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Short Communication

Real-time dosimetry in radiotherapy using tailored optical fibers

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HIGHLIGHTS

- Tailored-made Ge-doped optical fiber for radioluminescence based dosimetry.
- Sensitivity to photon and electron beam in radiotherapy range.
- No plateau effect compared to Al_2O_3:C.
- Dose rate independent for case of absorbed dose measurement.

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ABSTRACT

Real-time dosimetry plays an important role for accurate patient-dose measurement during radiotherapy. A tiny piece of laboratory fabricated Ge-doped optical fiber has been investigated as a radioluminescence (RL) sensor for real-time dosimetry over the dose range from 1 Gy to 8 Gy under 6 MV photon beam by LINAC. Fiber-coupled software-based RL prototype system was used to assess essential dosimetric characteristics including dose response linearity, dose rate dependency, sensitivity, repeatability and output dependence on field sizes. The consistency level of RL photon counts *versus* dose rate was also compared with that of standard Al_2O_3:C chips. Sensitivity of Ge-doped fiber were found to be sufficiently sensitive for practical use and also provided linear dose responses for various dose rates from 100 cGy/min to 600 cGy/min using both 6 MV photon and 6 MeV electron beams. SEM-EDX analysis was performed to identify Ge-dopant concentration level within the optical fiber RL material. Accumulated doses were also estimated using simple integral technique and the error was found to be around less than 1% under dissimilar dose rates or repeat measurements. The evaluation of the Ge-doped optical fiber based RL dosimeter system indicates its potential in medical dosimetry.

1. Introduction

Advanced cancer treatment modalities such as volumetric modulated arc therapy and intensity modulated radiotherapy has made possible highly conformal treatment plans with reduced danger to healthy tissues from incoming radiation. The reliability of dose verification for these complex clinical routine requires real-time *in vivo* dosimetry (Chiodini et al., 2009). Specially made Ge-doped fiber optic RL dosimetry system seems to be a suitable option to meet the requirements because of a number of features it offers: (i) a small sensor with high spatial resolution, (ii) no electrical component near the patient, (iii) real-time sensing, (iv) fast readouts, (v) no interference effect by electromagnetic waves from clinical linear accelerators, (vi) water impervious (Begum et al., 2015) enabling intracavity measurements, etc. Referring to the code of practice IAEA (TRS) 398, the variation between planned and delivered doses must remain within 3%. If the differences go above 5%, the reasons for discrepancy must be checked and the treatment should not be continued until the problem is addressed (IAEA Technical Report Series, 2000).

RL is the instantaneous emission of light from dosimetric materials exposed to ionizing radiation. According to energy band theory the incident radiation excites electrons into the conduction band, leaving hole states near the valence band. Some electrons recombine with holes at the recombination center (energy levels

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between the valance and conduction band where electrons lose all their energy before returning to the valence band) releasing characteristic RL light owing to relaxation of electronic states (Chung et al., 2015; Yukihara and McKeever, 2011). Generally the intensity of RL yield (measured in photon counts) is proportional to the dose rate of incident radiation, making it suitable for real-time dosimetry.

In recent years RL dosimetry is increasingly used for real-time dose assessment in radiotherapy (Molina et al., 2013). Since RL dosimetry provides for *in-situ* monitoring of the dose-rate, direct feedback can be provided to the medical physicists and oncologists. Any malfunction in the radiation sources can be immediately identified, enabling rapid safety precaution intervention (Ciocca et al., 2012).

For a particular dose rate RL intensity over the entire irradiation session should be constant. Until now the carbon-doped aluminum oxide (Al_2:O_3:C) crystal has been the basis of most common commercially available RL/OSL sensors. However, RL signal from Al_2:O_3:C crystal demonstrates a plateau effect (Andersen., 2011; Santiago et al., 2012; Beierholm et al., 2008). Some other crystalline phosphors have also been reported to have shown RL sensitivity, albeit, inconsistent (Santos et al., 2013; Santiago et al., 2009). This inconsistency arises from the crystal owing to their physical structure (Andersen et al., 2010). The major contribution of the plateau effect is from fluorescence resulted owing to limitations of the physical structure of the crystal (Chiodini et al., 2014). Therefore, the search for new scintillators having constant RL characteristics and well-suited for use with optical waveguides is ongoing.

A laboratory-fabricated Ge-doped silica optical fiber sample was used as the RL sensor and the signal was compared to that of use of a commercial Al_2O_3:C crystal. RL responses were acquired by an in house assembled PMT system. Study has been made of the quality of responses to both electron and photon beams which have shown to be consistent for any specified dose rate. A comprehensive discussion of the findings is done in the following sections.

2. Materials and methods

2.1. Scintillator fiber fabrication

The probe (Ge-doped silica optical fiber, 604 µm total diameter, 100 µm core diameter) used in this study as the dosimeter was fabricated using Modified Chemical Vapour Deposition (MCVD) method. The details of fabrication process are described in more relevant articles (Rahman et al., 2015; Mat-Sharif et al., 2013). This particular method was used because of its availability to the authors. It is important to acknowledge that other methods for doping Ge into SiO_2 may result in different dosimetric properties which may be better, or worse.

2.2. SEM-EDX analysis of fabricated fiber

The Ge dopant distribution in the core of silica optical fiber creates trap center which plays a vital role in such dosimetric techniques. Tailor-made fiber was manufactured to fulfill the requirements with a desired concentration of Ge doping not usually available in the core of commercial telecommunication optical fiber. SEM-EDX analysis (30 kV electrons) of Ge-doped optical fiber was carried out to confirm the relative presence of Ge dopant in the silica fiber core. Fig. 1 represented that deposition occurs in layers during MCVD fiber fabrication process; bright rings represent Ge concentrated area and dark rings show relatively less Ge and more SiO_2. The intensity of the spectrum was recorded and analyzed to find the weight % of the fiber constituent elements (*i.e.*, Ge, O and Si) also shown in the figure.

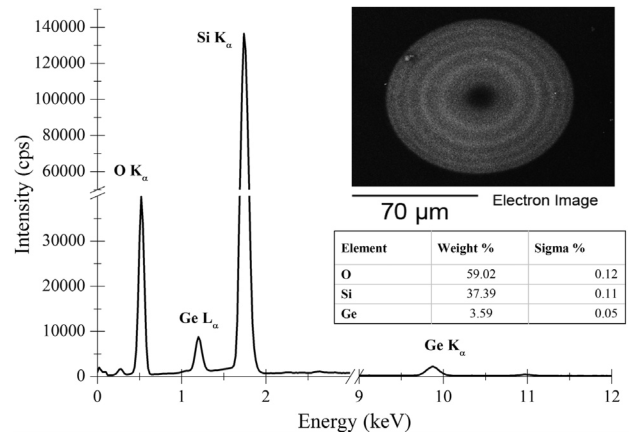

Fig. 1. SEM-EDX analysis of tailor-made 100 µm core Ge-doped optical fiber.

2.3. Probe preparation

The RL sensor probes were prepared from the fabricated Ge-doped optical fiber of about 2 cm lengths and coupled with the core of 1 mm PMMA (SH4001 Super ESKA PMMA of numerical aperture 0.5) optical fiber of length 10 m as shown in Fig. 2. The piece of Ge-doped scintillator fiber was properly lined up with the core of light guiding PMMA fiber to ensure maximum signal transfer. The active volume of the probe was then wrapped with opaque black tape to avoid incoming ambient light. For comparison, the RL signal from a segment of Al_2O_3:C crystal attached to the edge of the same type of PMMA fiber was also captured.

2.4. Instrumentation

During irradiation, the RL signal generated in the dosimeter sensor was transmitted through the PMMA fiber and reflected by a low pass 505 nm dichroic mirror to a photomultiplier tube. A band pass filter from 315 to 445 nm was placed in front of the PMT, reducing further noise. A photon counting unit was connected to the computer to display the RL signal through National Instruments (NI) Labview interface. A schematic of the RL reader system is shown in Fig. 3.

2.5. Irradiation

RL measurement for Ge-doped optical fiber sensor was performed with photon (6 MV) and electron (6 MeV) beams from clinical LINAC (Varian 2100CD). In both cases the source to surface distance were kept at 100 cm and the field size was set at (10×10) cm^2. The probe was placed at the center of the radiation

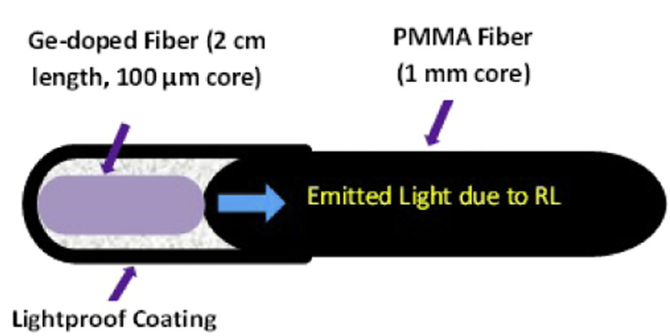

Fig. 2. Diagram detailing the assembly of the tip of the fiber optic dosimeter probe.