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THERMOLUMINESCENCE OF Ge- AND Al-DOPED SiO_2 OPTICAL FIBERS SUBJECTED TO 0.2–4.0 Gy EXTERNAL PHOTON RADIOTHERAPEUTIC DOSE

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In this work, we studied the thermoluminescence response of Ge- and Al-doped optical fibers, its linearity, energy dependence, and sensitivity. The Ge-doped optical fibers demonstrate useful TL properties and represent an excellent candidate for use in TL dosimetry of ionizing radiation. The TL response increases monotonically over a wide photon dose range, from 0.2 Gy to 4.0 Gy. The TL results for these fibers have been compared with similar TL data for phosphor TLD-100. Commercially available Al- and Ge-doped optical fibers have both been found to yield a linear dose-TL signal relationship, although the Al-doped fiber provides only 5 % of the sensitivity of the Ge-doped fibers. The TL characteristics of Ge-doped optical fiber, plus its small size (125 μm diameter), high flexibility, ease of handling, and low cost compared with other TL materials, make this commercial optical fiber a very promising TL material for use in medicine, industry, reactor operation, and a variety of other areas.

Keywords: *thermoluminescence, dosimetry, photon, optical fiber.*

Introduction. Thermoluminescence dosimetry (TLD) has been widely applied in such areas as clinical radiation medicine and personal and environmental monitoring of ionizing radiation. TLD has the advantage of providing a very sensitive small-size dosimeter equivalent to human tissues when correctly chosen [1]. Present studies of doped SiO_2 optical fibers are of interest because of their high sensitivity, low cost, and easy preparation. Some research groups have reported favorable radiation effects in such media, the development of optically stimulated luminescence methodology for use with doped optical fiber material, the measurement *in situ* of radiation-induced optical absorption in silica core fibers exposed to fission nuclear reactors, the measurement *in vivo* of the absorbed dose in patients treated by radiation therapy, and the diagnostics and use of optical fiber material directly as a nuclear track detector for fission fragments [2, 3].

Radiotherapy is one of the primary modalities used in the treatment of malignant diseases. In regard to external photon beam radiotherapy, this is usually carried out with more than one radiation beam in order to achieve a uniform dose distribution within the target volume and a dose as low as possible in healthy tissues surrounding the target. X-rays are used in radiotherapy for treatment of different types of diseases or cancers [4, 5].

We have studied SiO_2 optical fibers as radiation dosimeters to measure the absorbed dose to patients for *in vivo* dosimetry in order to overcome spatial resolution limitations of existing dosimetry systems [6–9]. The thermoluminescence response of Ge- and Al-doped optical fibers subjected to photon and electron irradiation has been investigated because they are also impervious to water to the extent that in some instances it then becomes possible to locate the fiber dosimeter within a particular tissue of interest [10–14]. These optical fibers are also able to maintain a consistent TL response after repeated exposures. The SiO_2 commercial optical fiber studied demonstrates useful TL properties and is an excellent candidate for use in TL dosimetry of ionizing radiation. A response of the Ge- and Al-doped SiO_2 optical fibers to the low-dose photon irradiation ranging from 0.02 to 0.24 Gy was reported in [6–8]. The present work investigates the response of the above fibers to 0.2–4.0 Gy photon doses with the aim to use them for in-vivo dosimetry (IVD) during radiation therapy (RT) in medical treatments.

Materials and Methods. *Material preparation.* The commercially available Al- and Ge-doped optical fibers chosen for this work are from INOCORP (Canada); they have an external diameter of 124.7 ± 0.1 μm and a doped core diameter of 9 μm. They were selected based on their availability, homogeneity, and low cost. First, the protective polymer layer was

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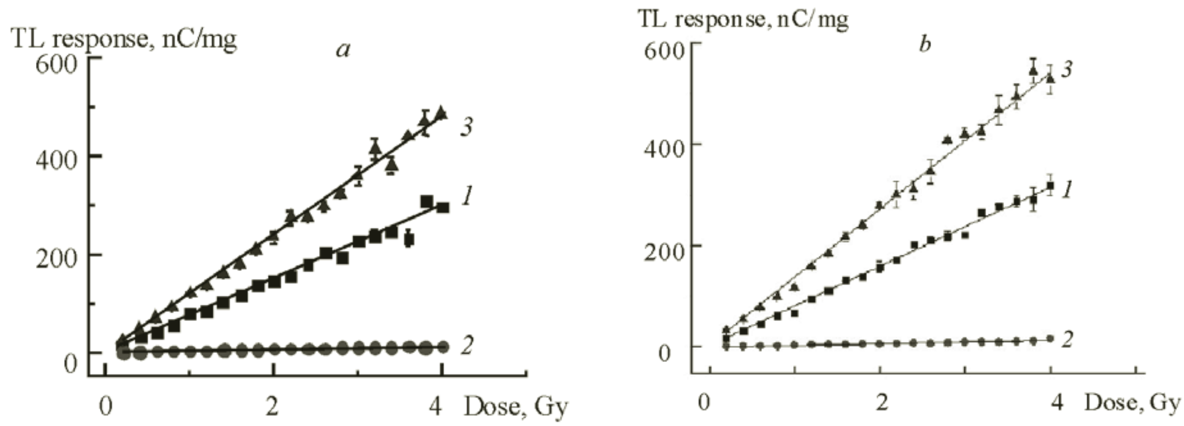

Fig. 1. The TL response of the Ge- (1) and Al-doped (2) optical fibers and TLD-100 (3) for 6 (a) and 10 MV (b) photon irradiation.

removed from the optical fiber, and then the core was cleaned of chemical and resin residues using a moist cotton cloth and subsequently cut into 0.5 ± 0.1 cm long pieces. The mass of each fiber was measured using an electronic balance (PAG, Switzerland). This allowed the TL yield to be normalized to unit mass of the fiber. The optical fibers were handled using vacuum tweezers (Dymax 30 – Charles Austen Pumps Ltd). The details of material preparation are presented in [6–8].

Preheating. Preheating of the fibers retained in an alumina container was performed at 400^{o}C for a period of 1 hour. To avoid thermal stress following the annealing cycle, the fibers were left inside the furnace for 18 hours to finally equilibrate at a temperature of 40^{o}C [6]. The TLD-100 rods were placed on a stainless steel plate and annealed for 1 hour at 400^{o}C and subsequently for 2 hours at 100^{o}C. After cooling, the fibers were placed into an opaque plastic container in order to minimize exposure to potentially high ambient light levels.

Exposure to radiation. The Al- and Ge-doped optical fibers and TLD-100 rods were irradiated using 6 and 10 MV photon beams at a 200 MU (monitor units)/min nominal dose rate from a Primus MLC 3339 linear accelerator located at the Department of Radiotherapy and Oncology, Hospital Sultan Ismail, JB, Malaysia. The dose, arranged to be from 0.2 to 4.0 Gy, was received by a field 10 × 10 cm in size at a source-to-skin distance (SSD) of 100 cm.

Instrumentation. The optical fiber TL yield was read out using a Harshaw 4500 TL reader. A nitrogen atmosphere was used both to suppress spurious light signals from triboluminesence and to reduce oxidation of the heating element. The following parameters were used during the readout: preheat temperature of 50^{o}C for 10 s; readout temperature of 300^{o}C for 33 s, and a heating rate of 10^{o}C/s. Finally, an annealing temperature of 300^{o}C was applied for 10 s to sweep out any residual signal [7].

Results and Discussion. *Photon dose dependence of the TL material*. The results of the experiments are presented for a luminescence temperature of 300^{o}C and a heating rate of 10^{o}C/s. However, an increase in the heating rate from 1.7 to 17^{o}C/s is known to result in a decrease of the TL main peak height for the TDL-100 by 1.7 times. There are data that optical Ge-doped fibers show a similar trend, causing a rise in temperature that corresponds to the TL response maximum. The experimental dependence of the TL response on dose in the 0.2–4.0 Gy range for the doped fibers and TLD-100 under 6 MV photon irradiation is presented in Fig. 1a. Each data point was obtained by taking an average of three individual fiber readings. The error bars represent the standard error of the mean. It is shown that the TL response varies linearly with the dose. The change in the TL yield per unit of absorbed dose for the Ge-doped optical fiber was found to be 74 $nCi{\cdot}mg^{-1}{\cdot}Gy^{-1}$ against 3.5 $nCi{\cdot}mg^{-1}{\cdot}Gy^{-1}$ for the Al-doped sample. Thus, the sensitivity of the former is ≈20 times higher than that of the latter. The response of the Al-doped optical fiber is as low as ~3% of the TLD-100 medium signal.

Figure 1b shows the TL responses (nCi/mg) of the optical fibers to 10 MV photon irradiation. For the Ge-doped optical fiber, the slope is 80 $nCi{\cdot}mg^{-1}{\cdot}Gy^{-1}$, while that for the Al-doped sample is 3.5 $nCi{\cdot}mg^{-1}{\cdot}Gy^{-1}$. So, the Ge-doped fiber sensitivity is ≈20 times higher than that of the Al-doped fibers. Moreover, the TL/photon response for TLD-100 is a factor of 1.5 higher than that of the Ge-doped fibers, while the Al-doped fibers showed practically no response.

Energy dependence of the TL response. If a TL material is to be used for radiation dosimetry, one of the main characteristics that must be known is its energy-dependent response. The TL response is estimated with respect to the LINAC nominal energy. Figure 2 shows the TL responses of the Ge- and Al-doped optical fibers and TLD-100 media for a 2 Gy

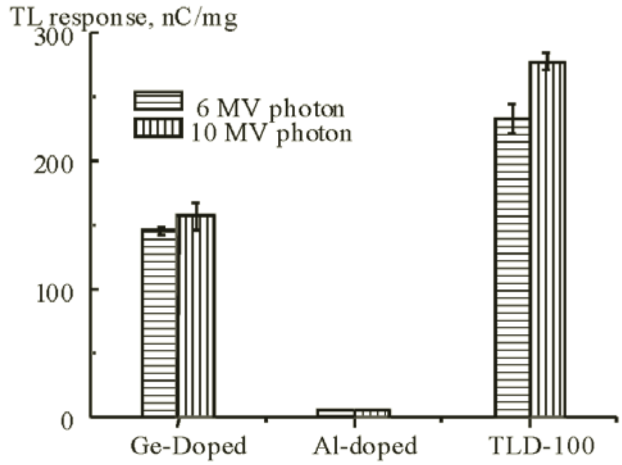

Fig. 2. The TL response of the Ge- and Al-doped optical fibers and TLD-100 media for 2 Gy irradiation dose with photon energy of 6 and 10 MV.

TABLE 1. The TL Sensitivity ($nCi \cdot mg^{-1} \cdot Gy^{-1}$) for TLD-100 and Ge- and Al-Doped Optical Fibres after 6 and 10 MV Photon Irradiations

TL material	10 MV photon, present work	6 MV photon	
		Present work	Experiment [9]
TLD-100	138.46	121.90	3.0×10^7
Ge-doped fiber	79.72	73.72	3.0×10^6
Al-doped fiber	3.29	3.16	3.0×10^5

irradiation dose with photons of 6 and 10 MV energies, which are, respectively, 146.06 ± 3.33 and 157.68 ± 10.63, 6.30 ± 0.82 and 6.46 ± 0.12, and 233.07 ± 1.34 and 277.93 ± 6.07 nCi/mg. From the figures, a relative energy dependence can be seen. The spectrum for these energies is very wide and the dominant effect is Compton scattering (or even pair production), which depends on Z_{eff}. It is shown that the dosimeter response magnitude at higher energy is slightly larger than that at lower-energy photon irradiation.

Sensitivity of the doped SiO_2 optical fibers and TLD-100. The sensitivities of the Ge- and Al-doped optical fibers and TLD-100 are presented in Table 1. It shows that TLD-100 has a higher TL sensitivity compared to the other two TL dosimeters. A comparison of the TL sensitivity values observed in the present work and in previous experiments [9] showed the consistency between the results for both doped optical fibers, although the data were obtained using different LINAC machines and TL measurements.

Conclusions. The results of the experiments are presented for a luminescence temperature of 300°C and a heating rate of 10°C/s. The silica based Ge-doped thermoluminescence dosimeter shows higher sensitivity and better TL characteristics as compared with the Al-doped optical fiber. The doped optical fibers were compared with TLD-100 and found to show a linear dose–TL signal ranging from 0.2 to 4.0 Gy. The TL response depends weakly on the energy of photon irradiation. The Ge-doped optical fibers can provide better spatial resolution compared to the typical TLD-100. The large TL signal of the Ge-doped optical fiber can be used in a new dosimeter for a wide range of applications in medical physics.

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REFERENCES

1. P. Mayes, A. Nahum, and J. C. Rosenwald, *Handbook of Radiotherapy Physics Theory and Practice*, France, Taylor & Francis (2007).
2. B. L. Justus, S. Rychnovsky, A. L. Houston, C. D. Merritt, and K. J. Pawlovich, *Radiat. Prot. Dosim*., **74**, 151–154 (1997).
3. B. L. Justus, K. J. Pawlovich, C. D. Merritt, and A. L. Houston, *Radiat. Prot. Dosim*., **81**, 5–10 (1999).
4. A. L. Houston, B. L. Justus, P. L. Falkenstein, R. W. Miller, H. Ning, and R. Altemus. *Radiat. Prot. Dosim*., **101**, 23–26 (2002).
5. G. Espinosa, J. I. Golzarri, C. Vázquez, and R. Fragoso, *Radiat. Meas*., **36**, 175–178 (2003).
6. N. H. Yaakob, H. Wagiran, I. Hossain, A. T. Ramli, D. A. Bradley, S. Hashim, and H. Ali, *Nucl. Instrum. Methods A*, **637**, 185 (2011).
7. N. H. Yaakob, H. Wagiran, I. Hossain, A. T. Ramli, D. A. Bradley, S. Hashim, and H. Ali, *J. Nucl. Sci. Technol*., **48**, No. 7, 1–3 (2011).
8. N. H. Yaakob, H. Wagiran, I. Hossain, A. T. Ramli, D. A. Bradley, and H. Ali, *Appl. Radiat. Isotop*., **69**, 1189–1192 (2011).
9. S. Hashim, *The Thermoluminescence Response of Doped Silicon Dioxide Optical Fibers to Ionizing Radiation*, Universiti Teknologi, Malaysia (2009).
10. Y. A. Abdulla, Y. M. Amin, and H. B. Khoo, *J. Radiol. Prot*., **22**, No. 4, 417–421 (2002).
11. A. T. Ramli, D. A. Bradley, S. Hashim, and H. Wagiran, *Appl. Radiat. Isot*., **67**, No. 3, 428–432 (2009).
12. A. L. Yusoff, R. P. Hugtenburg, and D. A. Bradley, *Radiat. Phys. Chem*., **74,** 459–481 (2005).
13. G. Espinosa, J. I. Golzarri, J. Bogard, and J. Garcia-Macedo, *J. Radiat. Prot. Dosimetry*, **18**, 1–4 (2006).
14. H. Wagiran, I. Hossain, D. Bradley, A. N. H. Yaakob, and T. Ramli, *Chin. Phys. Lett.*, **29**, No. 2, 027802 (2012).