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Segments of a commercial Ge-doped optical fiber as a thermoluminescent dosimeter in radiotherapy

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ABSTRACT

Optical fibers have been proposed as dosimeters in both diagnostic and radiotherapy applications. A commercial germanium (Ge)-doped silica fiber with a 50 μm core diameter which showed good thermoluminescence (TL) properties was selected for this study. The radiation sources used were a high dose rate brachytherapy iridium-192, MV photon and MeV electron beams from a linear accelerator. The coating of the fiber was chemically removed and then annealed at 400 °C for 1 h prior to irradiation. After irradiation, the fiber was read on a Harshaw Model 3500 TLD reader. The optical fiber had one well-defined glow peak at 327 ± 2 °C at all the radiotherapy energies. The dose response was linear within the clinical relevant dose for all these energies. Reproducibility was mainly within 4–6% (one standard deviation) for high energy photons and electrons. The fiber was found to be energy independent within the MV photon energy range. At room temperature the fading up until 1 month was around 6% which was within the 6% uncertainty of the sensitivity calibration of the fiber. Re-using the fiber four times did not significantly alter the sensitivity factor. The optical fiber was found to be dose rate as well as angular independent. Central axis depth dose curves of both 10 MV photons and 12 MeV electrons using the fiber showed relatively good agreement to standard depth dose curves in water within 4%. The Ge-doped fiber is a promising TL dosimeter but improvements have to be made to reduce the reproducibility within 3% for high energy photons and electrons.

1. Introduction

Optical fibers, made from fused silica, are about the diameter of a human hair and transmit light over large distances with very little loss. Optical fibers comprise two essential components; a core region surrounded by an annular cladding region. The core of the optical fiber serves to guide light along the length of the optical fiber. The cladding region has a slightly lower index of refraction than the core and physically supports the core region. Its primary function is to ensure that very little light is lost as it propagates along the core of the optical fiber. Optical fibers are invariably coated to protect them from moisture in the environment, which would otherwise greatly reduce their lifespan. This protective layer often takes the form of a thick acrylate coating.

Optical fibers have suitable characteristics which enable them to be used as ionizing radiation sensors. The key attributes are excellent spatial resolution due to its size (few tens of microns); water and corrosion resistance; and its modest cost (Grattan and Meggitt, 2000). The application of an optical fiber as a dosimeter has been carried out based on different physical mechanisms such as thermoluminescence (TL) (Abdulla et al., 2001; Yusoff et al., 2005; Espinosa et al., 2006), radiation induced attenuation (Lu et al., 2000; Huston et al., 2001; O'Keeffe et al., 2005), radioluminescence and optically stimulated luminescence (OSL) (Huston et al., 2002;Aznar et al., 2004; Yukihara et al., 2005; Mones et al., 2006; Benevides et al., 2007).

For germanosilicate optical fibers, it has been established that the signal from the core material is more intense than that from the larger substrate (Khanlary and Townsend, 1992). Hence the luminescence spectra and the glow peak arise mainly from the signal in the core. When the optical fiber is irradiated, free electrons are generated and are trapped in the material. These traps are provided by lattice defects or impurities and are deep enough to prevent the escape of electrons for an extended period of time at room temperature. On heating the trapped electrons are released and recombine at luminescence centers resulting in emission of light. The intensity of light is proportional to the absorbed dose. The OSL process is similar to the TL process except that the trapped electrons are released optically and not thermally. Once heated the stored information in TLD is erased totally. However, OSL

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dosimeters can be re-read as light does not erase all the information. The OSL dosimeters when coupled with a fiber optic can provide in vivo real-time dose measurements in radiotherapy and in diagnostic radiology (Huston et al., 2002; Benevides et al., 2007).

Commercial optical fiber as a thermoluminescence dosimeter (TLD) is a better alternative to commercial TLDs due to its better resolution and lower cost. For an optical fiber to function as a TLD several general characteristics such as reproducibility, energy dependence, dose rate dependence, angular dependence, fading and re-annealing have to be satisfied. The TL response is also influenced by the type of fiber. In our study a commercial Ge-doped silica fiber (National Optics Institute INO) with a 50 μm core diameter was selected to study the feasibility of the fiber as a dosimeter in radiotherapy using the TL response.

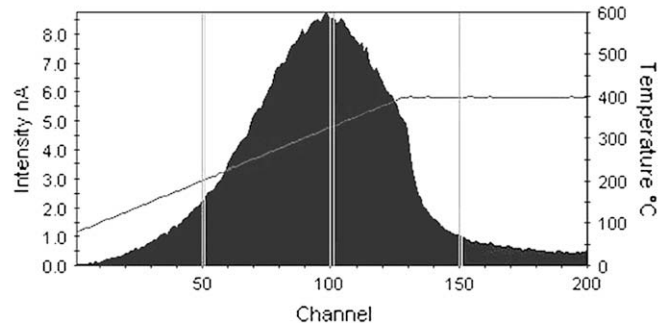

Fig. 1. TL glow curve of a Ge-doped optical fiber.

2. Materials and method

The commercial Ge-doped silica glass optical fiber is a multimode fiber with a core diameter of 50 μm and a cladding diameter of 124.7 ± 1.0 μm which includes the core. The coating which also includes the core and the cladding has a diameter of 252.0 ± 0.7 μm. The optical fiber is supplied at a standard length of 5 m.

The fiber was cut into strips of 5 cm length so that the coating can be more conveniently removed chemically. These segments were then cut to 8 mm lengths and were arbitrarily selected for irradiation. The optical fiber of 8 mm length fitted exactly into the rod-type planchet of the Harshaw Model 3500 TLD reader. All measurements were based on one 5 m fiber.

In general, there are four essential steps in the experiment. These are optical fiber coating removal, annealing, irradiation and readout.

2.1. Coating removal

The optical fiber coating was removed chemically using a solvent named dimethylformamide (DMF) in a fume cupboard (Fitzpatrick et al., 2003). The optical fiber was soaked in the solvent for a few minutes. This caused the optical fiber to swell and the coating material was chemically weakened. The optical fiber was then pulled tightly through a clean cloth to remove the coating. It was then dipped in water to clear the remaining DMF from the optical fiber.

2.2. Annealing

In this study, the optical fibers were annealed using a Nabertherm Program Controlled S27 Furnace. The fibers were wrapped in aluminum foils and annealed at 400 °C for 1 h. The fibers were then removed and allowed to cool at room temperature.

2.3. Sample irradiation

After annealing, the optical fiber was irradiated on a Siemens Mevatron MD2 linear accelerator (LINAC) at Mount Miriam Hospital. The LINAC has dual x-ray energies of 6 MV and 10 MV and has electron energies ranging from 5 MeV to 14 MeV. Irradiation with photons of mean energy 397 keV was done using a micro-Selectron-high dose rate (HDR) iridium ^{192}Ir with a remote after-loading system.

In general, the source-to-surface distance (SSD) was set at 100 cm and the field size used for MV photons was 10 × 10 cm^2 whilst a field size of 15 × 15 cm^2 was selected for MeV electron energies. Optical fibers of 8 mm length were placed and taped on a Gammex RMI solid water phantom (30 cm length × 30 cm width) at the desired depth. Since the optical fibers were randomly selected, they would represent different segments of the 5 m length fiber. They were placed at the center of the field. To provide sufficient backscattering, 10 cm slab of solid water phantom was placed below the fiber. For photons, the dose measurement was done at 5 cm depth whilst for electrons, the dose measurement was done at depth of maximum dose (d_{max}).

For irradiation using the ^{192}Ir brachytherapy source, a Perspex phantom slab with dimensions 30 cm × 30 cm × 4 cm had a drilled groove which served as a holder for a 3 cm diameter applicator. Slabs of solid water phantom were placed above and below the Perspex phantom during the dose measurements. This setup only allowed two optical fibers of 8 mm length to be placed at 2 cm and 5 cm directly from the source which was located in the applicator.

2.3.1. Dose response, reproducibility and energy dependence

The optical fibers were irradiated at 397 keV and 10 MV photon energies and 12 MeV electron energy for doses ranging from 0.2 Gy to 12 Gy. For each dose a minimum of 3 fiber readings were taken for the high photon and electron energies. To assess the reproducibility at least 4 or more fibers were read at a selected dose and energy.

The optical fibers were also irradiated at 6 MV photons and 5 MeV, 8 MeV and 14 MeV electrons for energy dependence study.

2.3.2. Re-annealing and fading

Three optical fibers of 8 mm length were selected for this study. The optical fibers were exposed to different known doses and the TL readings obtained. The fibers were then re-annealed and re-used. The process was repeated four times.

For the fading experiment, the number of fibers exposed to 0.92 Gy and 5 Gy using 10 MV photons were 10 and 20 respectively. For 0.92 Gy, the fibers were read on the day of the exposure as well as two weeks post-irradiation whilst for 5 Gy readings were taken on the day of the exposure, 1 day, 2 weeks and 1 month after irradiation. A total of five fibers were used for each reading.

2.3.3. Dose rate and angular dependence

For angular dependence, the optical fibers were placed under a semi-circular Perspex phantom which has a radius of 7 cm. This

Table 1
Dose reproducibility of 10 MV photons and 10 MeV electrons.

Source	Dose (Gy)	Number of fibers read	Charge (nC)		
			Mean	SD	SD in %
10 MV photons	0.92	7	26.09	1.55	5.93
10 MV photons	9.19	8	255.09	11.75	4.61
12 MeV electrons[a]	5	8	154.07	4.75	3.13
12 MeV electrons[a]	5	4	154.55	5.48	3.60

[a] Measurement done on different days.