoluminescent response of commercial SiO_2 optical fibre to gamma-radiation.* Journal of Radioanalytical and Nuclear Chemistry. **264**, 107-111.
[8] Youssef, A.A. (2003). *The thermoluminescence response of Ge-doped and Er-doped optical fibres in radiation therapy*, PhD Dissertation, University of Malaya.
[9] R. Chen and S.W.S. McKeever (1992). *Theory of Thermoluminescence and Related Phenomena*, New York: World Scientific.
[10] A.L. Yusoff, R.P. Hugtenburg and D.A.Bradley (2005). *Review of development of a silica-based thermoluminescence dosimeter.* Rad. Phys. Chem. **74:** 459–481.