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ORIGINAL PAPER

Thermoluminescence properties of Yb–Tb-doped SiO_2 optical fiber subject to 6 and 10 MV photon irradiation

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Abstract: This paper reports thermoluminescence characteristics of thermoluminescence dosimetry 100 chips and Yb–Tb-doped optical fibers irradiated with 6 and 10 MV photons. Thermoluminescence response of both dosimeters increases over a wide photon dose range from 0.5 to 4 Gy. Yb–Tb-doped optical fibers demonstrate useful thermoluminescence properties and represent a good candidate for thermoluminescence dosimetry application with ionizing radiation. The results of this fiber have been compared with those of commercially available standard thermoluminescence dosimetry-100 media. Commercially available Yb–Tb-doped optical fibers and said standard media are found to yield a linear relationship between dose- and thermoluminescence signal, although Yb–Tb-doped optical fibers provide only 10 % of the sensitivity of thermoluminescence dosimetry-100. With better thermoluminescence characteristics such as small size (125 μm diameter), high flexibility, easy of handling and low cost, as compared to other thermoluminescence materials, indicate that commercial Yb–Tb-doped optical fiber is a promising thermoluminescence material for variety of applications.

Keywords: Thermoluminescence; Energy response; Dosimetry; Photon; Optical fiber

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1. Introduction

Scientists have explored many new radiation sources in the past five decades to improve quality of our daily life. Although radiation has tremendous benefits, it can also induce cancer and genetic defects. Thus, environmental and personal dosimetry is an important science in which, normally, notably low radiation doses or dose rates can be quickly, simply and easily measured [1].

Silicon dioxide (SiO_2) optical fibers as a new material for thermoluminescence dosimetry (TLD) have been extensively studied to understand and improve the material characteristics better and develop new thermoluminescence (TL) materials. Optical fibers are notably attractive in a variety of radiation dosimetry applications because of their small size, flexibility, low cost and commercial availability [2]. Abdulla et al. [3] have performed a TL study on commercially available Ge-doped silica-based fiber optic in the dose range from 1 to 120 Gy with a fast fading rate (2 % within 6 h and 6 % within 30 days). Hashim et al. [4] have used commercially available Ge-doped optical fiber and compared it with aluminum-doped optical fiber. Effect of doping concentration on thermal activation energy of trap centers in irradiated LiF: Mg^{2+} single crystal has been examined by Sadeghi et al. [5]. Thermoluminescence characteristics of X-ray induced kyanite mineral and its thermal quenching parameters have been studied by Kalita and Wary [6]. Singh et al. [7] have made reappraisal of the peak shape method for general order thermoluminescence. Some thermoluminescence parameters of blue-green emission band of pegmatite rock have been studied by Soliman and Aziz [8]. Recently, we have investigated TL responses of Ge- and Al-doped SiO_2 optical fibers to photon and electron irradiation [9–14].

Encouraging results from these studies have led to development of fiber radiation dosimeters to examine TL dosimetric characterization and such properties as glow

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curves parameters, energy dependence, relative energy response and dose rate effect. In many TLD applications, main purpose is to determine the absorbed dose in human tissue. Megavoltage photons remain the most prominent type of radiation source in radiotherapy where energy is chosen to target tumors at different depths [4]. Hence, TLD and human tissue should have equal energy responses. In the present paper, we have investigated TL characteristics of Yb–Tb-doped optical fibers from 0.5 to 4 Gy dose with 6 and 10 MV photon irradiations.

2. Experimental details

A study was performed on two types of TL materials: LiF: Mg, Ti (TLD-100) and Yb–Tb-doped optical fiber. TLD-100 chip of size 3.2 mm × 3.2 mm × 0.89 mm was supplied by Harshaws. Yb–Tb-doped optical fiber was manufactured by CorActive (Canada). For Yb–Tb-doped optical fiber, cladding diameter was 125.0 ± 2.0 μm and coating diameter was 250.0 ± 15.0 μm. Protective polymer layer of the optical fiber was first removed from the fibers and residual material was cleaned of chemical and resin residues using a moist cotton cloth. The cloth was subsequently cut into 0.5 ± 0.1 cm long pieces. The mass of each fiber was measured using an electronic balance (PAG, Switzerland), which helped normalizing TL yield to the unit mass of fiber.

The materials were preheated at 400 °C for 1 h, during which fibers were retained in an alumina container. The fibers were maintained in a furnace for 18 h to reach temperature of 40 °C [10]. For TLD-100 chips, annealing routine was to place them in a stainless steel plate and anneal for 1 h at 400 °C and subsequently for 2 h at 80 °C. To minimize exposure to potentially high ambient light levels, after cooling, the samples were placed in an opaque container [9–11].

Yb–Tb-doped optical fiber and TLD-100 chip were placed along the beam axis at a depth of 10 cm in a solid phantom and irradiated using 6 and 10 MV photon beams at 200 MU (monitor units) min^{-1} nominal dose rate from linear accelerator Primus MLC 3339. The delivered dose was arranged from 0.5 to 4.0 Gy, which was obtained using a field size of 13 cm × 13 cm and positioned at a standard source-surface distance of 100 cm.

TL yield was obtained using a Harshaw 3500 TL reader. N_2 atmosphere was used to suppress spurious light signals from triboluminescence and to reduce oxidation of the heating element. Following parameters were used during the readout: preheat temperature was 50 °C for 10 s; readout temperature was 300 °C for 33 s, and heating rate was 10 °C s^{-1}. Finally, an annealing temperature of 300 °C was applied for 10 s to sweep out any residual signal [11].

3. Results and discussion

3.1. Thermoluminescence glow curve

Figure 1 shows the glow curve of Yb–Tb-doped SiO_2 optical fiber, subjected to 6 MV photon irradiations with the dose ranging from 1.0 to 3.0 Gy. The glow curve varies with heating mode and heating temperature. There is a broad peak for Yb–Tb-doped SiO_2 optical fiber and the glow peaks are at approximately 170 °C. As the dose increases, peak of the glow curve also increases.

Figure 2 shows the glow curve of TLD-100, subjected to 6 MV photon irradiation with a dose ranging from 1.0 to 3.0 Gy. The glow peak appears at approximately 210 °C. Peak of glow curve for TLD-100 slightly shifts to the right when dose and intensity increase. These glow curves of TLD-100 have better resolution than those of Yb–Tb-doped SiO_2 optical fiber.

3.2. Thermoluminescence response

A good dosimeter system should be able to provide a linear relationship between TL emissions and measured absorbed dose. Linearity of TL materials can be determined using regression coefficient (R^2) value, which is obtained from the graph of TL response. The change in TL yield per unit dose is known as sensitivity. A high sensitivity helps determining a low dose. Sensitivity of TL materials can be determined from slope of the graph. TL response of Yb–Tb-doped SiO_2 optical fiber and TLD 100 chip that are subjected to 6 MV photon irradiations is plotted in Fig. 3. Each data point has been obtained by taking the average of three individual fiber readings. Regression coefficient (R^2) for Yb–Tb-doped optical fiber is 0.9898 and sensitivity is 41.309 nC $(mg\ Gy)^{-1}$. Error bars represent propagation error, which ranges from 0.6627 to 11.0079. Regression coefficient (R^2) for TLD-100 is 0.989 and sensitivity is 389.33 nC $(mg\ Gy)^{-1}$. These results are obtained after normalizing the TL yield to unit mass.

Figure 4 shows equivalent TL yield versus dose response characteristics of Yb–Tb-doped SiO_2 optical fiber and TLD-100 for 10 MV photon irradiations. Similar linear results have been observed in previous section. TL response of both dosimeters is linear until the dose of 4.0 Gy. Regression coefficient (R^2) for Yb–Tb-doped optical fiber is 0.9884 and sensitivity is 39.733 nC $(mg\ Gy)^{-1}$. Regression coefficient (R^2) for TLD-100 is 0.9866 and sensitivity is 491.41 nC $(mg\ Gy)^{-1}$. Therefore, sensitivity of TLD 100 is higher than that of Yb–Tb-doped optical fiber by a factor 10. Considerable variation has been observed in TLD-100 data throughout the given dose range. This variation is significantly larger than that obtained for Yb–Tb-doped fiber.

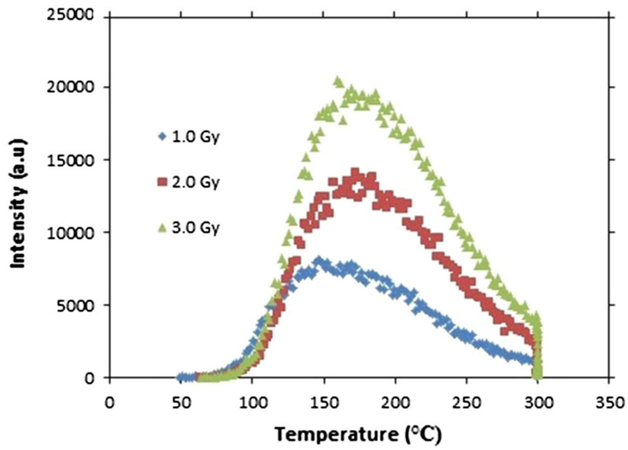

Fig. 1 Glow *curves* of Yb–Tb-doped SiO_2 optical fiber using 6 MV photon irradiation for different doses shown

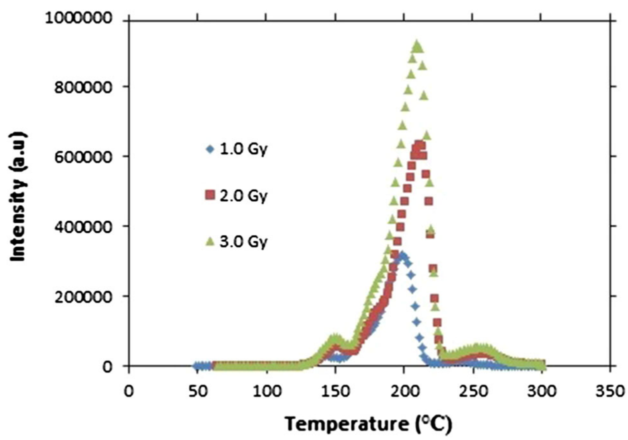

Fig. 2 Glow *curves* of TLD-100 using 6 MV photon irradiation for different doses shown

Another method to measure the linearity of each dose of TL materials is to determine normalized TL dose response, which is known as linearity index, *F(D)* given by Eq. (1).

$$F(D) = \frac{F(D)/D}{F(D_0)/D_0} \tag{1}$$

where *F(D)* is dose response at a dose *D* and D_0 is response at the lowest dose of dose response linearity. The ideal TLD material has $F(D) = 1$ for a wide range of doses. Linearity indices *F(D)* of Yb–Tb-doped SiO_2 optical fibers and TLD 100 media for 6 and 10 MV photons irradiation are plotted in Fig. 5(a) and 5(b). For 6 and 10 MV photons, the dose response is linear at 0.5 Gy and become super-linear or sublinear when dose increases to 4.0 Gy.

3.3. Energy dependence of TL material

Energy response of TLD is important to make it suitable for environmental and personal dosimetry applications,

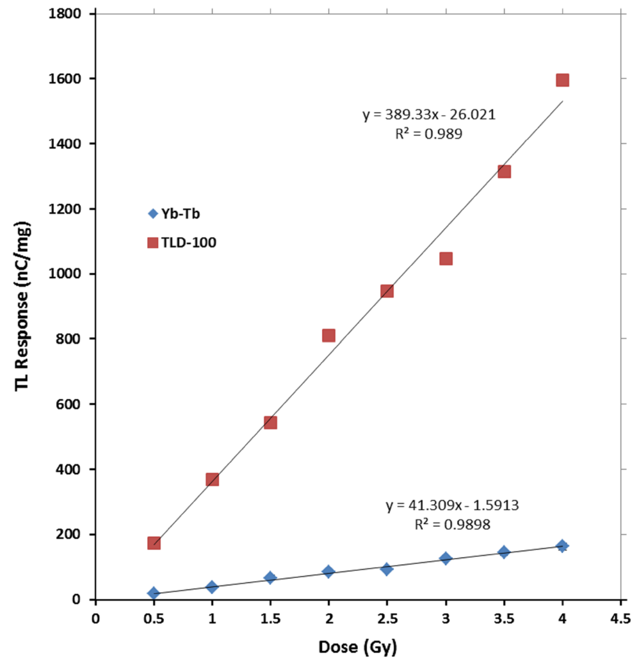

Fig. 3 TL response with dose for Yb–Tb-doped SiO_2 optical fiber and TLD-100 subjected to 6 MV photons

where a wide range of irradiation energy is possible. Figures 6 and 7 show the energy response of Yb–Tb-doped SiO_2 optical fiber and the TLD-100 media that are subjected to 6 and 10 MV photon irradiations. The delivered dose in this experiment ranges from 0.5 to 4.0 Gy. In Yb–Tb-doped SiO_2 optical fiber, 6 MV photon energy has a higher sensitivity of TL response than 10 MV photon energy by a factor 1.04. However, in TLD-100 media, 6 MV photon energy exhibits a lower sensitivity of TL response than that of 10 MV photon energy by a factor of 0.80. These results of TLD-100 are consistent with the previous results [14].

3.4. Fading

Fading is the storage effect on TL of a previously irradiated phosphor at a constant temperature. Loss of TL signal with time after irradiation is the most important problem in TL technique that is applied to different fields of dosimetry such as personnel, environmental and clinical dosimetry. Fading is caused by spontaneous escape of a charge carrier from a trap because of the ambient temperature. In this study, 6 MV photon irradiation has been used to investigate the fading effect. Figure 8 shows fading data of Yb–Tb-doped optical fiber. The nominal dose used for fading is 4 Gy. TL yield has been obtained 1 day per week for 30 days after irradiation. Percentage loss of TL signal for Yb–Tb-doped SiO_2 optical fibers on 7th, 21st and 28th day is 5.83, 15.65 and 18.55 % respectively.

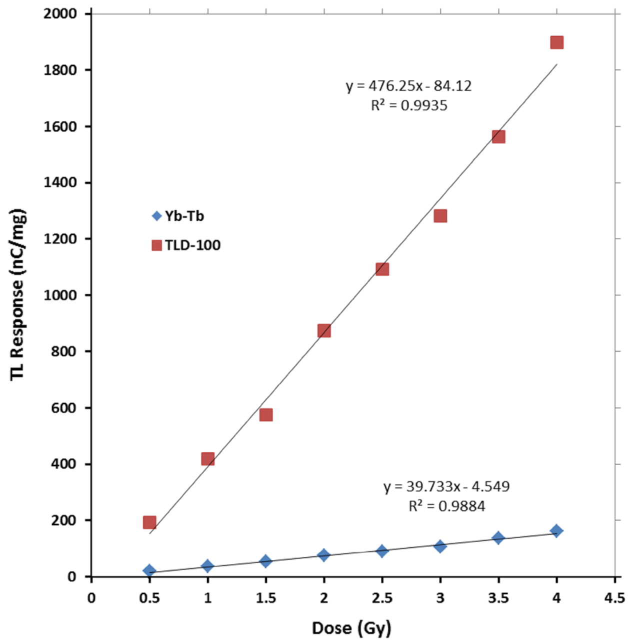

Fig. 4 TL response with dose for Yb–Tb-doped SiO_2 optical fiber and TLD-100 subjected to 10 MV photons

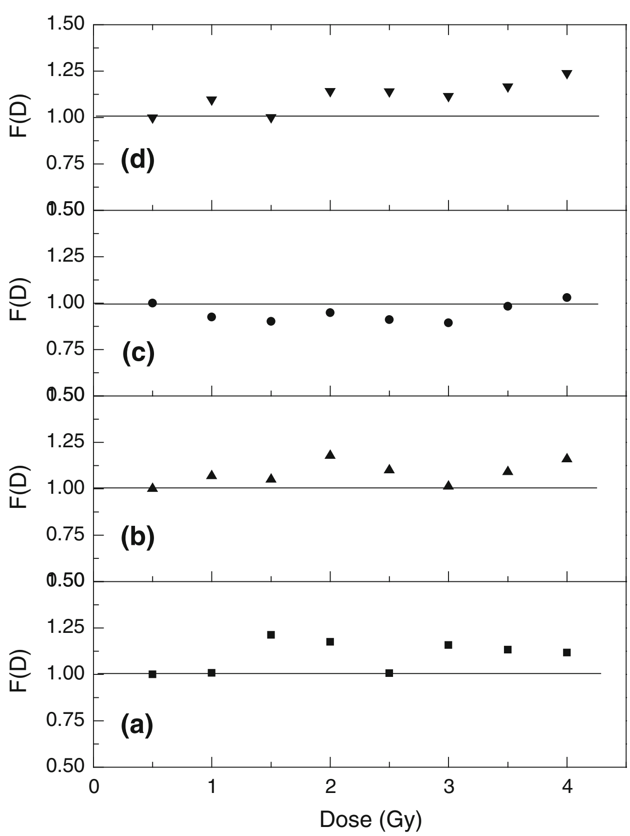

Fig. 5 Linearity index *F*(*D*) shown as a function of dose: (**a**) Yb–Tb-doped SiO_2 optical fiber with 6 MV photons, (**b**) TLD-100 with 6 MV photons, (**c**) Yb–Tb-doped SiO_2 optical fiber with 10 MV photons and (**d**) TLD-100 with 10 MV photons

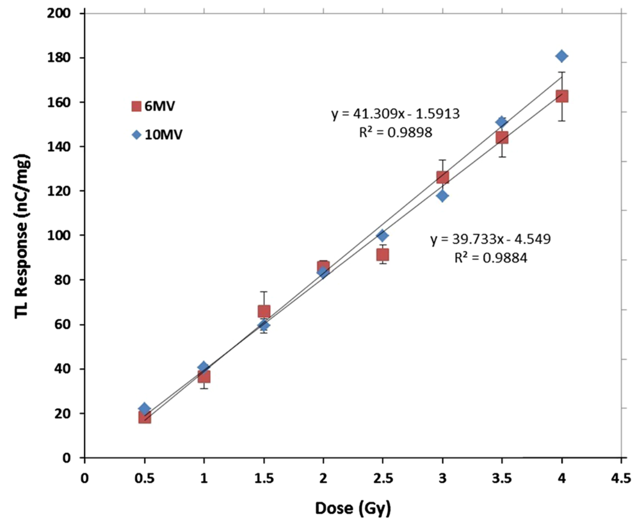

Fig. 6 Energy response of Yb–Tb-doped SiO_2 optical fiber for 6 and 10 MV photon irradiations

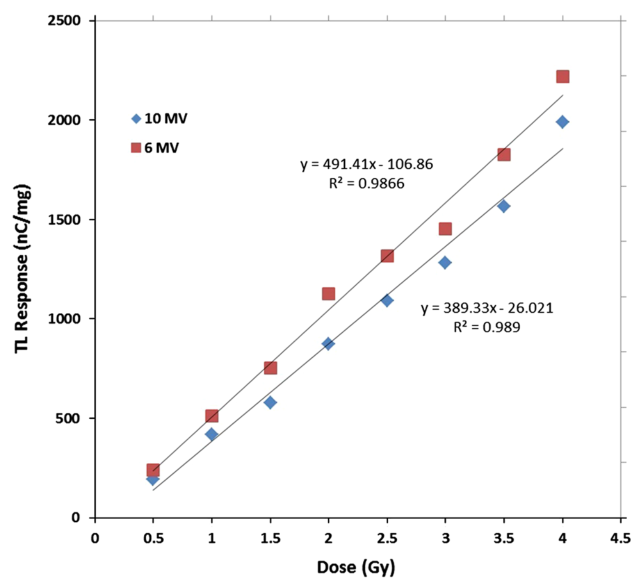

Fig. 7 Energy response of TLD-100 for 6 and 10 MV photon irradiations

3.5. Stability and re-used

Thermoluminescence materials can be re-used many times without any detectable changes in the material as long as they are not exposed to notably high doses. In this work, reproducibility factor has been investigated using 6 MV photons irradiation with a dose of 4 Gy. Yb–Tb-doped optical fibers have been re-used two times for the same dose level. Figure 9 shows reproducibility of Yb–Tb-doped optical fiber. Difference of the TL response between the first and second exposures is notably small. In this work,

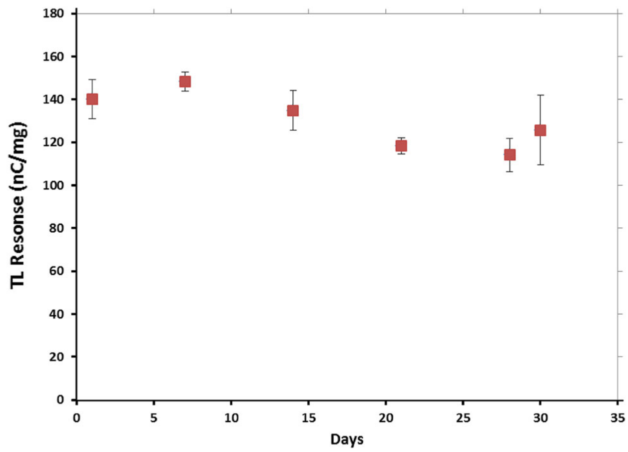

Fig. 8 Fading of Yb–Tb-doped SiO_2 optical fiber that was subjected to 6 MV photon irradiation

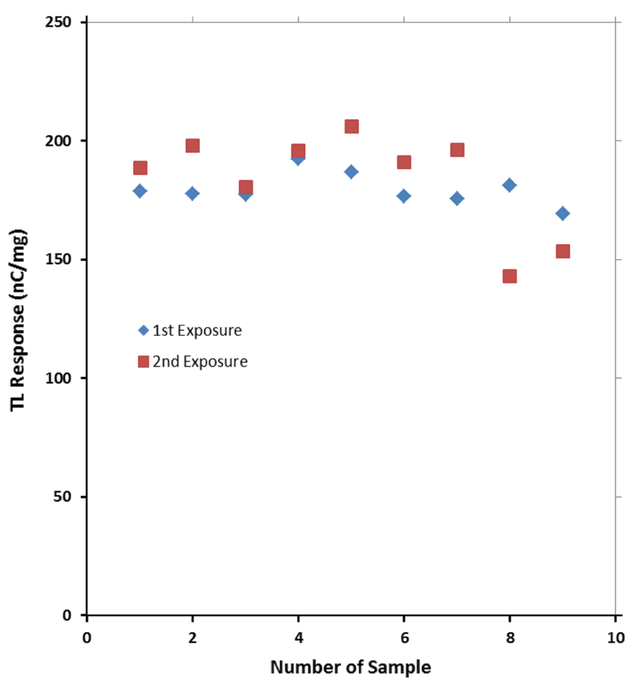

Fig. 9 Reproducibility of Yb–Tb-doped SiO_2 optical fiber at 6 MV photon

although these materials have been re-used many times, annealed and irradiated again, the obtained response after each re-use is not degraded.

4. Conclusions

This study demonstrates a number of features for thermoluminescence dosimetry of commercially available Yb–Tb-doped SiO_2 optical fiber using 6 and 10 MV photon irradiations. The glow curve, linearity with the dose, sensitivity and energy response of Yb–Tb-doped SiO_2 optical fiber are compared with standard TLD-100. TL energy response is feasible because the TLD-100 is consistent with previous results [14]. Moreover, low fading and reusability of Yb–Tb-doped SiO_2 optical fibres have been observed using 6 MV photon irradiation with a delivered dose of 4 Gy. Evidently, although Yb–Tb-doped SiO_2 optical fiber exhibits a lower sensitivity than does TLD-100, its sensitivity is useful for photon radiotherapy dosimetry, it has a good response linearity, it provides a spatial resolution and a low fading and it can be re-used.

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