Commercial optical fiber as TLD material

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ABSTRACT

This work presents a study of commercial SiO_2 optical fiber thermoluminiscence (TL) properties as part of efforts within the Dosimetric Application Project at the Physics Institute of the University of Mexico to develop new radiation detection materials and technologies. The SiO_2 commercial optical fiber studied demonstrates useful TL properties and is an excellent candidate for use in TL dosimetry of ionizing radiation.

The optical fiber has a glow curve between 30°C and 400°C after exposure to cobalt-60 (^{60}Co) gamma radiation, showing one very well defined glow peak with a maximum at 230°C. The TL response increases monotonically over a wide dose range, from 0.1 Gy to several kGy. It is linear in the range 0.1-3 Gy, which is important for personnel radiation dosimetry.

The optical fiber demonstrated high data reproducibility, low residual signal and almost no fading in our study. Moreover, the optical fiber can be re-used several times, after thermal annealing, without any detriment in the dose response.

All these TL characteristics, plus the small size of the 150-µm-diameter SiO_2 optical fiber, the high flexibility, easy handling and low cost compared with other TL materials, make the commercial optical fiber a very promising TL material for use in research, medicine, industry, reactors, and a variety of other applications.

INTRODUCTION

Alchemists in medieval times knew that minerals such as fluorite can be observed to emit light when heated in darkness. "On October 28, 1663, Robert Boyle reported to the Royal Society in London observations of a strange *glimmering light* when he warmed a diamond in the dark of his bedroom" (1). This phenomenon of thermal release of stored, radiation-induced luminescence (thermoluminisence)(2) was used to detect ionizing radiation as early as 1895 (3). Later on it was found that SiO_2 in soils can be used for archeological TL dating (4-6). More recently, research groups have reported a number of radiation effects in and applications of SiO_2 optical fiber such as: development of an optically stimulated luminescence methodology for use with doped optical fiber material (7-10) with valuable implications for use of the material as a dosimeter; measurement *in situ* of radiation-induced optical absorption in silica core fibers exposed to fission nuclear reactors [11]; measurement *in vivo* of the absorbed dose in patients resulting from radiation therapy and diagnostics [12]; and the use of the optical fiber material directly as a nuclear track detector for fission fragments [13].

METHODOLOGY

Material preparation: Commercial SiO_2 optical fiber manufactured by Nokia Cable®, with 150 µm diameter, was chosen for this work on the basis of availability, homogeneity and low cost. The protective plastic cover was peeled from the fiber, which was then cleaned of chemical and resin residues using moist cotton cloth, and cut into 5-mm-long pieces.

Storage and handling: Each optical fiber piece was placed inside a gelatin capsule for routine storage and handling and for irradiations. Each capsule contained approximately between 40 mg and 50 mg of optical fiber (10 pieces). The encapsulation guarantees homogeneity in the irradiation and easy handling for the reading process.

Preheating: Annealing tests were performed at temperatures between 390 °C and 490 °C to determine an optimal pre-exposure annealing procedure for erasing background signal accumulated during transportation and storage and minimizing the detection threshold. It was found that the best choice is to heat the material in a ceramic dish at 440°C for one hour, and then leave the material to reach room temperature inside the furnace over a 24-hour period to avoid thermal stress. After cooling, the material is put inside the capsule again under soft incandescent light, avoiding fluorescent light exposure.

Exposure to radiation: The optical fiber was exposed to a ^{60}Co gamma source (photoh energies of 1.17 MeV and 1.33 MeV), using a 6-mm-thick Lucite plastic shield for electronic equilibrium at doses between 0.01 Gy (1 R) and 3 Gy (300 R.), and between 4 Gy (400 R) and 5×10^3 Gy (5×10^5 R).

INSTRUMENTATION

TLD reader. TL measurements were made using a Model 2000-A and 2000-B Harshaw® TL reader, in a flowing nitrogen atmosphere, with a heating rate of 10 °C sec^{-1}. Optical fiber samples weighing approximately 4 mg were used for each measurement so that each gelatin capsule contains material for ten measurements. The data obtained for each single measurement is normalized by the mass of the material.

RESULTS

The TL response of the optical fiber with temperature was recorded and compared with the very well known glow curve of Lithium Fluoride (TLD-100), using the same reading conditions. The comparison of glow curves is shown in Figure 1.

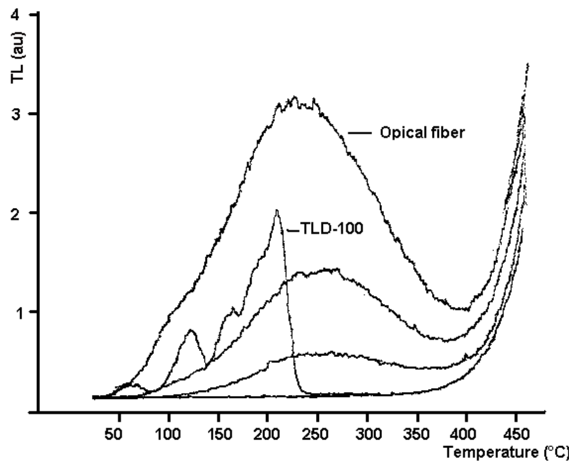

Figure 1. TL glow curves of Lithium Fluoride (TLD-100) material and SiO_2 optical fiber material.

The SiO_2 optical fiber presents only one glow peak, compared with the five peaks typical of TLD-100 (at 65 °C, 120 °C, 160 °C, 195 °C and 210 °C) [(6)]. Using the TLD-100 glow peaks as temperature references, it was found that the optical fiber glow peak is at 230 °C.

Mass dependence of the TL response: TL response from the optical fiber is shown as function of fiber mass for a dose of ?? Gy in Figure 2.. A linear relationship is observed between 4 mg and 50 mg. (Fibers weighing more than 50 mg could not be accommodated by the reader's heating plate.)

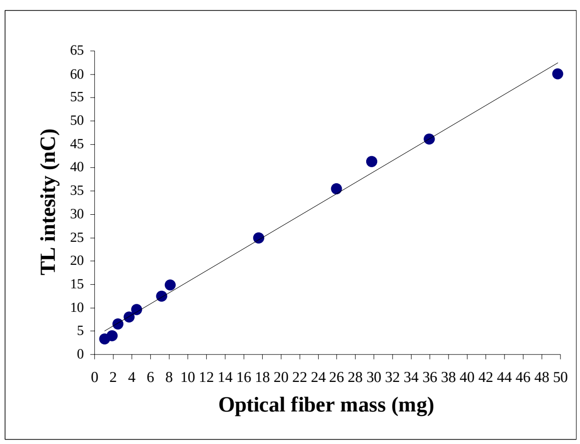

Figure 2. TL response as function of the optical fiber mass

Dose response: The gamma-photon dose response of the commercial optical fiber was analyzed in two dose ranges, .from 0.01 Gy to 3.0 Gy and. from 4.0 Gy to 5×10^3 Gy of gamma radiation. The. measurements show a linear dose response to 3 Gy, and monotonically increasing response to 5×10^3 Gy, as shown in Figures 3 and 4. The mean and standard deviation of 10 response measurements are shown for each dose in the figures.

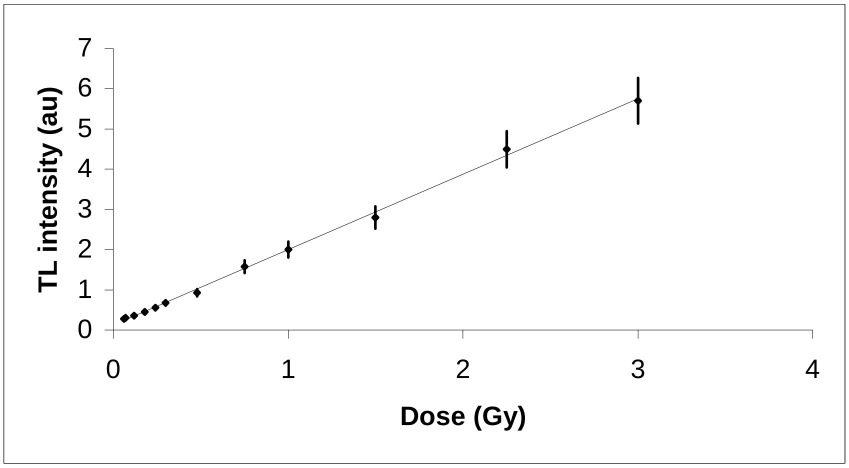

Figure 3. TL response of the optical fiber to low level gamma dose.

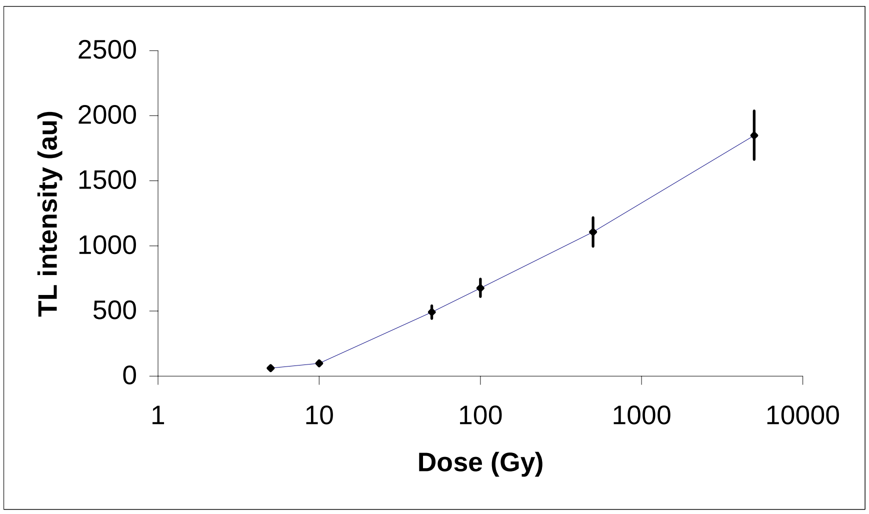

Figure 4. TL response of the optical fiber to high level gamma dose.

TL data reproducibility: Ten capsules, each with 10 cut optical fibers (~50 mg total), were exposed to the same dose (10 Gy) of gamma radiation to obtain a more precise measure of reproducibility in the response. The mean.and.standard deviation of these 100 measurements were determined to be (436.0 ± 20.7) nC g^{-1}.

Thermal annealing and re-use of the material: Another important characteristic of the optical fiber is that the material can be re-used as a dosimeter after annealing. The annealing procedure after each exposure and reading cycle was the same as previously described: 1 h at 440°C, followed by cooling for 24 h in the furnace. Table I shows the TL response of. re-used SiO_2 exposed at the same dose (10 Gy) in each reuse.

Table I. TL signal .response after multiple uses.

Re-used times	TL intensity (nC)	Re-used times	TL intensity (nC)
1	419.6	6	457.1
2	451.2	7	413.5
3	421.3	8	451.2
4	465.4	9	461.5
5	399.1	10	445.2
.		**Mean**	**438.51**
.		**Standard Deviation**	**23.1**

Residual TL: The residual TL signal depends mainly on the TL material, the magnitude of the previous exposure and the irradiation history of the individual detector. To determine the effect of previous irradiations on the residual TL signal, annealed virgin fiber. was irradiated with a 10-Gy dose and analyzed with the TL reader. The same fiber was then immediately re-analyzed. This test was performed 50 times and the ratio of means for the second and first readings. was. 0.06.

Fading: Thirty (30) gelatin capsules with optical fiber material were simultaneously irradiated with a. 10-Gy dose, and the material of one capsule was analyzed (10 measurements) each month, No significant fading of the TL signal was observed over 15 months. According to Euratom´s recommendation, .uncertainty introduced into the results due to the application of corrections for instability such as. fading should not exceed ±5% during the regular monitoring period.

Response of the SiO_2 optical fiber versus TLD commercial materials: The SiO_2 commercial optical fiber (29.8 mg) and TLD-100® LiF (23.7 mg) were irradiated at the same dose of 10 Gy. Using the same equipment and reading conditions, the optical fiber presents 1.3 times more TL signal than the LiF for this dose.

Glow curves for gamma and beta radiations: Figure 5 shows the glow curve of SiO_2 optical fiber for: a) gamma radiation, and b) beta particles, for the same delivered dose. The glow curves are very similar, showing one glow peak only.

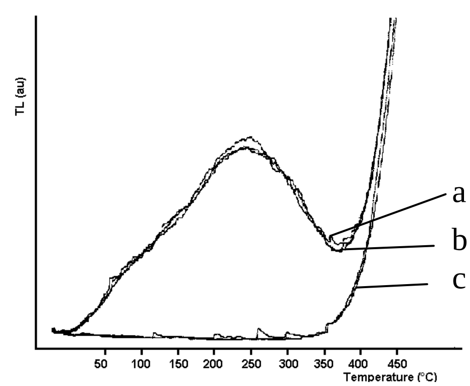

Figure 5. TL Glow curve of the Optical Fiber
exposed to: a) gamma radiation, b) beta particles, and c) residual signal.

Emission spectra: A Spex Fluorolog 2 spectrofluorimeter was used to detect the TL emission spectrum for SiO_2 fiber irradiated with ^{60}Co gamma photons. This system has a 0.34-nm emission monochromator with a R928 Hammamatsu photomultiplier and a controller computer. Emission spectra were obtained between 200°C and 280°C using a homemade heating system that reaches 300°C.

As shown in figure 6, the optical fiber has two emission peaks with approximately equal intensities centered at 400 nm (blue) and 575 nm (yellow). These two peaks are present at all temperatures at which the glow curve is observed, indicating that they arise from the same process. This result tells us that the material has two traps with different recombination energies, but with the same depth. Additional experiments are under way to further characterize this system.

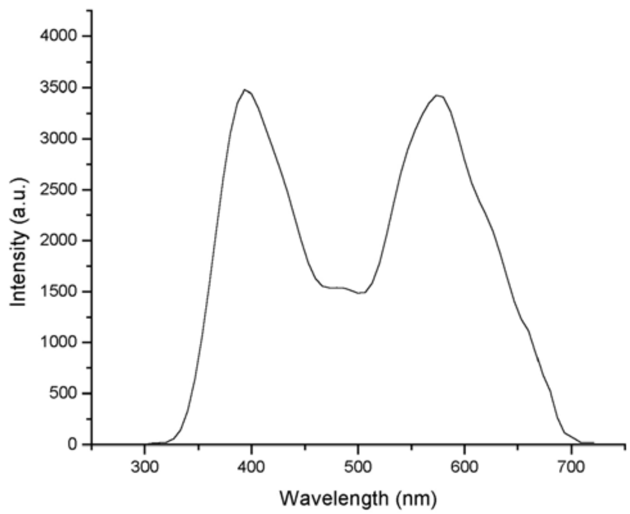

Figure 6. Emission spectra from the irradiated optical fiber, obtained between 200 and 280 °C.

CONCLUSIONS

The commercial SiO_2 optical fiber studied here responds monotonically (and, in some dose regions, linearly) to gamma photon radiation, carries a low residual TL signal, can be re-used several times, and demonstrates a very low degree of fading. The small size, flexibility, low cost and commercial availability of this material, make it very attractive for use in a wide variety of radiation dosimetry applications in very different fields: medicine, radiation protection, environmental radiation measurements, nuclear power production, and industry.

This study provides important parameters of SiO_2 optical fiber for its introduction as a thermoluminescence dosimeter suitable for a variety of applications.

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