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Low-dose photon irradiation response of Ge and Al-doped SiO_2 optical fibres

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ABSTRACT

We have investigated the thermoluminescent response and fading characteristics of germanium- and aluminium-doped SiO_2 optical fibres. These optical fibres were placed in a solid phantom and irradiated using 6 and 10 MV photon beams at doses ranging from 0.02 to 0.24 Gy delivered using a linear accelerator. In fading studies, the TL measurements were continued up to 14 days post-irradiation. We have investigated the linearity of TL response as a function of dose for Ge-, Al-doped optical fibre and TLD-100 obtained for 6 and 10 MV photon irradiations. We have concentrated on doses that represent a small fraction of that delivered to the tumour to establish sensitivity of measurement for peripheral exposures in external beam radiotherapy.

1. Introduction

Radiotherapy is one of the several modalities used in the treatment of malignant disease. External photon beam radiotherapy is usually carried out with more than one differentially angled radiation beam in an effort to produce an effective distribution of dose within the target volume while providing a dose as low as possible in healthy tissues surrounding the target. External-beam X-rays irradiation is popularly used in radiotherapy for the treatment of various cancers, including breast, brain, prostate, lung, gynaecologic tumours, lymph and bladder, etc. (Podgorsak, 2005). Thermoluminescent dosimetry (TLD) has been used in such situations due to the ease in processing the dosimeters as well as the accuracy and sensitivity of the TLD's.

Recently, a number of research groups have started to use SiO_2 optical fibres as a radiation dosimeter to measure absorbed dose by patients, in particular overcoming spatial resolution limitations of existing TL dosimetry systems (Hashim et al., 2009). The optical fibres are also impervious to water and in some instances it has also become possible to locate the fibres within a particular tissue of interest (Yusoff et al., 2005). The commercially available doped SiO_2 optical fibres studied herein demonstrate useful TL properties and represent an excellent candidate for use in TL dosimetry of ionising radiations (Hashim et al., 2010). As an instance it is already established that the fibres offer good sensitivity of several Gy (this being a typical dose level to tumour in radiotherapy).

The presence of impurities or the addition of dopants to silica can greatly enhance the sensitivity of silica to radiation by providing an increased number of traps. In addition, new defects and absorption bands can appear. In optical fibre for telecommunications, dopants are incorporated in the silica glass to modify its refractive index to obtain total internal reflection. The present work represents a preliminary study of photon irradiation response of commercially available Ge- and Al-doped SiO_2 optical fibres. In particular, interest focuses on the ability of such fibres to measure doses at the periphery of irradiation fields, such values represents a small fraction of the tumuor dose. Comparison of sensitivity has also been made using the standard photon TL material, TLD-100.

2. Materials and methods

2.1. Material and preparation

The Ge- and Al-doped optical fibre used herein are manufactured by INOCORP (Canada) and have an outer diameter of 124.7 ± 0.1 μm. The core diameter is 9 μm. The protective polymer layer of the optical fibre was removed from the fibres using a fibre stripper (Fremont Inc., USA). A moist cotton cloth dipped into

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ethanol was used to clean the doped SiO_2 optical fibre core to minimise the possibility of any remnant polymer cladding. Subsequently, the fibre was cut to lengths of 0.5 ± 0.1 cm using an optical fibre cleaver (Fujikura Ltd., Japan). The mass of each fibre was measured using an electronic balance (PAG, Switzerland). This allowed TL yield to be normalised to unit mass of the fibre. The optical fibres were handled using vacuum tweezers (Dymax 30, manufactured by Charles Austen Pumps Ltd.).

2.2. Annealing

Annealing is the thermal treatment used to erase any irradiation memory from the thermoluminescent material, stabilizing the trap structure and restoring it to initial conditions existing before irradiation. In the present work, annealing was performed at 400 °C for a period of 1 h, the fibres being retained in an alumina container during this period. To avoid thermal stress following the annealing cycle, the fibres were left inside the furnace for 18 h to finally allow the material to equilibrate at a temperature of 40 °C (Hashim et al., 2009). For the TLD-100 rods, the annealing routine was to place these in a stainless steel plate arrangement and to anneal for 1 h at 400 °C and subsequently for 2 h at 100 °C. After cooling, the fibres were placed inside a opaque container in order to minimise exposure to the potentially high ambient light levels, this being the usual practise in management of TLD media.

2.3. Exposure to radiation

The Ge- and Al-doped fibres and TLD-100 rods were placed at the surface of a solid phantom media (comprising of polymethylmethacrylate PMMA, of dimension 20×20 cm^2) and irradiated with 6 and 10 MV photon beams at a nominal dose rate of 200 monitor unit (MU) min^{-1}, as provided by a Siemens Primus MLC 3339 linear accelerator (situated at the Department of Radiotherapy and Oncology, Hospital Sultan Ismail, Johor Baru, Malaysia). The dose delivered was chosen to be 0.02 to 0.24 Gy, with a field size of 10 cm × 10 cm and a source to surface distance (SSD) of 100 cm.

2.4. Instrumentation

The optical fibre TL yield was read out using a Harshaw 4500 TL reader (Department of Physics, Institut Ibnu Sina, UTM). N_2 atmosphere was used to suppress spurious light signals from triboluminesence and also to reduce oxidation of the heating element and fibres. During readout the following parameters were used: preheat temperature of 50 °C for 10 s; readout temperature of 300 °C for 33 s and heating rate of 10 °C/s. Finally, an annealing temperature of 300 °C was applied for 10 s to sweep out any residual signal.

3. Results and discussion

3.1. TL glow curve

The intensity of luminescence as a function of temperature is called the thermoluminescent glow curve. This glow curve varies with the mode of heating and the heating temperature. Fig. 1 shows the glow curve yield for a Ge-doped optical fibre, typified by a broad peak. TL yields as a function of temperature (i.e., the glow curves) were recorded using a heating rate of 10 °C/sec. The readout temperature was 300 °C from the time-temperature profile set up for the TLD reader. The area under the curve represents the radiation energy deposited. While the glow curve for Al-doped optical fibre is similar in shape to that of Ge-doped optical fibres, nevertheless the scale of emission is quite disimilar, the greater yield (by a factor > 20) being obtained using Ge-doped fibres.

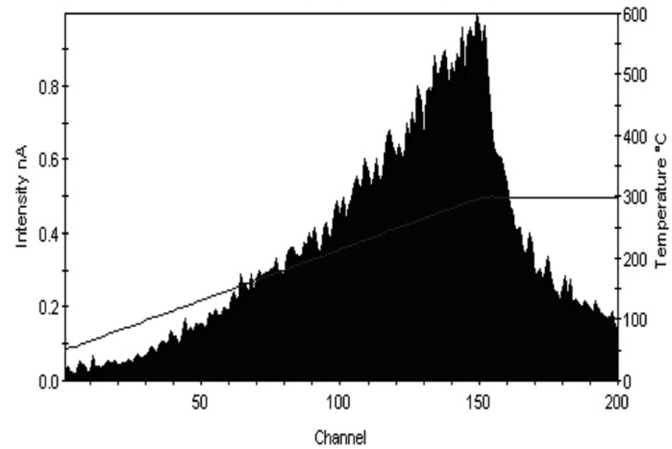

Fig. 1. Glow curve for the Ge-doped optical fibre material following 6 MV photon irradiations.

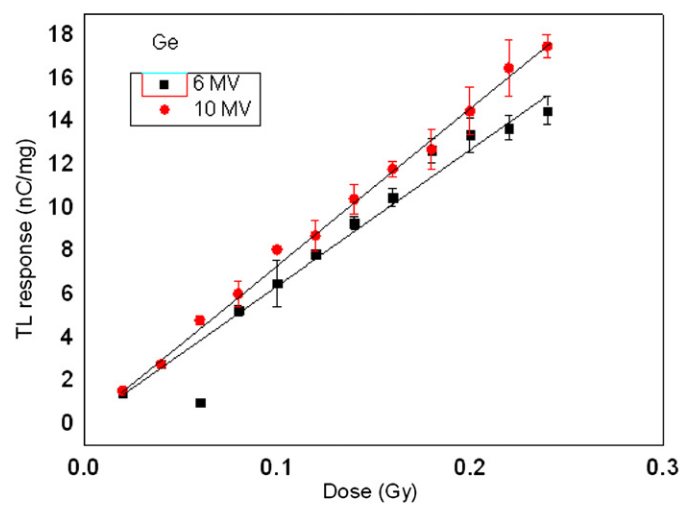

Fig. 2. TL response of Ge-doped optical fibres irradiated with 6 and 10 MV photons versus dose. (The standard error of the mean is in the range of 0.11–1.3.)

3.2. Response to photons

If a TL material is to be used for any dosimetric applications in the field of photon radiation, one of the main characteristics that must be known is its energy response (Oberhofer and Scharmann, 1981). A dosimeter is said to have a good energy response if its response per unit dose shows little variation with photon energy. For this investigation the samples were irradiated using 6 and 10 MV photons, the available photon energies for radiotherapy at the particular centre in which the irradiations were carried out. Figs. 2–4 show TL response obtained for 6 and 10 MV photon irradiations for Ge- and Al-doped optical fibre and TLD-100 media, respectively. It is shown that the energy response, specifically the response per unit dose, for both optical fibre and TLD-100 media shows little variation with photon energy.

3.3. Linearity

The ideal dosimeter would respond proportionally over a wide range of dose. For present interest, it is extremely useful for a particular TL medium to have a linear TL-absorbed dose response