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A study and characterization of the optically stimulated luminescence response of commercial SiO_2 optical fiber to gamma radiation

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Everyday, is coming more common the use of optically stimulated luminescence (OSL) as radiation measurement methodology. Although the OSL response characteristics of several chemical compounds such as aluminum oxide, beryllium oxide, potassium chloride and fused quartz have already been studied, research into new OSL materials is of continuing scientific and commercial interest. The thermoluminescence (TL) response characteristics of commercially, Nokia® SiO_2 optical fiber have previously been studied. The aim of this work is to characterize the OSL response of the SiO_2 optical fiber to gamma radiation.
The material preparation, pre-annealing, aliquot preparation, and OSL reading procedures are presented together with preliminary results of the investigation into the OSL response characteristics of the SiO_2 optical fiber. The total luminescence was found to be a linear function of gamma radiation dose within the range investigated (15.6 to 93.8 mGy). The experimental method yielded high reproducibility and very low residual effect. The OSL fading curve suggests that the optical fiber can be used for OSL measurements for approximately 150 hours (around 6 days) after exposure to gamma radiation. Taking into account the limits imposed by this fading, optical fiber can be successfully used as an OSL material to measure radiation doses such as those resulting from radiological accidents.

Keywords: OSL; SiO_2; optical fiber; gamma exposure.

Cada vez es más común el uso de luminiscencia ópticamente estimulada (LEO) como método de medición de la radiación. A pesar de que ya se han estudiado las características de la respuesta LEO de varios compuestos químicos tales como óxido de aluminio, óxido de berilio, cloruro de potasio, y cuarzo; la investigación de nuevos materiales LEO es de interés científico y comercial. Las características de la respuesta termoluminiscente (TL) de la fibra óptica comercial de SiO_2 (Nokia®) ha sido estudiada anteriormente. El objetivo de este trabajo es caracterizar la respuesta LEO de la fibra óptica de SiO_2a la radiación gamma.
La preparación del material, tratamientos térmicos, preparación de alícuotas y procedimientos de lectura LEO, se presentan junto con los resultados preliminares de la investigación sobre las características de la respuesta LEO de la fibra óptica de SiO_2. La luminiscencia total resultó para ser una función lineal de la dosis de radiación gamma dentro del rango investigado (15,6 a 93,8 mGy). El método experimental tuvo alta reproducibilidad y muy bajo efecto residual. La curva de desvanecimiento LEO sugiere que la fibra óptica se puede utilizar para las mediciones de LEO por aproximadamente 150 horas (alrededor de 6 días) después de la exposición a la radiación gamma. Teniendo en cuenta los límites impuestos por este desvanecimiento, la fibra óptica puede ser utilizada con éxito como un material LEO para medir la dosis de radiación, como en los accidentes radiológicos.

Descriptores: LEO; SiO_2; fibra óptica; exposición gamma.

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1. Introduction/Scope

Since the discovery of ionizing radiation, the development of radiation detection methods and associated materials has played a key role in promoting the understanding of the nature of radiation and its interaction with matter. Scientists such as Huntley *et al.* [1], Fain *et al.* [2], and Bailiff *et al.* [3] have pioneered the development of a new radiation dosimetry method called optically stimulated luminescence (OSL) which takes advantage of the luminescence emitted from an irradiated insulator or semiconductor during exposure to light and the proportionality of the intensity of this luminescence to the energy absorbed by the material from the ionizing radiation.

Radiation measurement methods as thermally stimulated exoelectron emission (TSEE), thermoluminescence (TL) and optically stimulated luminescence (OSL) are based in the promotion of electrons in a crystal lattice from the absorption of energy deposited by ionizing radiation, followed by externally stimulated release of all or part of the energy, when the promoted electrons are demoted to lower states [4,5,6]. Only a few materials have been developed as OSL dosimeters, however many others are currently being studied.

The primary advantages of OSL over TL and TSEE are manifested in the optical readout procedure of the former, which does not require heating of the sample, and thus avoids the problems associated with thermal quenching [6], heating-induced changes in the characteristics of the impurities in the material, and eliminates the need for reliable and reproducible preheating and heating schemes.

This paper presents the results of an investigation into the OSL response of commercially SiO_2 commercial optical fiber in tubular form to gamma radiation, using the continuous wave OSL (CW-OSL) excitation method.

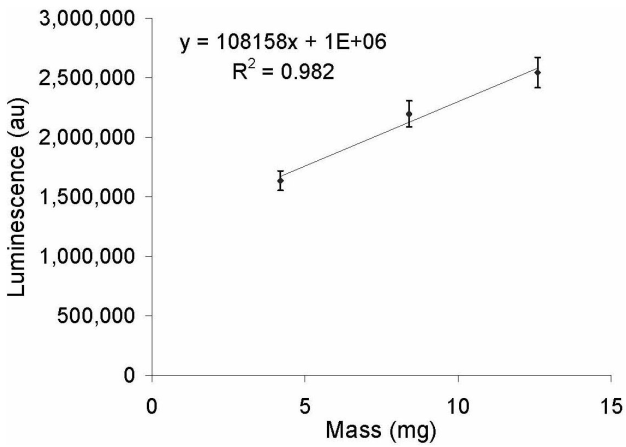

FIGURE 1. Total luminescence as a function of optical fiber mass.

2. Experimental procedure

2.1. Material preparation

Commercially 125 μm diameter, SiO_2 optical fibers manufactured by Nokia® were selected for this work on the basis of their availability, homogeneity and low cost. The optical fibers were received from the factory covered with a plastic coating. The coating was peeled away and the fibers were cleaned of chemical and resin residues using a moist cotton cloth. The cleaned fibers were then cut into 5 mm long sections, each weighing approximately 0.14 mg.

2.2. New material preheating

The sections of cleaned optical fiber were preheated in a ceramic dish at 440°C for 1 h and then left inside the furnace over the subsequent 24 h period to cool down to room temperature, preventing thermal stress. This pre-exposure annealing procedure helped to eliminate any background response that may have accrued during production, transportation and storage. The optimum preheating time and temperature used were based on the results of previous work [7]. Properly prepared the SiO_2 optical fibers can be used first for OSL analysis and then for thermoluminescence (TL) analysis without a significant detriment to the TL signal. The optical fibers were stored inside gelatin capsules for easy handling. This process was carried out under soft incandescent (red or yellow) light in order to prevent exposure of the fibers to sunlight and indoor fluorescent lighting.

2.3. Sample preparation

Optical fiber aliquots were prepared in a darkroom under soft incandescent lighting. The fiber material was supported using circular aluminum plates 9 mm in diameter. A small amount of vacuum grease was deposited on the surface of each aluminum plate, leaving a homogeneous film to which the optical fibers would adhere. Previous measurements demonstrated that there was no appreciable background OSL contribution from the coated plates. A precisely-weighed quantity of material (4.2, 8.4 or 12.6 mg) was then placed on the coated surface of the aluminum plate. The mass of optical fiber material was verified by weighing each plate before and after transferring the fibers.

3. Instrumentation

3.1. OSL reader

The OSL system consisted of a Daybreak Nuclear and Medical Systems, Inc®, model 2200 OSL reader with software to provide continuous wave laser stimulation, a platter to hold 60 samples, and automated fitting of samples to the photomultiplier [8]. A green/blue (480 nm) excitation light was used. A preheating temperature of 110°C was chosen to avoid room temperature photon emission (isothermal phosphorescence). The laser was operated at 24 $mWcm^{-2}$ for an excitation time of 30 seconds. The entire process was carried out in a flowing nitrogen atmosphere.

3.2. Measurement procedure

The sample was raised automatically from the platter during readout by a temperature-controlled stage (thermoelectric finger), and light baffles from the above and beneath touched the platter to isolate the inactive samples adjacent to the sample under test from exposure to the excitation light.

3.3. Exposure to gamma radiation

The optical fiber material, mounted on the aluminum plate, was exposed to gamma radiation by a sealed ^{137}Cs source (E_γ = 0.662 MeV) with a dose rate of 0.0938 Gy/hour (verified by using a calibrated ion chamber). The samples were placed on a polymethyl methacrylate (PMMA) phantom located 55 cm from the radiation source.

4. Results

4.1. Total luminescence as function of optical fiber mass

The total luminescence for the 30-second excitation time was determined as a function of the optical fiber mass. Five aliquots of each mass (4.2, 8.4 and 12.6 mg) were irradiated with a gamma dose of 93.8 mGy. The luminescence was then read by the OSL reader (30 readings, each integrating the luminescence signal for 1 s). The mean total luminescences and the standard deviations for each of the three masses were calculated and are shown in Fig. 1 along with the least squares line of best fit.

4.2. CW-OSL curves for different radiation doses

Aliquots with 8.4 mg of optical fiber were irradiated with gamma radiation doses of 15.6, 31.3, 46.9 and 93.8 mGy from the ^{137}Cs source, and the luminescence intensity measured as a function of excitation time. The resulting CW-OSL curves are shown in Fig. 2. It is observed that the optical fiber material presents a typical set of OSL curves.

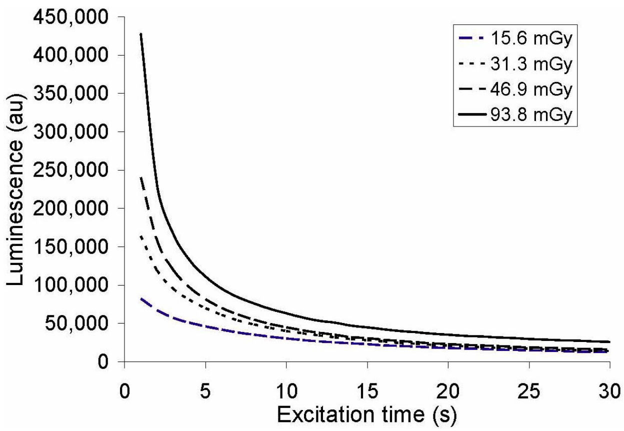

FIGURE 2. CW-OSL curves for four different gamma radiation doses.

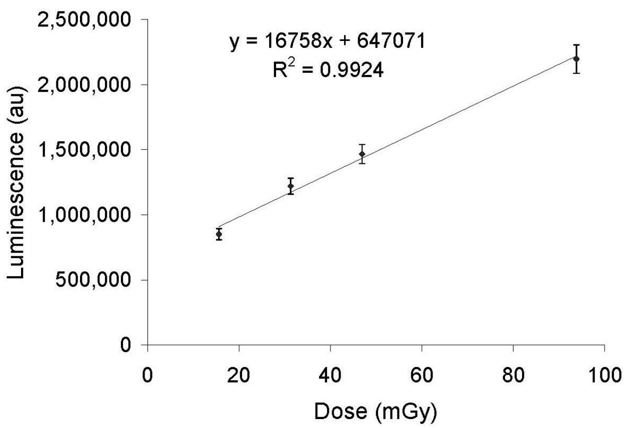

FIGURE 3. Total luminescence as a function of radiation dose.

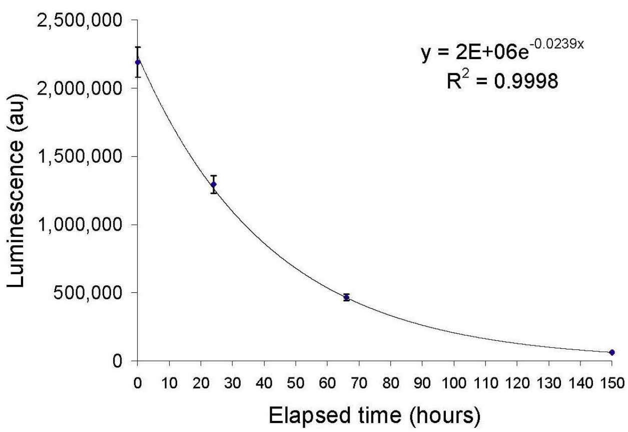

FIGURE 4. OSL fading curve of the optical fiber.

The relation between total luminescence and radiation dose was investigated using aliquots with 8.4 mg of optical fiber material. Five aliquots were irradiated with 15.6 mGy of radiation and the total luminescence for the 30-second excitation time read by the OSL reader. The procedure was repeated with three other sets of five aliquots irradiated with doses of 31.3, 46.9 and 93.8 mGy. The means and standard deviations for each of the four radiation doses are shown below in Fig. 3 together with the line of best fit.

4.3. Data reproducibility

Ten aliquots with 8.4 mg of optical fiber material were irradiated with a dose of 93.8 mGy, and the total luminescence read immediately after the radiation exposure. The arithmetical mean and standard deviation were 2,193,342 and 105,344 respectively. The results exhibit high reproducibility.

4.4. Residual OSL signal

The residual OSL signal depends mainly on the material, the magnitude of previous exposure to the excitation light, and the irradiation history of the individual detector. In order to determine residual effects, a sample with 8.4 mg of optical fiber and exposed to 93.8 mGy was read, and immediately re-read, with the Daybreak® OSL reader. This reading and re-reading procedure was carried out a total of 10 times. The mean of the second to first reading ratios was 0.23 ± 0.02.

4.5. OSL fading

Twenty optical fiber aliquots (8.4 mg) were irradiated with a gamma dose of 93.8 mGy. Five samples were measured immediately after the exposure, five samples after 24 hours, another five after 66 hours, and the last five after 150 hours. The resulting fading curve of the optical fiber material is shown in Fig. 4.

5. Conclusions

The commercially SiO_2 optical fiber investigated presents good characteristics as an OSL material. Total luminescence is a linear function of radiation dose within the range of radiation doses investigated (15.6 to 93.8 mGy). Data reproducibility is high and the residual signal ratio good. The study carried out here could be complemented by investigation of the responses at both lower and higher radiation doses.

The OSL fading curve is modelled by an exponential decay function, and suggests that the optical fiber can be used for OSL measurements for approximately 150 hours (around 6 days) after exposure to gamma radiation. Although this fading does impose a time limit, and thus a limit to the range of applications, we may conclude that the optical fiber can be used to measure radiation doses, for example in the cases of radiological accidents or emergencies, if less than approximately 6 days have elapsed between the radiation exposure and the OSL measurement procedure.

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