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RESEARCH ARTICLE

Development of optical fibers for food irradiation dosimeter

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Abstract

Different technologies and methods for enhancing food quality have been developed and applied in the last few decades. One of the latest technologies is by using ionizing radiation. Food irradiation is the technology that improves the safety and extends the shelf life of food by reducing or eliminating harmful microorganisms and insects. In order to provide for food safety, proper control or radiation detector of irradiated food seems very critical to facilitate international trade of irradiated foods and to enhance consumer confidence. In present studies, germanium-doped (Ge-doped) optical fibers of various forms and dimensions were used as radiation detector. The fibers were irradiated using electron beam (EPS 3000), with doses from 1 kGy up to 10 kGy, exceeding the dose range of all commercial high dose dosimeters used in food irradiation industry. A study has been made of linearity, reproducibility, and fading. The fibers showed a linear dose response over the studied range doses with mean of reproducibility less than 5 % variation between 1st exposure and 2nd exposure. TL fading of Ge-doped flat fibers has been found to be < 8.7%.

Keywords: Food irradiation, ionizing radiation, Ge-doped optical fibers, dosimetry, electron beam

INTRODUCTION

Food irradiation has been recently became one of the most successful methods to preserve food with minimum interruption to the functional, nutritional, and sensory properties of food products. According to Farkas *et al.* [1], food irradiation is conducted commercially, in order to improve the shelf life of the product. This food processing involves controlled application of energy from ionizing radiations such as gamma rays, X-rays, and electron beam for food preservation. Prior to 1980, limited work was carried out for the development of reliable detection methods for irradiated foods, including Perspex (PMMA) blocks, radiochromic film, high-purity Ge detectors (HPGe) and both ceric-cerous and ferrous sulphate (special solution). Unfortunately, some of these methods have poor sensitivity, limited dose range [2], contained toxic chemicals [3] and required a complex measurement process [4]. After 1980, extensive researches have been undertaken which resulted in the development of a range of test methods that could be used to reliably determine the irradiation status of a wide variety of foods.

Recently, some research groups started to use flat optical fibers as radiation dosimeter and some other researchers have been developed doped optical flat fibers with possible use as dosimeter material [5]. Flat fibers combine the structural advantages and functional benefits of planar devices [6]. Therefore, the main interest in this study was to investigate the dosimetric properties of fabricated Ge-doped optical flat fibers for usage in food irradiation industries. Table 1 shows the type of food and maximum dose (kGy) that required for food irradiation according to specific country. There were several applications of food irradiation in different dose levels (see Table 2).

MATERIALS AND METHODS

Preparation of Ge-doped flat fibers

An uncollapsed germanium silica dioxide (Ge-doped SiO_2) preform was fabricated using the standard modified chemical deposition (MCVD) technique. This method was carried out for the present TL media at the MCVD Laboratory, Cyberjaya Campus, Multimedia University, Malaysia. Reference made to the gas flow rate where 6 mol% of Ge flat fiber preform was produced. The flat fibers were produced by applying vacuum pressure and temperature to the doped hollow silica preform during the fiber drawing process [6]. This preform was drawn into a fiber cane of diameter 3-4 mm, at the facilities of the flat fibers laboratory, Department of Electrical Engineering, University of Malaya. The commercial Ge-doped 9 µm diameter optical fibers were observed to have Ge concentration in the range of 0.09 to 0.13 weight mol % of Ge.

Preparation of the samples before irradiation process

To prepare the flat fibers for irradiation, four steps were taken: (i) removal of the thin outer protective polymer layer of the fibers using fiber stripper (Model 8PK-326, Prokit's Industries Co Ltd, Taipei) (ii) cleaning of the bare fibers using propanol to remove any dust and oil; (iii) cutting of the fibers into 3.0 ± 1.0 mm lengths using optical fiber cleaver (Model CT-07 Fujikura High Precision, Tokyo) and (iv) annealing process. All samples were annealed using a furnace oven (Model TLD lab 01/400, Delta Advantech, Selangor) at a temperature of 400 °C for 1 hour and then slowly cooled to room temperature for 8 hours. The objective of annealing process was to eliminate any remaining TL signal by emptying the high temperature traps or interstitials [10].

Each optical flat fiber was weighted using an analytical balance (Model BSA224S-CW, Sartorius, Gottingen) and placed in a gelatine capsule. Each capsule contained at least four pieces of flat fibers. Vacuum tweezers (Dymax 5, Charles Austen, Surrey) have been used to handle the fibers, in order to minimize the formation of scratches on surface and deposition of dust or finger oil. The fibers were kept in a black box to minimize exposure to light.

Table 1- Some examples of current uses of food irradiation in different countries [7, 8].

Region	Country	Food	Maximum dose (kGy)
The Americas	USA	Pork	1.0
		Poutry	3.0
	Canada	Potato	0.1
		Spices	10.0
	Brazil	Strawberries	3.0
Europe	France	Camembert Cheese	3.5
	The Netherlands	Egg white	4.0
		Frog-legs	5.0
		Dried fruits	1.0
	U.K	Roots and tubers	0.2
		Shellfish	3.0
Asia and Europe	China	Garlic	0.1
		Rice	1.0
	Thailand	Mango	1.0
		Fermented sausage	4.0
	South Africa	Avocado	3.0
		Fruit juice	3.0

Table 2: Application by overall average dose [9].

	Application	Dose (kGy)
Low dose (up to 1 kGy)	Inhibit sprouting	0.03-0.15
	Delay fruit ripening	0.03-0.15
	Stop insect/parasite infestations	0.07-1.00
Medium Dose (1 to 10 kGy)	Delay spoilage of meat	1.50-3.00
	Reduce risk of pathogens in meat	3.00 – 7.00
	Increase sanitation of spices	10.00
High dose (above 10 kGy)	Sterilization of packaged meat	25.00 – 70.00
	Increase juice yield	25.00 – 50.00
	Improve re-hydration	25.00 – 50.00

Electron beam irradiation

There are several types of radiation used in food irradiation, e.g electron, gamma or X–ray irradiations. In this study, electron beam was chosen since it was the only radiation for food processing that currently ~~is~~ available at Malaysian Nuclear Agency, Bangi. The fiber samples were irradiated using electron beam machine EPS 3000. The samples were irradiated to various doses from 1 kGy up to 100 kGy. Electron beam can be used to treat food and food ingredients in order to eliminate microbial pathogens or at higher dose to sterilize food ingredients. Each optical fiber was placed in capsule and categorized accordingly prior to irradiation. Figure 1 shows the samples placed on the conveyer belt during irradiation.

TL measurement

The TL was read out by a TLD reader (Model 3500, Harshaw Chemical Company, Cleveland) at Nuclear Laboratory, Universiti Teknologi Malaysia, after 24 hours of post-irradiation. During the reading process, nitrogen gas was flowed through the sample chamber in order to suppress light stimulation from air and also to reduce the oxidation of the heating element and the fibers [11]. The time-temperature profile used in this readout process was as follows: preheat temperature of 50 °C, heating rate of 10 °C.s^{-1} and maximum temperature for data acquisition of 400 °C. This time-temperature profile has been set to obtain the complete capture of TL glow curve under optimum conditions.

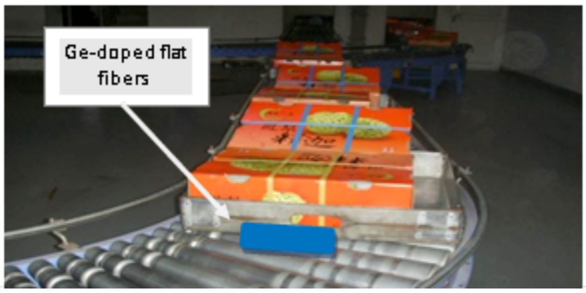

Figure 1 Fruits on the conveyor belt before electron irradiation.

RESULTS AND DISCUSSION

In order to explore the possibility of using these fibers in food irradiation, dosimetric properties such as dose response, reproducibility of the TL yield, and thermal fading were investigated for doses from 1 kGy up to 100 kGy.

TL response

The dose response is one of specific interest in seeking a practicable measurement device. Different doses (1 kGy up to 100 kGy) were used for the purpose of TL response study. Based on the coefficient of determination (R^2) for each flat fiber, all the fibers showed linear response in the 1-100 kGy range, as presented in Figure. 2. We defined the normalized dose response function (or supralinearity index) f (D) [11] as:

$$f(D) = \frac{\frac{F(D)}{D}}{\frac{F(D')}{D}} \quad (1)$$

where F (D) is the dose response at a dose *D* and *D'* is a low dose at which the dose response is linear. Therefore, our ideal dosimeter would satisfy f (D) = 1 only over a wide dose range. Mostly, it was found that f (D) = 1 only over a narrow dose range, up to a few Gy, in many TLD materials. In this study, the most ideal dosimeter was flat fibers doped Ge with R^2 = 0.979. Supralinearity, defined as f (D) > 1, was commonly observed, while sublinearity (f (D) < 1 was mostly observed during the approaching saturation. Some TL material has f (D) = constant over entire dose range and the response of the dosimeter was the same [12].

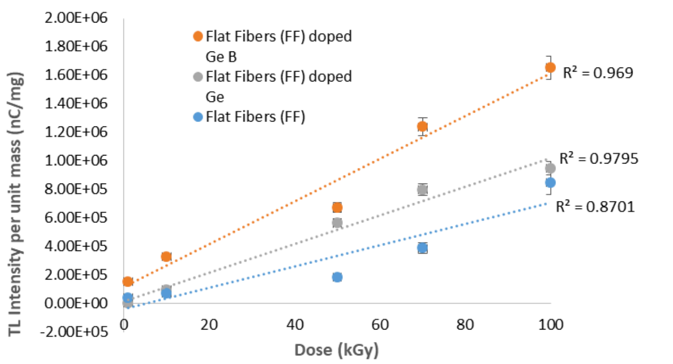

Figure 2 Linearity of Ge-doped, Ge-B doped and undoped flat fibers for kiloGray electron beam irradiation.

Reproducibility

For some TL materials, repeated usage might cause change to the deep, competing traps, and this change was accumulated with each reuse, causing the TL sensitivity to change over the usage period [13]. The study of reproducibility was performed by irradiating the Ge-B doped flat fibers to 5 kGy on two different days and the results were shown in Figure 3. The results showed that the reproducibility of Ge-

B doped flat fibers to be less than 5% variation based on standard deviation for 2 time sequential measurements.

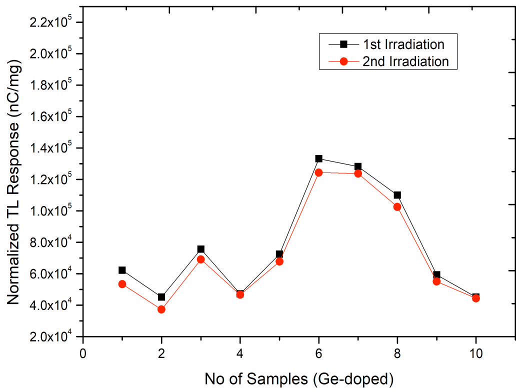

Figure 3 Reproducibility of Ge-B flat fibers after 2 irradiations.

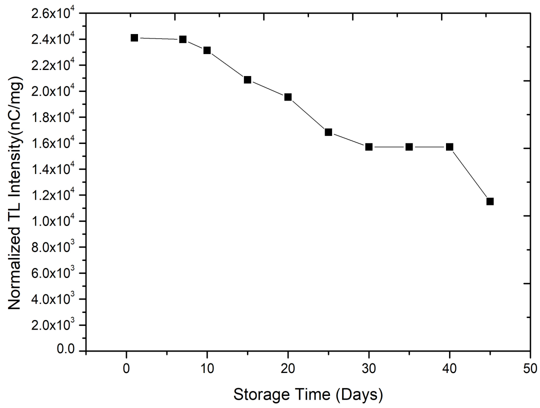

Figure 4 Fading for fabricated Ge-B doped flat fibers under normal ambient conditions.

Table 3 Fading for some commercial TLD materials [14].

TLD Dosimeter	TLD Materials	Thermal Fading
TLD 100	LiF:Mg, Ti	5-10% per year
TLD 200	CaF_2:Dy	16% in two weeks
TLD 400	CaF_2:Mn	15% in three months
TLD 500	Al_2O_3C	3% per year
TLD 600	^{6}LiF:Mg, Ti	5% per year
TLD 700	LiF:Mg, Ti	5% per year
TLD 800	$Li_2B_4O_2$:Mn	5% in three months
TLD 900	$CaSO_4$:Dy	8% in six months

Fading

Fading is an important characteristic of TL dosimeters. Fading can be defined as the decrease in the TL signal due to ambient environmental conditions, including during transfer and storage. In order to determine the fading characteristics, the optic fibers were annealed and irradiated to a dose of 1 kGy up to 4 kGy of cobalt-60 (Gamma cell 220 Excel, Atomic Energy, Canada) at Universiti Kebangsaan Malaysia. The fibers were stored in a dark room at constant temperature of 27 ℃. This fading study for optical fibers samples demonstrated a small decrease of the TL response during the elapsed period of time. The obtained results in Figure 4 showed that after 2 months of storage period, fading was reduced by 8.7%. Table 3 shows the fading rate for some commercial TLD materials. By referring to Table 3, the fading characteristic of the optical fibers was similar to TLD-400.

CONCLUSION

The main dosimetric characteristics of new Ge-, B- doped flat fibers such as linearity of TL with dose, reproducibility and fading rate have been studied. The studied optical fiber demonstrated useful TL properties and it seemed to be an excellent candidate for use in TL dosimetry for food irradiation. Introducing the detection of irradiated food is very important for implementation of quality control at all levels. Therefore, the Ge-B doped flat fibers were seen to offer promising performance and matching the need for measuring food irradiation doses.

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