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Enhancing the radiation dose detection sensitivity of optical fibres

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HIGHLIGHTS

- Improved TL yield of irradiated silica-based optical fibres.
- A range of forms of silica fibre have been fabricated.
- Large TL yield enhancement strongly suggests surface-strain defects generation.
- Novel forms with TL yields many times that of undoped capillary-fibre.

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ABSTRACT

A method for improving the thermoluminescence (TL) yield of silica-based optical fibres is demonstrated. Using silica obtained from a single manufacturer, three forms of pure (undoped) fibre (capillary-, flat-, and photonic crystal fibre (PCF)) and two forms of Ge-doped fibre (capillary- and flat-fibre) were fabricated. The pure fibre samples were exposed to 6 and 21 MeV electrons, the doped fibres to 6 MV photons. The consistent observation of large TL yield enhancement is strongly suggestive of surface-strain defects generation. For 6 MeV irradiations of flat-fibre and PCF, respective TL yields per unit mass of about 12.0 and 17.5 times that of the undoped capillary-fibre have been observed. Similarly, by making a Ge-doped capillary-fibre into flat-fibre, the TL response is found to increase by some 6.0 times. Thus, in addition to TL from the presence of a dopant, the increase in fused surface areas of flat-fibres and PCF is seen to be a further important source of TL. The glow-curves of the undoped fibres have been analysed by computational deconvolution. Trap centre energies have been estimated and compared for the various fibre samples. Two trap centre types observed in capillary-fibre are also observed in flat-fibre and PCF. An additional trap centre in flat-fibre and one further trap centre in PCF are observed when compared to capillary fibre. These elevated-energy trap centres are linked with strain-generated defects in the collapsed regions of the flat fibre and PCF.

1. Introduction

To-date, wide-ranging investigations have been made of the radiation dose detection capability of various types of passive dosimeters (Bradley et al., 2014; DeWerd et al., 2014; Halperin et al., 2014; Jafari et al., 2014; Marcazzó et al., 2013; Page et al., 2014; Pugliesi et al., 2014; Sahare et al., 2014; Salah et al., 2011; Twardak et al., 2014). The type of base material and constituent concentrations are the dominant factors influencing dosimeter performance. In recent years several materials have been the basis of new dosimeters with sensitivity and/or properties that improve upon existing capabilities, as for instance glass-based dosimeters doped with rare-earth materials. Examples of dopants and compounds include aluminium, copper (I), germanium, manganese, tin, zinc (Yusoff et al., 2005), lithium and barium (Timar-Gabor et al., 2011), zirconium oxide (ZrO_2) (Salah et al., 2011), copper activated calcium borate (CaB_4O_7:Cu) nanocrystals (Erfani Haghiri et al., 2013a), manganese doped calcium tetraborate (CaB_4O_7:Mn) nanocrystal (Erfani Haghiri et al., 2013b), lithium potassium borate glass doped with titanium oxide (TiO_2) and magnesium oxide (MgO) (Alajerami et al., 2013), dipotassium yttrium fluoride

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(K_2YF_5) crystals doped with samarium (Sm^{3+}) and terbium (Tb^{3+}) ions (Marcazzó et al., 2013). An additional form of glass based dosimeter that has attracted considerable and growing attention are silica-based optical fibres (Bradley et al., 2014), offering a range of advantages over other passive dosimeter types. These include high spatial resolution, by virtue of their very small size ($\sim$125 μm) relative to many other forms of dosimeter, linear dose response in both the low and high dose regimes (Alawiah et al., 2013a, 2013b; Girard et al., 2013), capability for real time remote monitoring (Fernandez et al., 2008; O'Keeffe et al., 2007), lower cost (Espinosa et al., 2006) and relatively high dose sensitivity (Abdul Sani et al., 2014).

A standard optical fibre has a core with higher refractive index compared to the cladding, typically provided for by doping with rare earth elements. The structural defects thereby produced within the fibre core represent the main basis for TL radiation dosimeter applications. Over and above the defects generated by the dopant impurities in the core, additional defects are induced in the optical fibre core during the fibre drawing process, influenced by fibre tension and the neck-down shearing effect (Friebele et al., 1976; Hanafusa et al., 1987; Hibino and Hanafusa 1986; Lee et al., 1998). These defects provide additional dose detection sensitivity of optical fibres, a situation not observed in sol–gel based or other forms of glass dosimeter. Other than these types of defects contributed from the choice of elements and their concentration doped in optical fibres or from the fibre drawing condition, additional new defects can be generated in optical fibres by fusing optical fibre wall surfaces during the drawing process. To-date, such defect generating mechanisms have not been harnessed in a controlled way in producing elevated sensitivity optical fibre TL dosimeters, a matter to be addressed in this paper.

The approach is entirely novel, to the best of our knowledge there being no other published reports showing such method for improvement in the TL yield of undoped optical fibres. The proposed method can be further applied to doped optical fibre preforms (the doped silica starting material, prior to fibre production) to further enhance TL yield. The main objective of this study is to demonstrate the proposed method for improving dose detection sensitivity in optical fibres, both pure and in silica fibre of arbitrary dopant concentration. For this purpose, three types of undoped optical fibres namely capillary optical fibre, flat fibre, and photonic crystal fibres, have been fabricated and tested for radiation dose detection. The thermoluminescence (TL) responses of these fibres are compared under 6 and 20 MeV electron iradiation and their glow curves are presented. Finally, the TL response of a doped capillary and flat fibres are presented and compared with that of the undoped capillary and flat fibres.

2. Materials and methods

2.1. Fibre fabrication

Five different types of optical fibre have been fabricated for this study (Fig. 1), three made using undoped preform and two with doped preform. The undoped fibres include capillary optical fibre, flat fibre, and photonic crystal fibre are shown in Fig. 1a–c, respectively. The doped fibres are capillary and flat fibre are shown in Fig. 1e and f, respectively. The undoped fibres are made from an ultra-pure silica glass tube termed Suprasil-300 (Heraeus Holding GmbH, Hanau, Germany), with outer and inner diameter of 25 mm and 19 mm, respectively. The doped fibres are made with ultra-pure glass tube as the substrate (obtained from the same manufacturer) and the doping is applied using the modified chemical vapour deposition (MCVD) process. Germanium of about 8.5% by weight (referenced to the applied gases in the MCVD process) were applied to the fibre preform. It should be noted that the concentration and material used in this study has been adopted with the restrictive intent of demonstrating the utility of the proposed method. As such, the doping recipe used herein does not

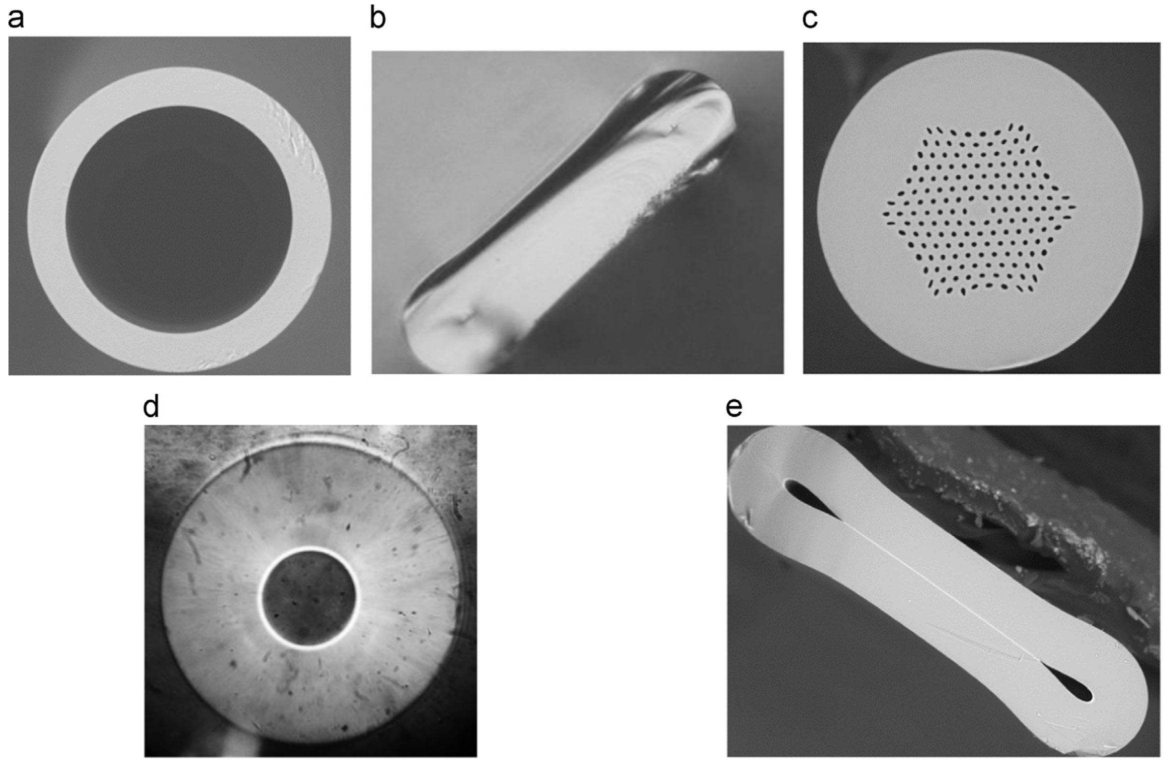

Fig. 1. Optical fibre images: (a) undoped capillary fibre; (b) undoped flat fibre; (c) undoped PCF; (d) doped capillary fibre; and (e) doped flat fibre. See text for information on the dimensions of the various fibres.