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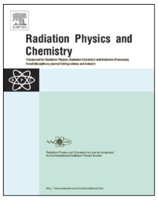

Radiotherapy dosimetry and the thermoluminescence characteristics of Ge-doped fibres of differing germanium dopant concentration and outer diameter

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HIGHLIGHTS

- We investigate the influence of elevated dopant concentration of fabricated Ge-doped optical fibres.
- Basic dosimetric characteristics of the TL media were obtained.
- 6% mole Ge-doped optical fibres offer promising thermoluminescence (TL) properties.

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ABSTRACT

We examine the influence of elevated dopant concentration on the thermoluminescence characteristics of novel Ge-doped silica fibres. Basic dosimetric characteristics of the TL media were obtained, including linearity, reproducibility, energy dependence, fading, minimum detectable dose and glow curve analysis, use being made of a ^{60}Co gamma irradiation facility (mean energy 1.25 MeV) and an electron linear accelerator producing photons at an accelerating potential of 6 and 10 MV. The 6 mol% Ge-doped fibres were found to provide TL response superior to that of 8- and 10 mol% Ge-doped fibres, both for fibres with outer diameter of 241 μm and 604 μm. Concerning reproducibility, obtained under three different test conditions, at $<10\%$ the 6 mol% Ge dopant concentration was observed to provide the superior coefficient of variation (CV). In regard to energy dependence, the 10 mol% Ge doped cylindrical fibres produced the largest gradient values at 0.364 and 0.327 for the 241 μm and 604 μm diameter cylindrical fibres respectively and thus the greatest energy dependency. Measured 33 days post irradiation; the 6 mol% Ge doped cylindrical fibres showed the least TL signal loss, at 21% for the 241 μm cylindrical fibre and $<40\%$ for the 604 μm cylindrical fibres. The results also revealed that the 6 mol% optical fibres provided the lowest minimum detectable dose, at 0.027 Gy for 6 MV photon beams. Evaluations of these characteristics are supporting development of novel Ge-doped optical fibres for dosimetry in radiotherapy.

1. Introduction

The basic dosimetric characteristics of commercially produced Ge-doped silica (SiO_2) telecommunication fibres including linearity with dose, fading and energy dependence have been investigated in detail by a number of workers (Abdulla et al., 2001; Hashim et al., 2009, 2010; Ramli et al., 2009; Abdul Rahman et al., 2010a, 2012; Asni et al., 2011; Issa et al., 2011; Yaakob et al., 2011a, 2011b, 2011c; Noor et al., 2011, 2012; Ong et al., 2009; Bradley et al., 2014; Ramli et al., 2015). Such studies have involved a variety of radiation sources, including photons, neutrons, electrons, alphas and protons.

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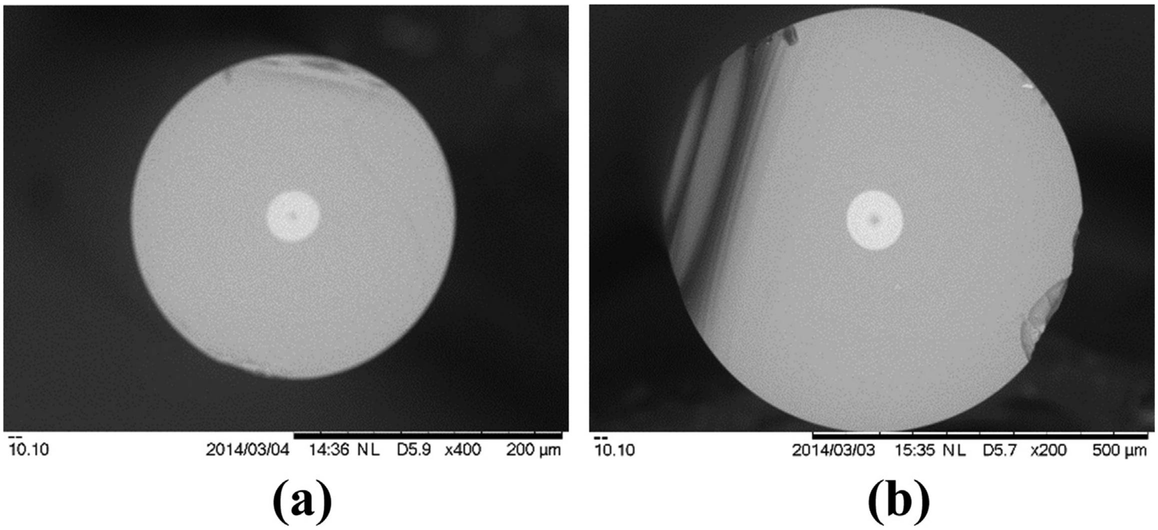

Fig. 1. SEM image of 241 µm (a) and 604 µm (b) diameter Ge-doped cylindrical SiO_2 fibres.

More recently the use of commercially available Ge-doped silica optical fibres in various clinical situations has been studied, including in interface radiation dosimetry (Abdul Rahman et al., 2012), synchrotron microbeam radiation therapy dosimetry (Abdul Rahman et al., 2010b), brachtherapy dosimetry (Issa et al., 2012), intensity modulated radiation therapy verification (Noor et al., 2010, 2011) and external beam radiotherapy dosimetry audits by mailed dosimeters (Noor et al., 2014).

In all such investigations it has been apparent that TL performance is influenced by the type of fibres, including the dimensions of the fibre core (the dopant being confined within the core). More generally, it is clear that dopant concentration is of importance in seeking optimal TL yield of TL media (Mobit and Kron, 2006), with low concentrations tending to produce less sensitive media but conversely one is also limited in the extent to which dopant concentration can be increased before self-absorption reduces TL yield, a matter which we investigate herein for tailor-made Ge-doped SiO_2 fibres. In such regard, prior work has concerned Ge-doped telecommunication fibres, Khanlary and Townsend (1993) finding the TL yield from absorbed energy to be greatest in those fibres containing the greater density of imperfections, whether in the form of dopants or defects induced by thermal and radiation energy. However, as previously mentioned and demonstrated by Yusoff et al. (2005) for sol-gel prepared media, beyond some optimum defects concentration the TL sensitivity of Ge-doped silica decreases. With increase in trap density reduced traps separation occurs, with commensurate increase in recombination, the light emitted being reabsorbed by electrons to be subsequently re-trapped elsewhere, a process generally referred to as self-absorption.

The aim of the present study is to investigate the effect of differing germanium dopant concentrations and dimensions of cylindrical fibres on the thermoluminescence characteristics of Ge-doped optical fibres that have been fabricated for radiotherapy dosimetry.

2. Materials and methods

2.1. Fabrication and designation of the cylindrical optical fibres

Preforms were fabricated using a standard modified chemical vapour deposition (MCVD) technique, with silica tetrachloride ($SiCl_4$), germanium tetrachloride ($GeCl_4$) bubbler and oxygen (O_2) being introduced into the tube in vapour form; the system was heated using a travelling burner operating at a temperature of approximately 1900 °C. Three Ge-doped silica fibres preforms with elevated germanium dopant concentrations (6, 8 and 10 mol%, referenced to the gas flow rate) have been fabricated for this study, the Ge deposition being produced in a Suprasil ultra-pure silica hollow-tube hollow substrate.

Prior to deposition, the substrate tube was etched with a flow of sulphur hexafluoride (SF_6) in order to clean the inner parts, allowing for improved chemical bonding between the doping elements and the substrate. At ~2200 °C, the Ge-doped tube preform was then collapsed down to make a solid-core Ge-doped preform (hereafter referred to as collapsed-Ge-doped-preform). These processes were applied for the three concentrations (6%, 8% and 10% weight gas flow rate) to fabricate three pairs of collapsed Ge-doped-preforms.

The collapsed-preforms were then used to draw down traditional cylindrical optical fibres (hereafter referred to as cylindrical fibres) at the drawing facilities available at the University of Malaya. Two different sizes of fibres, i.e., small and large outer diameters (~241 and ~604 µm, respectively) were produced. The desired diameters were obtained by considering the simplified mass conservation equation defined as follows:

$$v_{in}\,A_{in} = v_{out}\,A_{out} \tag{1}$$

with v_{in} the feeding speed, v_{out} the drawing speed and A_{in} and A_{out} the preform cross sectional area and output fibres cross sectional area respectively. The drawing process was initiated through the formation at 2100 °C of a gravity-fed glass drop from the lower end of the preform, followed by the pulling of the fibres into the desired diameter, adjusting the feeding and drawing speed and appropriate furnace temperature to satisfy a pulling tension within the range 30–50g. All of the optical fibres were fabricated without the polymer coating conventional for optical fibres so as to be suitable for dosimeter applications. Fig. 1a and b show examples of a small and large diameter cylindrical optical fibres, respectively. The actual cylindrical fibres core and cladding diameters and their weights are presented in Table 1 for the three Ge concentrations.

2.2. Irradiation and readout

Preparation of the optical fibres for irradiation has been detailed by Noor et al. (2014). For irradiation a Varian Clinac Linear Accelerator located at the University Malaya Medical Centre was