Applied Radiation and Isotopes 100 (2015) 79–83

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

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

Thermoluminescence characteristics of Ge-doped optical fibers with different dimensions for radiation dosimetry

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

[a] Faculty of Engineering, Multimedia University, 63100 Cyberjaya, Selangor Darul Ehsan, Malaysia
[b] Bangladesh Atomic Energy Commission, Bangladesh
[c] Telekom Research and Development, Lingkaran Teknokrat Timur, 63000 Cyberjaya, Selangor Darul Ehsan, Malaysia
[d] Department of Physics, Faculty of Science, University of Malaya, 50603 Kuala Lumpur, Malaysia
[e] Department of Physics, University of Surrey, Guildford GU2 7XH, UK

HIGHLIGHTS

- Five different dimension Ge-doped silica optical fibers were used as TL-material.
- The effective atomic number (Z_{eff}) of the fiber samples was in the range 13.25–13.69.
- The TL response of the samples was compared against standard TLD-100 chips and commercial Ge doped optical fibers.
- The largest core optical fiber (100 μm) provided TL yield some 4 times greater than that of the commercial Ge-doped optical fiber.

ARTICLE INFO

Article history:
Received 25 July 2014
Received in revised form
30 October 2014
Accepted 30 October 2014
Available online 7 November 2014

Keywords:
Ge-doped optical fiber
Radiation dosimetry
Effective atomic number
SEM–EDX analysis

ABSTRACT

Important thermoluminescence (TL) properties of five (5) different core sizes Ge-doped optical fibers have been studied to develop new TL material with better response. These are drawn from same preform applying different speed and tension during drawing phase to produce Ge-doped optical fibers with five (5) different core sizes. The results of the investigations are also compared with most commonly used standard TLD-100 chips (LiF:Mg,Ti) and commercial multimode Ge-doped optical fiber (Yangtze Optical Fiber, China). Scanning Electron Microscope (SEM) and EDX analysis of the fibers are also performed to map Ge distribution across the deposited region. Standard Gamma radiation source in Secondary Standard Dosimetry Lab (SSDL) was used for irradiation covering dose range from 1 Gy to 10 Gy. The essential dosimetric parameters that have been studied are TL linearity, reproducibility and fading. Prior to irradiation all samples ~0.5 cm length are annealed at temperature of 400 °C for 1 h period to standardize their sensitivities and background. Standard TLD-100 chips are also annealed for 1 h at 400 °C and subsequently 2 h at 100 °C to yield the highest sensitivity. TL responses of these fibers show linearity over a wide gamma radiation dose that is an important property for radiation dosimetry. Among all fibers used in this study, 100 μm core diameter fiber provides highest response that is 2.6 times than that of smallest core (20 μm core) optical fiber. These fiber-samples demonstrate better response than commercial multi-mode optical fiber and also provide low degree of fading about 20% over a period of fifteen days for gamma radiation. Effective atomic number (Z_{eff}) is found in the range (13.25–13.69) which is higher than soft tissue (7.5) however within the range of human-bone (11.6–13.8). All the fibers can also be re-used several times as a detector after annealing. TL properties of the Ge-doped optical fibers indicate promising applications in ionizing radiation dosimetry.

1. Introduction

Ionizing radiation dosimetry is important for the protection of patients and workers against detrimental effects of excessive exposure of radiation. Different types of materials and techniques have been investigated to assess the magnitude of ionizing radiation. Among them, "thermoluminescence dosimeters (TLD)" are

* Correspondence author at: Faculty of Engineering, Multimedia University, 63100 Cyberjaya, Selangor Darul Ehsan, Malaysia.
E-mail addresses: go2munmun@yahoo.com, mahfuzabaec14@gmail.com (M. Begum).

http://dx.doi.org/10.1016/j.apradiso.2014.10.025
0969-8043/

increasingly being used in different fields such as medical institutions, environmental monitoring etc. The most common commercially available TL phosphor is lithium fluoride, LiF:Mg,Ti (^{6}Li–7.5%, ^{7}Li–92.5%). The existence of a trace amount of impurities (magnesium) in the lattice structure of LiF provides enhanced thermoluminescence response than its purest form (Khan, 1994).

In recent years, several researchers have investigated TL response of silica optical fibers to develop new TL material with additional advantages than conventional TLDs. Different types of radiation including photons, electrons, protons, beta, alpha particles etc. have used for the studies and obtained promising TL characteristics in ionizing radiation dosimetry (Noramaliza et al., 2012; Yaakob et al., 2011; Abdul Rahman et al., 2011; Hashim et al., 2010; Issa et al., 2011).

Optical fiber is usually made of two concentric layers "core" and "cladding" with different index of refraction. TL properties of SiO_2 optical fiber depends on the trapping process that is caused by the occurrence of structural defects in the material (Abdul Rahman et al., 2011). Types and concentration of impurities in the material also effects TL response. Silica optical fibers also have several properties to overcome some limitations of commonly used TL materials such as water-resistant (Yaakob et al., 2011; Abdul Rahman et al., 2010; Hashim et al., 2009; Ong et al., 2009). This property paves the way for their use in intercavitary and interstitial measurements and also has high spatial resolution due to its small size and also low cost. These characteristics of optical fibers make it very promising for dosimetric applications.

In this paper, we report the investigation of dosimetric characteristics of five different core sizes of Ge-doped silica optical fibers including photon dose response, reproducibility and fading for gamma irradiation. The results of the study are also compared with commercially available standard TLD-100 chips (LiF:Mg,Ti) and commercial multimode Ge-doped optical fiber (Yangtze Optical Fiber, China) that was fabricated for communication purposes. Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDX) analysis of the fibers have also performed to study the relative elemental composition since TL response strongly depends on it. This technique is also used to determine effective atomic number Z_{eff} of the fiber-dosimeters.

2. Materials and methods

Five different core sizes of Ge doped optical fibers have been purposely fabricated by Modified Chemical Vapor Deposition (MCVD) process with sufficient dopant concentration and pulled from the same preform with different tension and speed values during the drawing phase. Core and cladding diameters of the fiber-samples are respectively (20/120) μm, (40/241) μm, (60/362) μm, (80/483) μm and (100/604) μm.

2.1. Sample preparation

The fibers were cut into approximately 5 mm long pieces using optical fiber cleaver (Cl-03 Max, ILSIN, Korea) and diamond-cutter (S90R, Thorlabs) and cleaned with acetone. The weight of each fiber was determined carefully using an electronic balance (Mettler Toledo, Switzerland) to normalize each measurement. The samples were handled using a vacuum tweezers to avoid scratches and contamination at the surface of optical fiber-samples that may affect TL response.

2.2. Annealing process

Annealing was carried out for each group of optical fibers immediately before each irradiation of gamma radiation. During the process the fibers were kept in an alumina container and annealed in an oven (Lindberg/Blue M, USA) at a temperature of 400 °C for 1 h period for erasing background signal and low-temperature glow peaks. TLD-100 chips were also annealed for 1 h at 400 °C and subsequently 2 h at 100 °C to remove all residual TL signal (Hossain et al., 2013). After heating, to avoid thermal stress the samples were slowly cooled inside the oven to finally equilibrate at a temperature of 20 °C. All fibers were located in gelatine capsule to provide homogeneity in the irradiation, routine storage and easy handling (Espinosa et al., 2006).

2.3. Irradiation of dosimeters

Ge-doped optical samples with five different core sizes, commercial multimode fibers and standard TLD-100 chips were exposed to Gamma-radiation from Cobalt-60 standard radiation source at SSDL-Nuclear Malaysia over the dose range from 1 Gy to 10 Gy. Perspex solid water phantom (Polymethyl methacrylate, PMMA) with dimension of $(30 \times 15 \times 30)\,cm^3$ was used to place the samples during irradiation maintaining source to surface distance (SSD) of 100 cm and field size-$(10 \times 10)\,cm^2$.

2.4. Readout system

TL response of the fibers was measured using Harshaw Model-3500 TLD reader under nitrogen (N_2) gas atmosphere to eliminate spurious light signals from triboluminescence and also to diminish oxidation of the heating element. During TL measurement different parameters were set. These were preheat temperature 80 °C for 10 s, acquired temperature rate 10 °C/s, acquisition time 13.33 s and maximum anneal temperature 400 °C to sweep out any residual signal. In this case, the luminescence intensity produced by heating the sample inside the TLD-reader is directly proportional to the absorbed dose of radiation.

2.5. SEM–EDX analysis of optical fibers

SEM–EDX analysis technique was carried out to map the relative distribution of dopant concentration inside five different core-diameter Ge-doped optical fibers. The effective atomic number, Z_{eff} of the fibers was also determined using this technique. It is important for predicting radiation interaction properties of dosimetric material. For SEM–EDX analysis, Ge-doped optical fibers of five different core-sizes were cut into 1 cm lengths using an optical cleaver. In attaching each sample to the stainless-steel sample-holder use was made of carbon tape, ensuring ease of flow of incident electrons to ground and also avoiding unwanted peaks to the X-ray spectrum on account of the low Z of carbon. In the process, high energy (30 kV) electrons interacted with optical fiber samples and produced characteristic X-rays with fixed wavelength for each element in the material and provided information about relative distribution of the compositional elements. The values of Z_{eff} for the samples were determined using the following Mayneord equation.

$$Z_{eff} = (a_1 Z_1^m + a_2 Z_2^m + a_3 Z_3^m + \dots\dots + a_n Z_n^m)^{1/m} \qquad (1)$$

where $a_1, a_2, a_3 \dots\dots a_n$ are the weight fraction contributions of each element in the optical fibers to the total number of electrons in the mixture. The value of m adopted for photon practical purposes is 2.94 (Khan, 1994).