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Gamma irradiated thermoluminescence response of Ge-doped SiO_2 fibre

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HIGHLIGHTS

- Fabricated tailor-made 6 mol% Ge-doped SiO_2 Fibre of different diameters.
- The smallest diameter fibre shows the greatest TL response.
- TL yield of all fibres show linear response with gamma dose.
- All fibres show maximum peak in glow curve between 250–310 °C.
- High response tailor-made fibre suitable for use as a TL dosimeter.

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ABSTRACT

Over the past decade and more, considerable interest has been shown in the thermoluminescence (TL) properties of silica-based single-mode optical fibres, in particular investigating potential ionising radiation dosimetry applications. Herein, study has been made of TL glow curve, dose response, reproducibility and fading of 6 mol% Ge-doped silica, fabricated in-house and produced in the form of cylindrical fibres. Three different pairings of doped-core and silica cladding diameters were produced: (40, 241) μm, (80, 483) μm and (100, 604) μm. The TL results were compared against that of TLD-100, one of the most sensitive commercially available LiF-based TL media. For all three pairings of diameters, closely similar TL glow curve were obtained, formed of a single peaked structure with a maximum TL yield located between the temperatures 250 and 310 °C. The TL yield of the fibres were linear over the range of doses investigated, from 1 Gy up to 10 Gy, their dose response exceeding that of TLD-100, the samples also being found to be reusable, without evidence of degradation.

1. Introduction

Silica (SiO_2) optical fibre is a flexible, transparent, glassy medium. In regard to electronic communications the doped optical fibre transmits light, generally over large distance and with very little loss (Ong et al., 2009). Normally, the fibre consists of a doped-core surrounded by an annular cladding region. The dopant, herein Ge, creates change in the refractive index at the core-cladding interface, enabling light guidance as a result of total internal reflection. Importantly for present radiation dosimetry interests, the dopant gives rise to the broad energy absorption bands typical of glassy as opposed to crystalline materials. It is to be noted that although the silica medium is generally amorphous, possibly with microcrystalline inclusions, the crystalline model does provide for the thermoluminescence (TL) features common to both crystalline and amorphous media and as such is commonly made use of in TL yield interpretation for radiation dosimetry. In regard to medical radiation medicine dosimetry applications, the addition of dopants at optimal concentrations and the presence of impurities in the silica can be expected to result in enhanced radiation sensitivity of the silica-based medium, providing an increased number of traps (Kamarul et al., 2011)

Over the past fifteen years or so, extensive study has been made of the TL yield from irradiated doped silica-based optical fibres (Abdulla et al., 2001; Yaakob et al., 2011). Absorption of energy from ionizing radiation, the basis of TL dosimetry, has been the focus of interest, with in this case the thermally stimulated light emission arising from the silica insulator, the core having

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been extrinsically doped with Ge. TL from semiconducting medium is also possible while metals fail to support the electron–hole trapping that provides for the necessary thermal de-trapping and subsequent TL (McKeever, 1995). Typically the intensity of emitted light is recorded as a function of temperature, yielding a glow curve, the shape of which is formed of one or more TL peaks, broad single peaks being a reflection of the non-localized trapping of amorphous media. In exposure to radiation, as long as unoccupied traps continue to exist and atomic displacements are not generated, the emitted light intensity can be expected to be proportional to the absorbed dose.

The optical fibres are known to offer unique capability for remote monitoring of radiation effects in materials, in particular in difficult-to-access or hazardous locations (Huston, 2001). Also, due to their small physical size (generally with available core dopant diameters from a few microns up to some several tens of microns), this form of TLD offers excellent spatial resolution. They are also water and corrosion resistant, of modest cost (Kron, 1999) re-usable, offer bone-tissue equivalence, and provide sensitivity that is sufficiently good for a comprehensive range of radiotherapy dosimetry applications. Finally, there is the freedom from cables and associated need for high voltages. As such, they are viewed to be highly useful in medical applications, including in measurements within anthropomorphic phantoms (Kron, 1999). The main features required for good TLD are reproducibility, stability, dose-rate independence and linearity. As Ge doped optical fibres have high TL sensitivity, storage-stability and reliability, they are now considered to be highly suited to a range of applications in ionising radiation dosimetry (Ong et al., 2009). Previous studies have shown that Ge-doped optical fibres offer superior performance when compared to several other types of commercially produced optical fibre, producing sensitivity across a wide range of doses (Noor et al., 2010).

In regard to gamma irradiation studies, in medicine these have been widely used in cancer treatment, continuing to be important in brachytherapy and in the external beam technique Gamma Knife radiosurgery, making use of many collimated beams of gamma radiation directed at small tumours, malignant and otherwise, as well as in treatment of Parkinson's disease. In diagnostic applications, gamma rays are the dominant source type in nuclear medicine studies, including in Positron Emission Tomography (PET).

Present study adds further crucial information in seeking to firmly establish this form of radiation sensor for medical applications. Specifically, this paper compares the response at penetrating gamma-ray energies for three different pairings of doped-core and silica cladding diameters: (40, 241) μm, (80, 483) μm and (100, 604) μm. Comparison is to be made against that of TLD-100, one of the most sensitive commercially available LiF-based TL media. Several key TL material properties required for dosimetric use will be studied herein, including glow curves, dose response, reproducibility and fading.

2. Materials and method

2.1. Sample preparation

Present research focuses on the TL response of Ge-doped silica (SiO_2) cylindrical fibres. The doped fibre preforms have been produced by the Telekom Malaysia Research and Development (TMRD) group and supplied at a standard length of 30 cm. The preforms were then fabricated into fibres using the pulling tower facility at the University of Malaya. The fibres, of 6% mole dopant concentration, were produced in the form of three different pairings of doped-core and silica cladding diameters respectively, as follows: (40, 241) μm, (80, 483) μm and (100, 604) μm. Table 1 shows the mean masses for each of the fibres. The fibres offer capability for high spatial resolution dosimetry, a matter of considerable importance in radiotherapy, particularly for dose delivery adjacent to sensitive structures. The fibre dimensions can be compared against those of Harshaw LiF TLD-100 chips with an areal footprint of $3.2 \times 3.2\ mm^2$, thickness 0.89 mm and mean mass 23.6 mg. The performance of the fibre dosimeters have been compared against that of these LIF dosimeters, the isotopic constituents being ^6Li (7.5%) and ^7Li (92.5%).

Table 1
Dimensions and mean mass of three different diameter fibres.

No.	Cladding diameter (μm)	Core diameter (μm)	Mass of fibre (mg)	Length (mm)
1	241	40	0.6 ± 0.1	6.0 ± 0.1
2	483	80	2.1 ± 0.1	6.0 ± 0.1
3	604	100	3.5 ± 0.1	6.0 ± 0.1

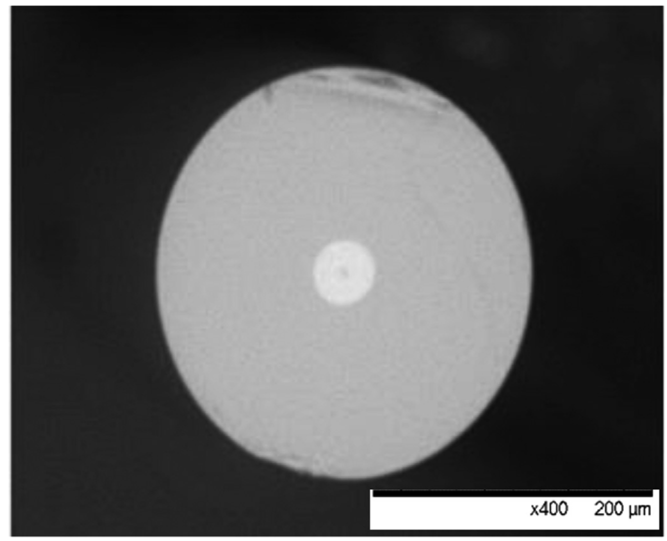

Fig. 1. Example cross-section of a cut cylindrical Ge-doped optical fibre, the image being obtained using a scanning electron microscope. At the centre of the fibre is the doped core, surrounded by annular cladding.

Fig. 1 shows an image of the typical cross-section of one such cylindrical Ge-doped optical fibre, obtained during SEM analysis. For screening purposes, a selection process to obtain uniform sensitivity fibres, the fibres were cut into 50 separate pieces, each 6 mm long, use being made of an optical fibre cleaver. The choice of 6 mm lengths was made in good part so that they could fit into the rod-type planchet of the Harshaw 3500 model TLD reader. To allow for normalization against mass, each separate sample was measured using an electronic beam balance that offers gram weight precision to 4 decimal places. A vacuum tweezer was used in handling the TL materials.

2.2. Annealing

The samples were first annealed for one hour in a furnace set at a temperature of 400 °C (Ong et al., 2009). during this process, the fibres were placed in a ceramic plate wrapped with aluminium foil. this annealing process Is crucial in standardising the TL sensitivities and background, removing any prior TL signal, primarily eliminating unstable low-temperature glow peaks (Hashim et al., 2009). Subsequently, the fibres were placed inside thin-walled (< 100 μm) 5 mm diameter gelatine capsules and placed in a light-tight box in order to minimize exposure to the ambient light