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Angular dependence of optical fibre thermoluminescent dosimeters irradiated using kilo- and megavoltage X-rays

F. Moradi[a,*], N.M. Ung[b,*], G.A. Mahdiraji[c,d], M.U. Khandaker[a], A. Entezam[a], M.H. See[e], N.A. Taib[e], Y.M. Amin[a], D.A. Bradley[f,g]

[a] Department of Physics, University of Malaya, Kuala Lumpur, Malaysia
[b] Clinical Oncology Unit, Faculty of Medicine, University of Malaya, Kuala Lumpur, Malaysia
[c] School of Engineering, Taylor's University, Subang Jaya, Selangor, Malaysia
[d] Flexilicate Sdn. Bhd., University of Malaya, Kuala Lumpur, Malaysia
[e] Department of Surgery, Faculty of Medicine, University of Malaya, Kuala Lumpur, Malaysia
[f] Department of Physics, University of Surrey, Guildford, Surrey, UK
[g] Sunway University, Institute for Health Care Development, Petaling Jaya, Malaysia

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ABSTRACT

Prior investigation of the suitability of optical fibres as thermoluminescent dosimeters for diagnostic and therapeutic radiation beams has not included detailed study of the effect of beam angulation. Present study of such response has made use of optical fibre of cylindrical shape, exposed to 30 kVp photons from an X-ray tube and a 6 MV photon beam from a linear accelerator. The effect of the irradiation medium was also studied, comparing response free-in-air against on-surface and in-depth irradiations through use of *solid-water*™ phantom. Standard optical fibre (ø =125 µm) shows non-uniform response to beams delivered at different incident angles. Monte Carlo simulation provided support for the experimental results, also obtaining absorbed dose in the fibres. The results of free-in-air condition simulated with mono-energy beam show angle-independent response for photons within the energy range 100–500 keV, while dependency has been observed for beam energies of < 100 keV and > 500 keV. Experimentally, the angular dependency up to 35% is observed in 30 kVp free-in-air, while in 6 MeV beam, this is reduced to 20%, 10%, and 3% in free-in-air, on phantom surface, and in-depth conditions, respectively. The observations have been justified by considering the range of secondary electrons in the dosimeter and the effect of scattered radiation.

1. Introduction

In recent years, optical fibre thermoluminescence dosimeters (TLDs) have been the focus of much development, recognition being made with respect to their adaptable characteristics and potential use in radiation therapy and other applications (Bradley et al., 2012). Thus said, practical dosimetry demands yet still more detailed knowledge concerning the various parameters that may have discernible influence on their accuracy. Past studies have most typically investigated the generally dominant characteristics of such sensors, including sensitivity and dose-response linearity, less detailed investigation being made of the response of the fibre dosimeters with respect to incident beam direction. In this regard, use of the optical fibre as a practical TL dosimeter typically involves the positioning of small sections of fibre (usually of 5 mm length), either on the smooth surfaces of a phantom, uneven body skin or even different sites inside tissues for *in-vivo* dosimetry applications. In case of complicated treatment fields, personal dosimetry or quality assurance in diagnostic applications etc., the angle of incidence of the irradiated beam can change dramatically. Such a situation demands characterization of the angular dependencies of the fibre dosimeter.

The effect of changes in angle of incidence have been studied for different types of dosimeters including ionization chambers, commercial TLDs, MOSFETs (metal oxide semiconductor field effect transistors), OSLDs (optically stimulate luminescence dosimeters) and even more recently developed systems such as plastic fibre-optic dosimeters. The angular dependence of a detector arises from the physical shape, asymmetries in this and inherent characteristics due to the special designs. Studies by Vohra et al. (1980), Hua Jin et al. (1992) and Guimaraes et al. (2007) have reported significant angular dependencies for $CaSO_4$, LiF and LiF/CaF_2 TLDs respectively, with the addition of filters in order to control energy dependence. Dong et al. (2002)

* Corresponding author.
E-mail addresses: morfar1982@gmail.com (F. Moradi), nm_ung@um.edu.my (N.M. Ung).

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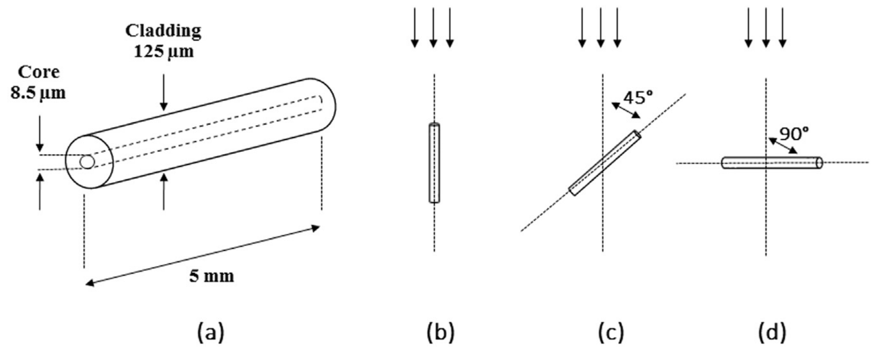

Fig. 1. Optical fibre geometry (a) and setup for angular dependence experiments (b-d).

reported alteration of the angular dependence of TLD-100H (LiF: Mg,Cu,P) with change in photon energy and also mentioned the asymmetric construction of the MOSFET to be responsible for its angular dependence. Jursinic (2007) and Kerns et al. (2011) studied the angular dependence of disk-shaped OSLDs (0.2 mm thickness with diameters of 7 & 5 mm respectively) in water equivalent phantoms, not finding any significant angular dependence. These all suggest angular dependence of the dosimeter to be affected not only by physical asymmetry but also by the energy of the radiation beam as well as the irradiation medium.

Two previous investigations have concerned the angular dependence of optical fibre TLD (Noor et al., 2014; Entezam et al., 2016). In both studies the possibility of asymmetric doping or microcrystalline structure of optical fibre have been suggested to be the cause of angular dependence in TL response, TL yield being investigated for a cladding/core diameter of 116/9 and 270/42 µm respectively. The results revealed immeasurable change in fibre response as a result of step by step rotation of the gantry of the linear accelerator teletherapy machine, from 0 to 360° around the samples, with the latter positioned perpendicular to the incident beam direction. However, the angular dependence of the optical fibre in non-perpendicular situations, a quite probable matter in practical applications, has yet to be studied. Since the potential use of these detectors in both the diagnostic and therapeutic energy ranges has been demonstrated (Issa et al., 2011; Noor et al., 2014), present study has investigated the effect of change in radiation incident angle with respect to fibre axis for both kilovoltage and megavoltage photon beams, also in different irradiation media. Monte Carlo simulations were used as the main tool in seeking support for the experimental observations.

2. Materials and methods

2.1. Sample preparation

Single mode communication optical fibre (SMF) has been used in this study, with diameters of 125/8.5 µm for the silica cladding/Ge-doped core. An elemental and structural characterization of this fibre type has been reported by Mahdiraji et al. (2015), through use of an EDX (energy dispersive X-ray) facility attached to a SEM (scanning electron microscope). The mean concentration of the doped germanium (Ge) SMF-1 core in silicon dioxide (SiO_2) was found to be 4.9%, surrounded by pure SiO_2 cladding. Chloroform was used to remove the outer polymer coat of the optical fibre. The fibres were then cut using a specially modified fibre cleaver (FC-6M, SUMITOMO ELECTRIC, Japan), preparing 5 mm length fibre samples as typically adopted in all recent studies, guided in part by the size of the heating tray of the TLD reader as well as the need to provide for ease of handling. The fibre samples have been annealed in accord with usual practice prior to irradiation in order to eliminate any thermal or irradiation history and to remove any low temperature peaks in TL glow curve, these being subject to a high degree of fading. This was accomplished by heating the fibres at 400 °C for 1 h in a preheated furnace and then allowing them to relax by gradual cooling, down to room temperature.

2.2. Irradiation setup

In this work both kVp and MV photon beam irradiations were performed. A portable X-ray generator ERESCO (model 200 MF4-R, General Electric, Germany) was made use of in irradiating the optical fibre samples with photons generated at 30 kVp, the tube current being 10 mA, the maximum possible for this tube. The stability of the output from the X-ray tube was checked using an ionization chamber (TM31013, PTW). Although a significant absorption at low keV energy range may happen in the chamber walls, it could still be used to monitor the reproducibility and linearity of the output dose with time. Five absorbed doses were arranged for, in the range 0.2–1 Gy. During the calibration stage, the fibres were positioned at an incident angle of 90°. A schematic of the irradiation geometry of the SMF-1 samples is shown in Fig. 1.

A total of 10 samples were irradiated for each dose value with a

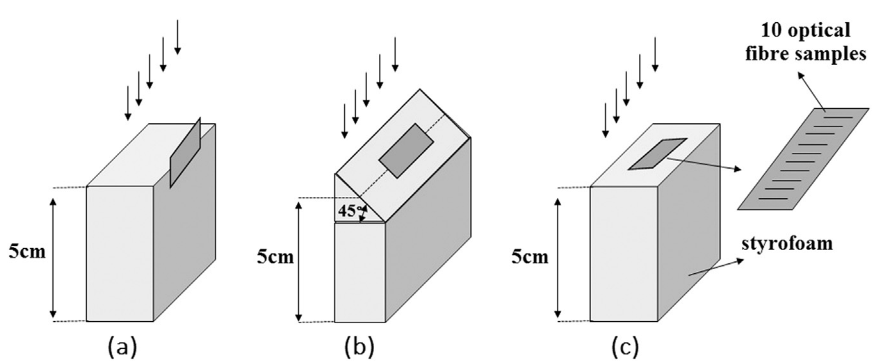

Fig. 2. Schematic diagram of experimental setup for free-in-air irradiations, for both keV and MeV X-ray exposures. (a) incident angle =0°, (b) incident angle =45° and (c) incident angle =90°.