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Characterization of fabricated optical fiber for food irradiation dosimetry

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Abstract

Food irradiation is a process carried out in order to improve hygienic quality and germination control, retarding sprouting, also enhancing physical attributes of the food product. In order to provide for food safety, radiation dosimetry in irradiated foods is required. In present studies use is made of germanium doped (Ge-doped) optical fibres of various form and dimensions. The fibres are irradiated using a gamma source irradiator (Gamma Cell 220 Excel), with doses from 1 kGy up to 10 kGy. For the particular Ge-doped optical fibres, investigation has been made of linearity with dose, reproducibility, and fading, intercomparisons being made. The fibres all exhibit TL yields that are linear with dose from 1 kGy up to 10 kGy, exceeding the dose range of all commercial high dose dosimeters used in the food irradiation industry. In respect of the flat fibre dosimeters, the mean reproducibility was found to be within 0.53% to 4.96%, also offering low signal loss (fading), within 13.41% (for fibres of cross-sectional dimensions 60 x 180 µm) to 20.12% (for fibres of cross-sectional dimensions 200 x 750µm), after 22 days of storage.

Introduction

Food irradiation is conducted commercially, not least in order to improve the shelf life of the product (Farkas *et al*., 2011). High energy irradiation has been introduced as a safe, dependable, inexpensive and clean sterilisation process. In the field of food irradiation, measurements of absorbed doses in the range of 1-5kGy are of paramount importance in ensuring the safe extension of shelf life of perishable food commodities (Rao *et al*., 2014). Thermoluminescence (TL) is the emission of light arising from the heating of typically solid samples that have previously been exposed to energetic radiation. The fractional absorption of energy incurred in the passage of the beam through the TL medium is mediated by excitation or ionization, subsequent light emission occurring through thermal stimulation. Given that the system is dependent upon electron trapping in defect centres, the heating process acts only as a trigger that helps in releasing the accumulated energy. In accord with the Boltzmann distribution, when the temperature of such material is raised, the trapped electrons release their excessive energy in the form of luminescence (Shinde *et al*., 2012). The processes of trapping and subsequent release of the stored energy find many valuable applications in ionizing radiation dosimetry, the TL spectrum containing important information about the trapping and energy release processes. This information is highly useful in selecting a particular TL material for a specific dosimetric application (Rafaei *et al*., 2014). In making use of these phenomena, several researchers have studied SiO_2 optical fibres (Bradley *et al*., 2012) and Nd-doped SiO_2 optical fibres (Rafaei *et al.,* 2014) as TL dosimeters, both in regard to low- and high-dose

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radiation scenarios. Currently, standard dosimeters in food irradiation have poor particle irradiation energy sensitivity, dictating a complex measurement process. Solid- and liquid-state dosimeters (e.g. crystalline alanine in a binder and potassium dichromate or ceric-cerous sulphate solution) are widely used in dosimetry applications at industrial irradiation plants. With well-defined measurement procedures, the alanine and dichromate systems are particularly well established dosimeters, adopted by national laboratories for reference dosimetry at the doses involved in industrial processing (Sephton *et al*., 2007). Thus said, the abilities of these dosimeters in real-world situations are limited due to fast signal fading, potential chemically toxicity and the fact that the glass vessels containing the media are easy to break. In an effort to overcome such limitation, the main interest in present study is to investigate the dosimetric characteristics of Ge-doped silica optical flat fibres for potential use in support of the food irradiation process.

Materials and Methods

Fabrication and design of silica dioxide flat fibres

The 6% mole Ge-doped optical fibre preform was fabricated using the standard Modified Chemical Vapour Deposition (MCVD) method, carried out for the present TL media at the MCVD Laboratory, Cyberjaya Campus, Multimedia University, Malaysia. As for the fibre production, the hollow preform was pulled using the pulling-tower facilities in the Flat Fibres Laboratory, Department of Electrical Engineering, University of Malaya. The flat fibres were produced by applying vacuum pressure and temperature to the doped hollow silica preform during the fibre drawing process (Dambul *et al*., 2012). Thus, several sizes of Ge-doped optical flat fibres were produced with cross-sectional thickness and widths of 60×180 µm, 85×270 µm, 100×350 µm, 165×620 µm and 200×750 µm.

Preparation of the ge-doped optical flat fibres and commercial ge-doped optical fibres

The flat fibres were cleaned using propanol and cut into 6.0±1.0mm lengths using an optical fibre cleaver (Ilsintech Precision Technology, Korea). Then the fibres were annealed in a furnace to remove any background radiation and mechanical exposure history of the sample. In regard to our use of commercial Ge-doped silica glass optical fibres acquired from CorActive, Canada, these comprise a doped core diameter of 9 µm with silica cladding diameter of 124.7 ± 1.0 µm. For the material preparation procedures, four steps were taken: (i) removal of the thin outer protective polymer layer of the fibres using a fibre stripper (Prokit's Industries Co. Ltd, Taiwan); (ii) cleaning of the bare fibres using propanol to remove any dust and oil; (iii) cutting of the fibres into 6.0±1.0 mm lengths using an optical fibre cleaver, and; (iv) annealing process. Both materials, the flat fibres and commercial fibres were annealed using a furnace (Carbolite, UK) at a temperature of 400°C for a period of one hour and then slowly allowed to cool the room temperature for 8 hours. The purpose of annealing process is to eliminate any remaining TL signal by emptying the high temperature traps or interstitials (Mahajna *et al*., 1997).

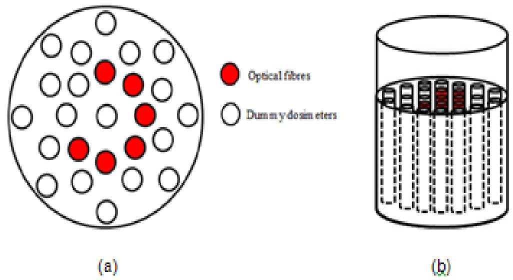

Figure 1. (a) The top view of Gammacell chamber with samples and dummy dosimeters. (b) The side view of Gammacell chamber

Four pieces of each optical flat fibre were weighed using an electronic balance (Mettler Toledo, Swiss), and placed in a gelatine capsule for convenience in handling. In order to minimise scratches on the surface of the fibres and deposition of dust or finger oil, vacuum tweezers (Dymax 5, UK) were used to handle the fibres. The fibres were kept in a black box to minimise exposure to light.

Gamma irradiation

The fibre samples were irradiated using a cobalt-60 gamma irradiator (Gamma Cell 220 Excel) at Universiti Kebangsaan Malaysia, providing a mean energy of 1.25 MeV and a dose rate of 2.07 kGy/hr at the time of irradiation. The samples were irradiated to various doses from 1 kGy up to 10 kGy. Figure 1 shows how the samples were placed inside locating holes in a chamber made from styrofoam, dummy dosimeters being placed inside any remaining empty holes. The dummy dosimeters used are made from solution of ceric-cerous filled into ampoules. The ampoules were placed in the empty holes of the chamber to ensure that the fibres were irradiated uniformly.

TL measurements

The TL was readout using a Harshaw TLD

Reader Model 3500, 24 hours post-irradiation. Nitrogen gas was flowed through the sample chamber during the readout process in order to suppress light stimulation from air and also to reduce the oxidation of the heating element and surface of fibres (Chen *et al.*, 1994). The time-temperature profile that was used in this readout process was as follows: preheat temperature of 180°C for 5s; readout temperature is 400°C for 6 s with the heating cycle rate of 35°C/s. An annealing temperature of 400°C was maintained for 10 s to eliminate any residual signals in the fibres.

Results and Discussion

Ge-doped silica optical fibres dosimetric characteristics

The main dosimetric properties of the fibres investigated in this study were dose response, reproducibility of the TL yield, and thermal fading, studied in order to explore the possibility of using these fibres in measuring doses from 1 kGy up to 10 kGy

TL and dose dependency

The dose response is of particular interest in seeking a practicable measurement device, ideally with the response linear over the full range of doses used in irradiation, allowing for reliable calibration and utilisation. Figure 3 shows the linearity index of flat fibres and commercial fibres where f(D) is defined as the deviation of TL from linearity (R. Chen *et al.*, 1994).

$$f(D)=\frac{(S(D)-S_0)/D}{(S(D_1)-S_0)/D_1} \qquad (1)$$

The measured TL signal is denoted as S(D). This can be the maximum intensity or the total area under the peak, as a function of the dose D, whereas $S(D_1)$ is the measured TL signal at low dose D_1 which is somewhere within the linear region of f(D). S_0 is the intercept on the TL intensity axis from the extrapolation of the linear region in the curves shown in Figure 2 (McKeever *et al.*, 1995). From the given equation, f(D)>1 is indicative of values of S(D) above the initial linear range, an expression of supralinearity, while when f(D)<1, this indicates sublinearity. Figure 3 shows that the linearity index for doses of 1 kGy up to 10 kGy. Each data point in Figure 3 has been obtained by taking a mean of four individual fibre readings. At 1 kGy, the yield of TL is generally sublinear, although for the flat fibre of dimensions 165 x 620 µm this appears to offer a supralinear response. For the flat fibre of dimensions 200 x 750 µm, the f(D) at doses from 4 kGy up to 10 kGy remains close to 1.

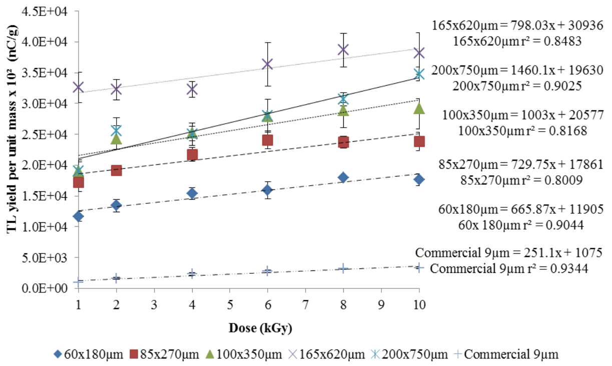

Figure 2. Linearity of the Ge-doped flat fibres and commercial fibres for kiloGray gamma irradiation

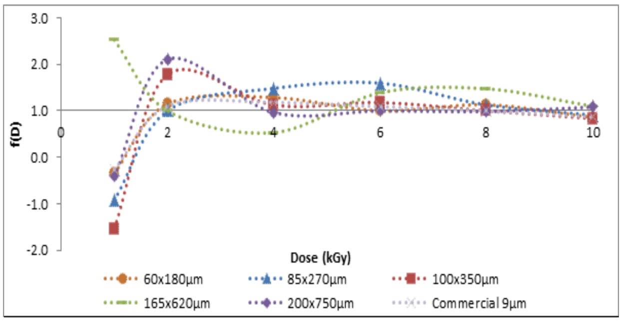

Figure 3. Linearity index of optical fibres

Reproducibility

The investigation of TL reproducibility was carried out by irradiating Ge-doped flat fibres to a dose of 1, 2, 4, 6, 8, 10 kGy. The reproducibility was calculated by taking the average of one standard deviation for each dosimeter. Table 1 shows the dose reproducibility of the Ge-doped flat fibres. The mean reproducibility obtained using the Gammacell was within 0.53% to 4.96%.

Fading

Fading has an important effect on dosimeters, decreasing the TL intensity under ambient environmental conditions, including during the time of transfer and storage. The fibres were irradiated at a dose of 10 kGy, again using the Co-60 irradiator. Figure 4 illustrates the fading rate of the fibres, measured at the 5th, 8th, 15th and 22nd day post-irradiation. TL intensity values were normalized to their value on the 5th day post-irradiation. After 22 days of storage, the intensity losses of the Ge-doped flat fibres were no greater than 20.12%. This can be compared with the fading of the 9 µm core diameter commercial fibres of 25.28%. It was found that the least TL fading rate of Ge-doped flat fibres was that for the fibres of cross-sectional dimension 60 x 180 µm, decreasing by just 13.41%. In a previous study for 9µm core diameter Ge-doped optical fibre dosimeters, a TL signal loss of ~11% was reported

Table 1. Dose reproducibility of the Ge-doped flat fibres

Energy (Source)	Dose (kGy)	TL yield per unit mass ×10² (nC/g)		
		Mean	SD	SD in %
1.25MeV	1	17353	714.26	4.12
	2	19165	101.79	0.53
	4	21410	1061.59	4.96
	6	24858	760.47	3.06
	8	23731	990.57	4.17
	10	23183	710.23	3.06

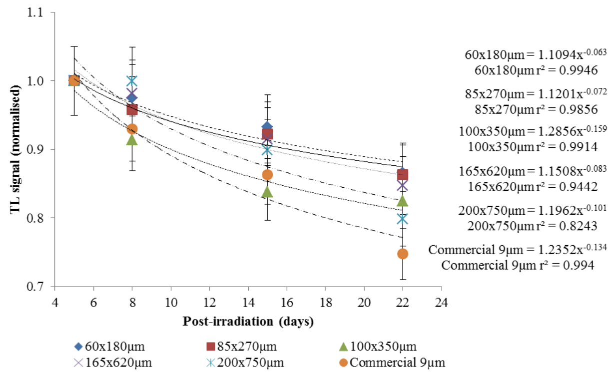

Figure 4. Post-irradiation of fading for fabricated Ge-doped flat fibres and also commercial fibres under normal ambient conditions

following storage time of 133 days and irradiation to a dose of 2 Gy using a 6 MV nominal photon energy (Noor *et al*., 2011).

Conclusion

The key dosimetric characteristics, linearity of TL with dose, reproducibility and fading rate of fabricated Ge-doped flat fibres have been studied, with dose delivery using a Co-60 source providing doses in the range from 1 kGy to 10 kGy. The Ge-doped flat fibres and commercial fibres are seen to offer favourable performance, matching the need for measuring food irradiation doses. The present study shows that the fabricated Ge-doped flat fibres warrants the superior performance, offering a viable system for food irradiation in the dose range from 1 kGy up to 10 kGy with relatively low fading. Also offering a cheap method for production of tailored fibres for dosimetry, as well as recognised is the considerable potential for extensive dose mapping within the food irradiation field.

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