Thermoluminescence response of thulium-holmium doped optical fiber by gamma irradiation

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This article reports the thermoluminescence characteristics such as linearity of response, sensitivity, and dose response of thulium-holmium doped silica optical fibers subjected to ^{60}Co gamma radiation source. Thulium-holmium doped optical fibers manufactured by CorActive with core diameter 11.5 ± 1.0 μm were used as the basic material for the research. Samples were irradiated with gamma radiation at doses range from 10 Gy to 100 Gy. Gamma beams were provided by Gammacell 220 Excel available at Applied Physics Study Center, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, Bangi, Selangor. It is found that the commercially available thulium-holmium doped optical fibers have linear dose-TL signal dependence. The average sensitivity of thulium-holmium fibers is 0.094 nC mg^{-1} Gy^{-1} and TL yield of absorbed dose is 2.55 nC Gy^{-1}.

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1. Introduction

Thermoluminescence (TL) properties of optical fibers irradiated by photons of different energy levels have been under investigation due to their great practical application in dosimetry. During last few years, thermoluminescence response of commercially available optical fibers doped with rare earth elements has been investigated using various kinds of irradiation [1-4]. The properties of gamma irradiation of Bi/Er co-doped optical fibers were investigated by D. Sporea et al. [5]. A. Poudel et al. observed the various properties of ZnO addition to Er3+, Yb3+ doped phosphate glasses irradiated by Alpha particle [6]. Radiation dosimetry is widely used in medical especially radiotherapy, and thermoluminescence dosimetry is the most common technique. Thermoluminescence Dosimeters (TLD) are used to monitor doses for medical and environmental applications. A good TL material, to use for dosimetric purposes, should be highly sensitive and exhibit a linear response between TL signal and dose as well as energy. A long term stability of stored dosimetric information at room temperature that involves thermal and optical fading is also required for a TLD. It should be very precise, retrieve information rapidly, possess good environmental stability, good water or tissue equivalence and have a wide range of sensitivities.

Optical fibers are of very interest in the TL dosimetry because they have many advantages such as wide useful dose range, small physical size, and reusability. Furthermore, the clinical dosimetry does focus on *in-vivo* dosimetry for accurate dose while putting dosimeter on patient's skin or natural body cavities. We investigated TL properties of Ge-, Yb-, Yb-Tb-, Al-, and Nd-doped SiO_2 optical fibers. The doping of rare earth elements (REE) can improve the TL properties of such material [3-4, 7-8]. Therefore, many new TLD materials doped with REE are investigated, and they reveal a few acceptable TLD characteristics but cannot be recommended as an optimized TL material [1-4, 7-8]. Previous studies motivated us to find TL properties of thulium-holmium (Tm/Ho) doped optical fibers, and to the best of authors' knowledge, no such investigation is yet reported. This research concerns the suitability of doped optical fiber as ionizing radiation dosimeters. Thulium is an important reference due to its properties that are similar to Yttrium and Scandium. These materials are being used in high-temperature superconductors [7], in arc lighting for its unusual spectrum, in "eye-safer" fiber laser devices [9-11] respectively, and the blue fluorescence of Tm-doped calcium sulfate has been used in personal dosimeters for visual monitoring of radiation [12,13]. Therefore, the thermoluminescence characteristics of Tm/Ho-doped optical fibers by gamma radiation are investigated here.

2. Experimental details

The fiber was cut into approximately 5 mm long by using an optical fiber cleaver. To obtain the TL yield per unit mass, the mass of each piece was determined using an electronic balance (PAG, Switzerland). In this study, the weight of each fiber is approximately 23.88 mg. Vacuum Tweezers were used for handling and grouping the fibers.

The TL materials were kept in a suitable container to keep them away from high temperature and ultraviolet radiations. During handling, it was ensured that the TL materials were not scratched or touched using a hand.

Each Tm/Ho-doped optical fiber was placed inside a gelatin capsule for routine storage, handling, and for irradiations. Each capsule contained three pieces of optical fibers.

All samples were exposed to ^{60}Co gamma irradiation emitted by Gammacell 220 Excel provided at Applied Physics Study Center, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, Bangi, Selangor. Energies of the gamma rays emitted from the Cobalt-60 source are 1.17 and 1.33 MeV, and the average value is 1.25 MeV. The readout of the dosimeters was done after three days of irradiation. TLD 3500 in Nuclear Lab, Faculty of Science Universiti Teknologi Malaysia was used to readout the TL response. For details of the experiment, readers are referred to these manuscripts [3-4, 8].

3. Results and discussion

3.1. Energy response and sensitivity

The TL characteristics of Tm/Ho-doped optical fiber irradiated by a ^{60}Co gamma source with an average energy of 1.25 MeVare presented in Table 1. The calculated relative response of these energies (1.17 and 1.33 MeV) is independent [15] and we have taken TL response at the average value 1.25 MeV of these energies. TL response, yield and sensitivity of the samples are investigated in this study. The dose response is discussed in terms of functional dependence upon absorbed dose of the measured TL signal. A good dosimetry system should be able to give a linear relationship between TL emissions and measured absorbed dose. TL response for TH-doped optical fibers dosimeter is normalized to unit mass. The TL yield is measured in nano Coulomb (nC).

Table 1. TL yield, response and sensitivity of thulium-holmium doped optical fiber.

Dose (Gy)	TL Yield (nC)	TL Response ($nC.mg^{-1}$)	Sensitivity ($nC. Mg^{-1}. Gy^{-1}$)
10	20.95	0.877	0.088
20	42.78	1.791	0.090
30	62.67	2.624	0.087
40	84.29	3.530	0.088
50	114.80	4.807	0.096
60	125.93	5.273	0.088
70	161.53	6.764	0.097
80	191.30	8.011	0.100
90	213.20	8.928	0.099
100	256.67	10.748	0.107

Fig. 1 shows the TL yield as a function of dose. A linear relationship between TL emission and the absorbed dose are important characteristics of any thermoluminescence dosimetric application. In this study, a linear TL response of Tm/Ho doped fibers is obtained from a dose range of 10Gy to 100Gy. The linearity can be confirmed by another factor that is the regression coefficient (R^2), which is a measure of how well the data correlate. The value of the regression coefficient for Tm/Ho doped optical fiber is 0.9897, which is very close to one and shows a very close correlation.

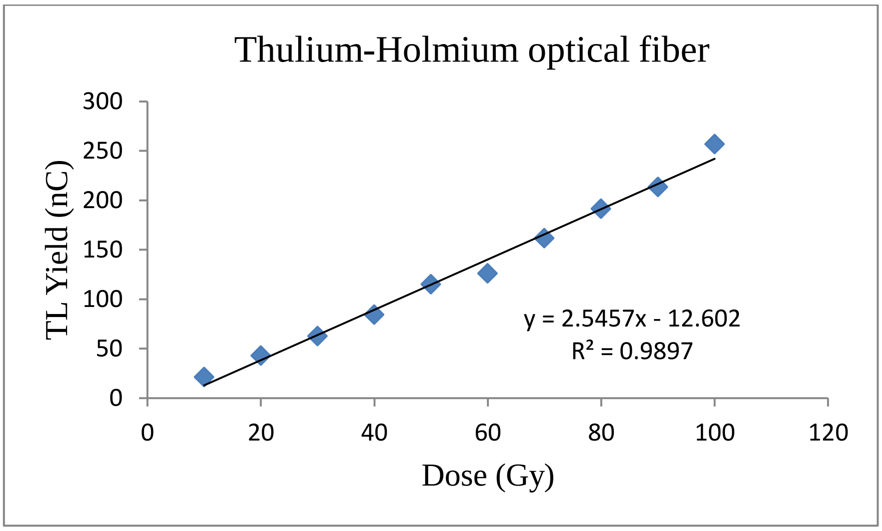

Fig. 1. The TL response of Thulium-holmium doped optical fiber versus dose

The change in the TL yield per unit dose is known as the sensitivity. A high sensitivity allows determining the response of low dose. Thermoluminescence sensitivity is a measure of the amount of TL signal per unit mass produced by a given material after exposure to irradiation. The sensitivity of Tm/Ho doped optical fibers can also be calculated by the following equation.

$$Sensitivity\ (nC.mg^{-1}.\ Gy^{-1}) = \frac{light\ emission}{D.m}$$

where D is the dose (Gy), in the linear region of the calibration curve and m is the mass of phosphor (mg).

The average sensitivity of Tm/Ho -doped fiber can be calculated by the following equation.

$$Average\ sensitivity = \frac{Total\ sensitivity}{N}$$

where N is the total number of sample.

The average sensitivity of Tm/Ho -doped fibers is 0.094 nC mg^{-1} Gy^{-1} and the absorbed TL yield is 2.55 nC Gy^{-1}. According to the radiation protection philosophy of the International Commission on Radiological Protection [16], the total radiation-related cancer risk is proportional to dose at low doses (100 mGy or less) and dose rates less than 6 mGy/hour averaged over the first few hours. This hypothesis is neither accepted nor welcomed globally because there is no information about the level of risk that is associated with very low dose exposure. Nevertheless, many people consider this as a prudent rule for public policies to avoid unnecessary risk from exposure.

3.2. TL glow curve

The thermoluminescence light emission that is known as the thermoluminescence glow curve is defined as the intensity of luminescence as a function of temperature, and it may exhibit several maxima. This glow curve varies with the mode of heating and heating temperature [17, 18]. The storage of samples for a long time can affect and change the stability of response. The area under a glow curve shows the deposited radiation energy. The gamma-irradiations have been done for ranges between 10 – 100 Gy. Fig. 2 presents a clearly visible glow curve of thulium-holmium doped fiber with dose 90Gy. The red line in the graph shows the readout temperature (300 °C) from the time-temperature profile setup for the TLD reader. The intensity of the glow curve ranges from 4 μA to 23 μA, and the maximum glow peak is at energy channel 150. The channel indicates the energy in the figure.

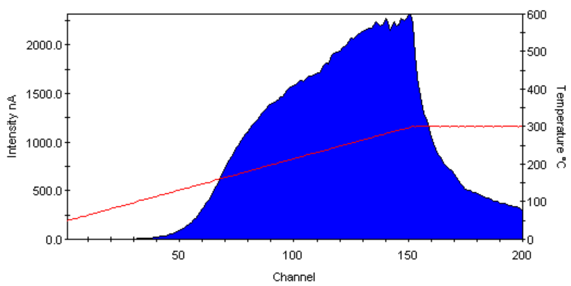

Fig. 2. The glow curve of Thulium-holmium doped SiO_2 optical fiber for 90 Gy dose of gamma irradiations

4. Conclusions

The main interesting result reported in this paper is concerning the TL response and glow curves for thulium-holmium doped fibers for a very wide range 10-100 Gy dose of gamma radiation. A linear dose response has been observed for gamma irradiation with a range from 10.0 to 100 Gy. The TL yield for Tm/Ho-doped fibers is 2.55 nC Gy^{-1}. The regression coefficient (R^2) is 0.9897. Tm/Ho-doped optical fiber yields a linear response to the high absorbed dose for gamma irradiation. The average sensitivity of the fiber is 0.094 $nCmg^{-1}Gy^{-1}$. The glow curve of Tm/Ho -doped optical fiber for 90 Gy dose of gamma irradiations is clearly visible.

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