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Ultraviolet radiation (UVR) dosimetry system and the use of Ge-doped silica optical fibres

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HIGHLIGHTS

- TL characterisation of Ge-doped SiO_2 optical fibres due to UVR was reported for the first time.
- Ge-doped SiO_2 optical fibres showed simple glow curve, good reproducibility and high sensitivity.
- Increasing of dopant concentrations can enhance the TL efficiency well.
- Ge-doped SiO_2 optical fibres produce a linear dose response when irradiated to UVA.

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ABSTRACT

Previous studies have shown that over exposure to ultraviolet radiation (UVR), either from sunlight or artificial sources, can cause severe biological effects including cataracts, photokeratitis and skin cancer. In this respect, there exists the need to introduce a sensitive UV dosimetric material capable of measuring radiation dose to high accuracy in order to deliver UVR safely and efficiently. Present study has focussed on the investigation of the potential thermoluminescent (TL) sensitivity of commercially available germanium (Ge)-doped silica (SiO_2) optical fibres subjected to UVR. The main interest of this study is to find out whether these doped SiO_2 optical fibres can be used as a sensible integrator of environmental UV exposures. In the present study, commercially available Ge-doped SiO_2 optical fibres have been used with a core diameter of 11 μm (CorActive, Canada), 23 μm (Central Glass and Ceramic Research Institute Kolkata, India) and 50 μm (Central Glass and Ceramic Research Institute Kolkata, India) and a cladding diameter of 125 ± 0.1 μm, irradiated over a wide range of UV dose. Results have shown that these fibres exhibit a linear dose response (with correlation coefficient better than 0.9852). The 50 μm fibre produces greater TL response than that obtained for 11- and 23 μm fibres. The TL results are compared with that of the well-established TL dosimeter material lithium fluoride.

1. Introduction

TL dosimetry has become the most commonly used dosimeter for routine monitoring of occupational radiation exposure (Bos, 2006). It is widely used in radiation protection, including in clinical dosimetry, personal and environmental monitoring. Due to their tissue equivalence and high sensitivity the most commonly used TLDs in medical applications are LiF:Mg,Ti, LiF:Mg,Cu,P and Al_2O_3:C. For applications in the field of UV radiation dosimetry the use of such TLDs has been studied by a number of workers (Delgado et al., 1996; Gronchi et al., 2012; Kharita et al., 1994). However these well-established crystalline based TLDs have basic limitations such as their hygroscopic nature, cost and the draw-back of having relatively poor spatial resolution (~few mm). With these restrictions in mind, the use of doped SiO_2 optical fibres has been introduced. The presence of dopants in the fibres provide the TL properties of the fibre; the fibres overcome the hygroscopic problem while offering an excellent spatial resolution and dose sensitivity (Bradley et al., 2012).

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Studies have been undertaken to investigate the TL performance and dosimetric utility of Ge-doped SiO_2 optical fibres in a variety of applications such as in the dosimetry of synchrotron beams (Abdul Rahman et al., 2010), kilovoltage therapeutic X-ray beams (Issa et al., 2011), proton irradiation (Hashim et al., 2006), photon irradiation (Abdul Rahman et al., 2011), electron irradiation (Hashim et al., 2009), and neutrons (Hashim et al., 2010). Results obtained have demonstrated that commercial Ge-doped SiO_2 optical fibres are capable of producing a good TL response relative to their small size, making them a promising TL material for use in a wide variety of dosimetric applications. Optical fibre TLDs can also be corrected to provide a tissue equivalent response and can be re-used repeatedly following thermal annealing, without any loss in dose response. These attractive features of the optical fibres make them well suited for use in clinical dosimetry.

To date, although a number of research groups have reported on the potential of Ge-doped SiO_2 optical fibres (Bradley et al., 2012), the TL sensitivity of Ge-doped SiO_2 optical fibres to ultraviolet radiation (UVR) is not well established. Therefore, present study focuses on examination of whether these Ge-doped SiO_2 optical fibres can be used as a sensible integrator of environmental UV exposures. UVR does not ionise atoms and molecules so that UVR dose deposition is via electron transitions, or in other words the transfer of electrons from low to higher energy levels. Because of the difference in energy between two such energy levels, electron transitions result from the absorption of electromagnetic radiation. As a result UVR can be absorbed very strongly in thin surface layers of the skin (Diffey, 1987).

UVR is used principally in hospitals for the treatment of skin disorders such as psoriasis and to a lesser extent eczema and vitiligo. UVB phototherapy and PUVA photochemotherapy (UVA in combination with a photosensitizing medication, typically psoralen) are two treatment modalities that are being increasingly used for the treatment of these skin diseases, particularly psoriasis (Lee et al., 2005). UVB phototherapy uses either long-band or narrow-band UVB (315–280 nm; 3.94–4.43 eV per photon) while UVA (400–315 nm; 3.10–3.94 eV per photon) is more penetrating. The main concern that arises from use of these two treatments is the risk of skin carcinogenesis (Diffey, 1988; Stern and Lange, 1988). As a result, it is important to introduce a UV dosimetric material for consistent monitoring of UV exposure in order to ensure efficient and safe delivery of UVR. The results obtained from this study will also be compared with TL measurements made using the well-established lithium fluoride (LiF) dosimeter.

2. Materials and methods

2.1. Dosimetry system

2.1.1. Ge-doped SiO_2 optical fibres

Present study will make use of commercially available Ge-doped SiO_2 optical fibres with a core diameter size of 11, 23 and 50 μm and a cladding diameter of approximately 125 ± 0.1 μm. The effective atomic number of the fibre is 11.4 (Ramli et al., 2009). The dopant concentration varies along the length of the fibre and this non-uniformity can influence the TL yield. As such, in this study use was made of fibres of pre-characterized screening sensitivity (see below), each sample being of length 5.0 ± 0.1 mm. Details for each optical fibre type used herein is provided in Table 1; Fig. 1 shows images of these.

For each type of dosimeter, a total of 500 fibres were prepared. The outer cladding layer of the plastic polymer was carefully removed from the coating of the optical fibre using a fibre stripper (Miller, USA). Following removal of the outer cladding layer, the fibre was cleaned using a cotton cloth dipped into methyl alcohol in order to completely remove traces of remnant polymer cladding. Then, the optical fibre was cut into individual fibres of length of 5.0 ± 0.1 mm using a fibre cleaver (CT-30 Fujikura, Japan), to ensure a standard situation for each sample. Following cutting, the average mass of each individual fibre was determined using an electronic balance (Mettler Toledo B303-S College Balance), allowing the TL yield to be normalised to unit mass of fibre. It was found that the average mass for each fibre was in the range of (0.13–0.15) ± 0.01mg

Table 1
Details of silica optical fibres used in present study.

Fibre core diameter (μm)	Doping levels	Supplier
11	GeO_2: 3.1 mol%	CorActive High Tech, Canada
23	GeO_2: 10.0 mol%	Central Glass and Ceramic Institute, Calcutta
50	GeO_2: 12 mol%	Central Glass and Ceramic Institute, Calcutta

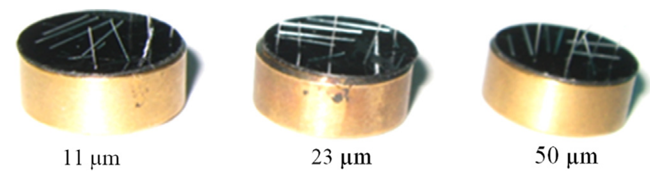

Fig. 1. Doped silica optical fibre with three different doped core diameter sizes: 11 μm, 23 μm and 50 μm.

2.1.2. TLD–LiF discs

For purposes of comparison of TL response, use has been made of TLD–LiF (TL 100) discs commercially manufactured by Teledyne Isotopes (Middlesex, United Kingdom) of diameter size 0.8 cm and average mass of 31.4 ± 0.2 mg. A similar experimental setup to that previously adopted for the fibres and chalk discs were used for irradiation of the LiF discs.

2.2. Irradiation setup

UVA irradiation was performed in a University of Surrey Advanced Technology Institute (ATI) clean-room designed for photolithography, coming complete with UV safe lighting. The irradiation was made using a 100 W mercury arc lamp (Omnicure UV series 1000) emitting UVA radiation of wavelength 365 nm. The UV lamp was set up at a distance of 10 cm vertically above the irradiation surface. A UV probe (Vari-Wave II, serial number: Q-439 calibrated) was used to measure the UVA intensity measured as 9.95 mW cm^{-2} ± 0.03%. The UVA system is shown in Fig. 2. Each irradiation was carried out using 20 selected optical fibre samples, prepared and placed in a small Petri dish, subsequently placed centrally under the UVA source. The samples were irradiated over a range of UVA dose by simply increasing the exposure time from 0 to 360 min, varying the dose from 18–215 J cm^{-2}. Similar experimental setup and parameters were used to irradiate LiF discs.

2.3. Readout system

The TLD reader system used in this study was a 654 TOLEDO TL reader (Pitman Instruments, Weybridge, England). After irradiation, the TL yields of the irradiated samples were readout and measured using the TOLEDO TL reader operating under a nitrogen gas atmosphere. The nitrogen gas flow was set to 400 ml/min to reduce the effects of triboluminescence (which occurs due to mechanical stress applied on the surface of the fibre) and also to