Sensors and Actuators A 270 (2018) 72–78

Contents lists available at ScienceDirect

Sensors and Actuators A: Physical

journal homepage: www.elsevier.com/locate/sna

Radioluminescence of Ge-doped silica optical fibre and Al_2O_3:C dosimeters

A.K.M. Mizanur Rahman[a,c,*], Mahfuza Begum[b,c], Mahbuba Begum[a], H.T. Zubair[c], H.A. Abdul-Rashid[c], Z. Yusoff[c], D.A. Bradley[d,e]

[a] Health Physics Division, Atomic Energy Centre, Bangladesh Atomic Energy Commission, 4 Kazi Nazrul Islam Avenue, Shahbag, Dhaka 1000, Bangladesh
[b] Health Physics & Radioactive Waste Management Unit, Institute of Nuclear Science and Technology, Atomic Energy Research Establishment, Bangladesh Atomic Energy Commission, Ganakbari, Savar, Dhaka, Bangladesh
[c] Fibre Optics Research Centre, Faculty of Engineering, Multimedia University, Jalan Multimedia, 63100 Cyberjaya, Malaysia
[d] Department of Physics, University of Surrey, Guildford GU2 7XH, United Kingdom
[e] Sunway University, Institute for Health Care Development, 46150, PJ, Malaysia

ARTICLE INFO

Article history:
Received 25 September 2017
Received in revised form 8 December 2017
Accepted 15 December 2017
Available online 19 December 2017

Keywords:
Radioluminescence
Ge-doped optical fibre
NanoDots Al_2O_3C
Afterglow

ABSTRACT

Using an electron accelerator producing a 6 MV X-ray photon beam several experimentally observed excitation phenomena that are associated with radioluminescence (RL) have been investigated, the signal originating from a Ge-doped silica optical fibre and commercial nanoDot Al_2O_3:C dosimeters. Using PMMA optical communication fibres the RL signals have been guided from the beam-delivery room out to the readout instrumentation that has been located beyond the concrete maze providing effective radiation shield. Ge-doped silica fibre memory effects and afterglow (phosphorescence) were compared with that of the commercial Al_2O_3:C dosimeter. Immediately following RL, observation was made of the decay curves of the afterglow signal of Al_2O_3:C. Conversely, there was little practically observable afterglow for the Ge-doped fibre used for the majority of present investigations (the dopant concentration of this being 3.6 wt %). Among three different concentration of Ge-doped fibres that were subsequently investigated in a follow-up study, the intensity of afterglow was found to be greatest for the more highly doped concentration (7.0 wt % Ge), with progressive reduction of the effect for the Ge 4.7 wt % and Ge 3.6 wt % fibres. These observations can be compared against the much more marked RL memory effect observed using the Al_2O_3:C chips. Current results point to the Ge-doped silica optical fibre being a highly promising candidate for real-time RL dosimetry and sensing.

1. Introduction

Radioluminescence (RL), a phenomenon occurring during the interaction of ionizing radiation with optically transparent matter, has been studied over the past three decades, pointing to RL being a potentially strong candidate for real-time radiation dosimetry. Investigations of RL applied to real-time medical dosimetry are embryonic but of growing interest, increasingly being used as an instance in real-time dose assessment in radiotherapy [1]. RL fibre dosimetry is of particular interest herein, now recognized as an attractive technique [2] and one that can be further strengthened by seeking strong suppression of the noise component towards approaching a noise-free signal. This includes the RL signal needing to be manifestly free of spurious spectral super positions, allowing realization of a simple and practical dosimeter by avoiding the need for subtraction or correction algorithms [3]. Instantaneous radiation dose verification can be achieved through conditioning of the RL signal, forming a reliable source of real-time information. In order to be useful for such purposes, materials need to be sensitive and to have RL signal characteristics that are consistent, distinguishable and linearly responsive with the incident radiation. This is the focus of the present paper.

Fibre-coupled luminescence dosimetry represents the state-of-the-art, based on RL/OSL (Optically Stimulated Luminescence) techniques, as currently being applied in the field of medical dosimetry. Here, a small-volume luminescence generating mate-

---

[*] Corresponding author at: Health Physics Division, Atomic Energy Centre, Bangladesh Atomic Energy Commission, 4 Kazi Nazrul Islam Avenue, Shahbag, Dhaka 1000, Bangladesh.
E-mail address: mizanbaec14@gmail.com (A.K.M.M. Rahman).

https://doi.org/10.1016/j.sna.2017.12.032

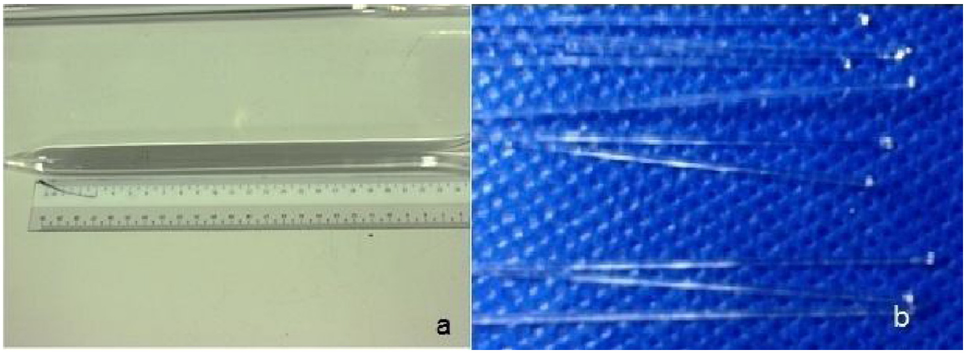

Fig. 1. (a) Preform; (b) 604 μm diameter fibres produced from the preform.

rial is attached to a long fibre cable to obtain real-time information at a distance. However, two specific aspects may represent limiting factors to the performance of the currently adopted carbon-doped aluminium oxide Al_2O_3:C RL dosimetry system [4] as well as to other forms of scintillating material for use in radiotherapy: (i) the "stem effect", spurious luminescence originating as a consequence of the irradiation of the signal carrying fibre, and; (ii) the "memory effect", RL sensitivity increasing during prolonged exposure to ionizing radiation. While in a recent study it was seen that the RL intensity of BeO gives rise to reduced phosphorescence (afterglow) and stem effect [5], its toxicity is one drawback in its use in medical dosimetry, with as an instance the potential for causing chronic lung disease (chronic beryllium disease) [6]. In use of Al_2O_3:C several researchers [7–10] have sought to deal with the growth in photon counts from Al_2O_3:C over the period of irradiation by using mathematical modelling or other techniques such as pre-irradiating the Al_2O_3:C crystal with a certain level of dose (such as 20 Gy).

Doped silica optical fibres have shown promising RL properties for on-line dosimetry (real-time, prompt evaluation), with the distinct possibility and promise of remote monitoring at relatively large distances from the radiation source. Interest in such dosimeters is growing fast [11–13], drawing favourable attention owing to their exceptional thermoluminescence (TL) properties. Thus said, to-date the lack of online monitoring capability has limited their use, particularly in radiotherapy [14–19]. The luminescence properties of Ge-doped SiO_2 fibre are affected by dopant concentration along the core of the fibre [20]. It is also known that all glasses yield prompt luminescence giving rise to a degree of RL following irradiation by ionizing radiation. In silica optical fibre, the introduction of controlled amounts of dopant defects, either intrinsically or extrinsically, have been shown to significantly enhance their sensitivity to radiation [21], with a high yield of luminescence being a pre-requisite for any good quality RL dosimeter. Indeed, optimal incorporation of luminescence centres in the host material is highly desirable, the local environment around the dopant and doping concentration being two factors playing an important role in determining the radiation response [22].

In the present work, under photon beam irradiation using a medical linear accelerator, effects such as memory, afterglow and the plateau of RL nature have been investigated, comparison being made between lab-fabricated Ge-doped silica optical fibre dosimeters and commercial Al_2O_3:C. The RL responses were acquired using a prototype photo-multiplier tube (PMT)-based reader system. In so doing, it is expected that the outcome of present study will pave the way towards formulating a fuller understanding of the RL characteristics of these materials, also laying down avenues towards pursuing further research into the use of Ge-doped optical fibres as real-time dosimeters.

2. Material and methods

2.1. Dosimeter samples preparation

For dosimetric purposes, the Ge-dopant in the SiO_2 core is vitally important. Concentrations of Ge in commercial silica fibres have previously been suggested to be sub-optimal in regard to the TL yield from irradiated fibres [23], also therefore potentially limiting in respect of their RL yield. Thus to investigate the potential dependence of the RL yield on dopant concentration, optical fibres with greater Ge dopant concentrations than those commercially available have been fabricated, with details as provided below. Three different concentrations of Ge-doped silica have been chosen for the project, each fibre produced from the variously doped silica being purposely pulled down to a diameter of 604 μm, a dimension somewhat greater than that we have typically produced for TL studies, for which we have used values of <150 μm. Here it can be further noted that the greater the cross-sectional area of the cylindrical fibre the greater should be the number of traps [15], a diameter of 604 μm also being compatible with the larger core size signal-carrying polymethyl methacrylate (PMMA) fibre.

The Ge-doped fibre dosimeters used in this study were fabricated in-house at Multimedia University, Malaysia use being made of a Modified Chemical Vapour Deposition facility. A standard procedure was followed, with use being made of $GeCl_4$ and $SiCl_4$ precursors and very high purity O_2 gas used as the carrier. Amorphous silica (from the homogeneous gas phase reaction between $SiCl_4$ and O_2 gas at ≈1300 °C) was deposited inside a rotating high-purity Suprasil F300 (silica) tube (Heraeus Quarzglass GmbH) to form the soot. Oxides of Ge are also deposited at this stage, with a much lower retention than the oxides of silica (≈50% for silica and ≈5–15% for germania). Thus, it forms a mixture that contains Ge atoms incorporated into a silica host. The soot is sintered at much higher temperatures (≈1900 °C) and then collapsed into a solid cylindrical tube at ≈2100 °C. This ensures the formation of a Ge-doped silica core. In this way, three different concentrations of Ge-doped preforms were prepared with variation of flow of O_2 gas into the $GeCl_4$ bubbler along with flow O_2 gas with $SiCl_4$ bubbler. The manufacture of an optical fibre involves two steps: preform fabrication and the drawing process. The preforms produced in the fabrications stage were subsequently pulled into fibre of total diameter 604 μm as previously mentioned, making use of the pulling tower available at the University of Malaya. An example preform and example fibres are shown in Fig. 1.

The RL sensor probes were then prepared from the Ge-doped optical fibres, using Ge-doped fibre lengths of some 2 cm coupled with PMMA fibre of core diameter ~1 mm (SH4001 Super ESKA, Mitsubishi, Japan) and of length 10 m. These RL probes were inserted into a polyoxymethylene (Delrin) ferrule, with one end aligned with the core of polished PMMA fibre. The details of the