Gamma radiation response of FBG inscribed in 20-µm core graded-index polymer CYTOP fiber

I. Chapalo[1], A. Gusarov[2], A. Ioannou[3], K. Chah[1], A. Pospori[3], Y.-G. Nan[1], K. Kalli[3], and P. Mégret[1]

[1] University of Mons, Electromagnetism and Telecom Department, Boulevard Dolez 31, 7000 Mons, Belgium
[2] SCK-CEN, Boeretang 200, 2400 Mol, Belgium
[3] Cyprus University of Technology, Photonics and Optical Sensors Research Laboratory, Saripolou 33, 3036, Limassol, Cyprus.

We investigate online response of a fiber Bragg grating (FBG) inscribed in a polymer optical fiber on gamma radiation. The fiber had a 20-µm graded-index CYTOP core and 250-µm XYLEX overclad. The FBG was inscribed by fs laser using the plane-by-plane technique. We irradiated the grating by ^{60}Co sources at the dose rate of 5.3 kGy/h. The reflection peak (RP) of the grating was monitored before, during and after irradiation (online) using a commercial interrogator placed outside of the irradiation field. The FBG was connected with the interrogator by 10-m single-mode silica patchcord. We firstly applied a 40-kGy dose and then, after ≈90 hours of recovery, we applied the second dose of 80 kGy. The FBG demonstrated a blue shift of the RP during both sessions of irradiation. The speed of the RP change increased during receiving ≈15 kGy of the first irradiation, and then, the RP changed linearly with -3.5 pm/kGy speed. During the second irradiation, the RP changed linearly during the entire irradiation session with -4.13 pm/kGy speed. The linear FBG response to the received dose can be prospective for gamma radiation dosimetry.

Introduction

Changes of physical properties of optical fiber under ionizing irradiation can be applied for fiber optic dosimetry. Indeed, this aspect of development has been intensively investigated over the past decades [1,2]. The interest to optical fiber dosimetry is due to the possibility of online and distributed sensing, remote interrogation and small size of sensitive elements. Recently, increased attention from researchers has been focused on using polymer optical fibers (POFs) as a sensitive element for gamma- and X-rays dosimetry. Sensors based on the radiation induced attenuation (RIA) effect in the visible range in polymetylmethacrylate (PMMA) POF demonstrated an advantage of strong sensitivity compared to silica fiber [3,4]. Another POF type investigated for dosimetric applications is perfluorinated fiber based on CYTOP material. It demonstrated significantly stronger RIA in UV-VIS range comparing to PMMA [5]. FBGs inscribed in CYTOP fiber have been investigated under gamma radiation as well. They show blue wavelength shift of their reflection peaks as a result of gamma irradiation in standard 120-µm core graded-index PF-POF [6].

In this work, we investigate the gamma radiation effect on the Bragg wavelength (BW) of the FBG inscribed in a few-mode graded-index POF with 20-µm CYTOP core and 250-µm XYLEX overclad. The BW was monitored online before, during and after irradiation. We show the BW evolution over time for two irradiation sessions with received doses of 40 and 80 kGy. We compare the obtained dependences with earlier published results for FBGs inscribed in standard CYTOP fiber of 120-µm core.

Experimental setup

Experiments were conducted at a Brigitte irradiation facility (SCK-CEN, Belgium). The irradiation setup consists of ^{60}Co gamma radiation sources forming a cylindrical volume at a depth of seven meters in a water pool and providing the dose rate of 5.3 kGy/h (Fig. 1). For irradiation, the FBG was placed inside a stainless steel container, which can be sealed for under-water operation. The container was placed down to irradiation zone for a specified time according to the required irradiation dose using an industrial hoist. Before and after irradiation, the container was stored under water at a depth of ≈2 meters for pre irradiation stabilization and post irradiation monitoring of the BW. Temperature inside the contained was stabilized at 42°C by the oven controlled by the Eurotherm 2408 controller. A 9-m long tube of 5-cm diameter was hermetically connected to the container, so that the optical cables can be passed from the equipment setup towards the investigated samples. The FBG was connected to the standard commercial interrogator (FiberSensing FS2200) using 10-m SMF-28 patchcord threaded through the tube.

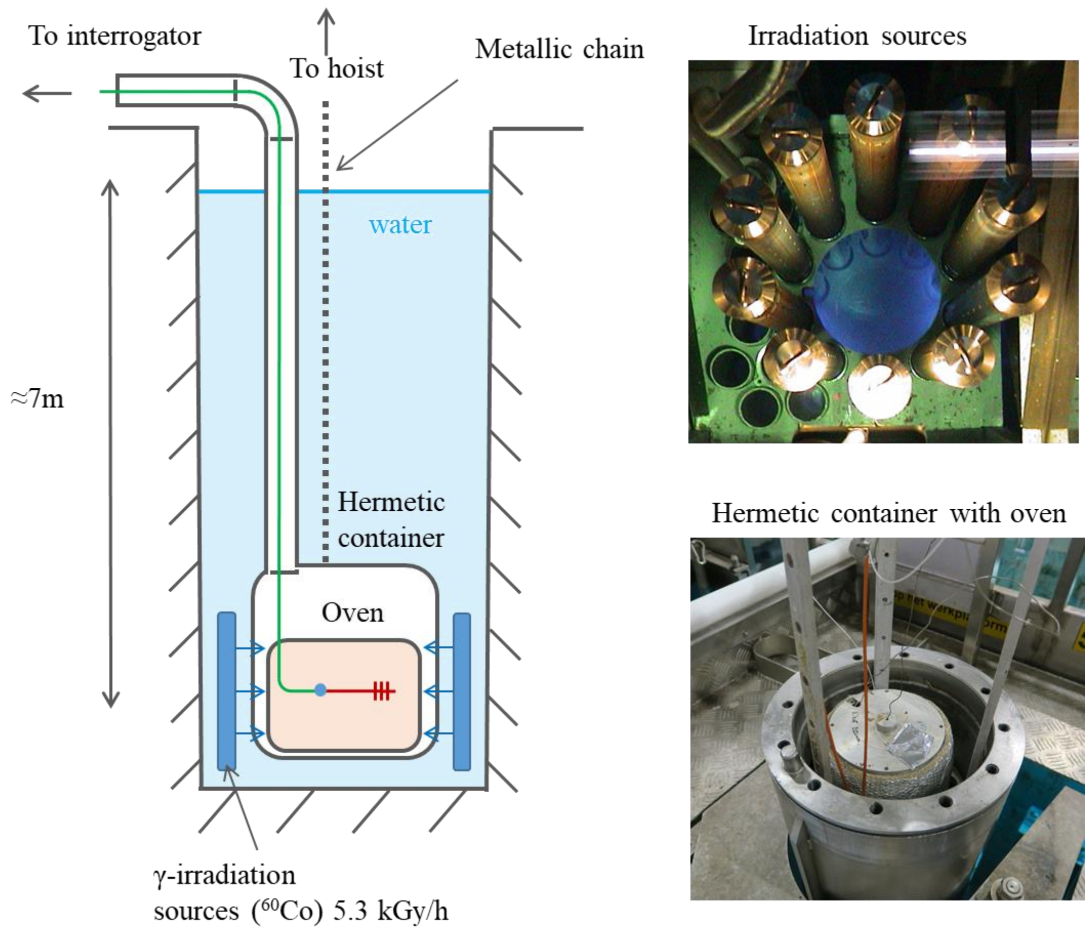

Fig. 1 Schematic of the experimental setup and photographs of irradiation sources and the container.

For the FBG inscription, we used the POF designed and produced by Chromis Technologies. It has a few-mode graded-index CYTOP core of 20-μm diameter and an effective refractive index of 1.34. Reduced core diameter allows to decrease a possible number of excited mode groups in the POF by 3-4. Accurately adjusted launching conditions provide stable single-peak reflection spectrum of the FBG [7]. A protective overclad of a 250-μm diameter is made of a XYLEX material, which is a blend of polycarbonate and an amorphous polyester. The FBG of 1 mm length was inscribed by femtosecond pulses generated by a HighQ laser femtoREGEN source at λ=517 nm (220 fs pulse duration and 1 kHz repetition rate) using a plane-by-plane direct inscription method [8]. The POF sample containing the FBG was centered and connectorized with a standard silica SMF pigtail using two manual translation stages and the UV-curing glue. The FBG was annealed at 65°C during 3 hours before the experiment.

We performed two irradiation sessions with doses of 40 and 80 kGy. Between the sessions, we lifted the container with the FBG out of the irradiation zone and we stored it at underwater position during ≈90 hours for monitoring the BW evolution after irradiation. The BW was monitored with the same procedure after the second irradiation session as well.

Experimental results

Fig. 2 (a) shows the evolution of the BW over time. After underwater stabilization, the FBG demonstrates the BW blue shift during the first (40-kGy) irradiation. After the first irradiation, a weak recovery of the BW (≈20% of the first irradiation BW shift) is seen during up to 10 hours and then, a slow decrease of the BW at a rate of ≈0.7 pm/h is observed. The second irradiation (80 kGy) again caused the blue shift of the BW, however, the recovery is significantly stronger than after the first irradiation.

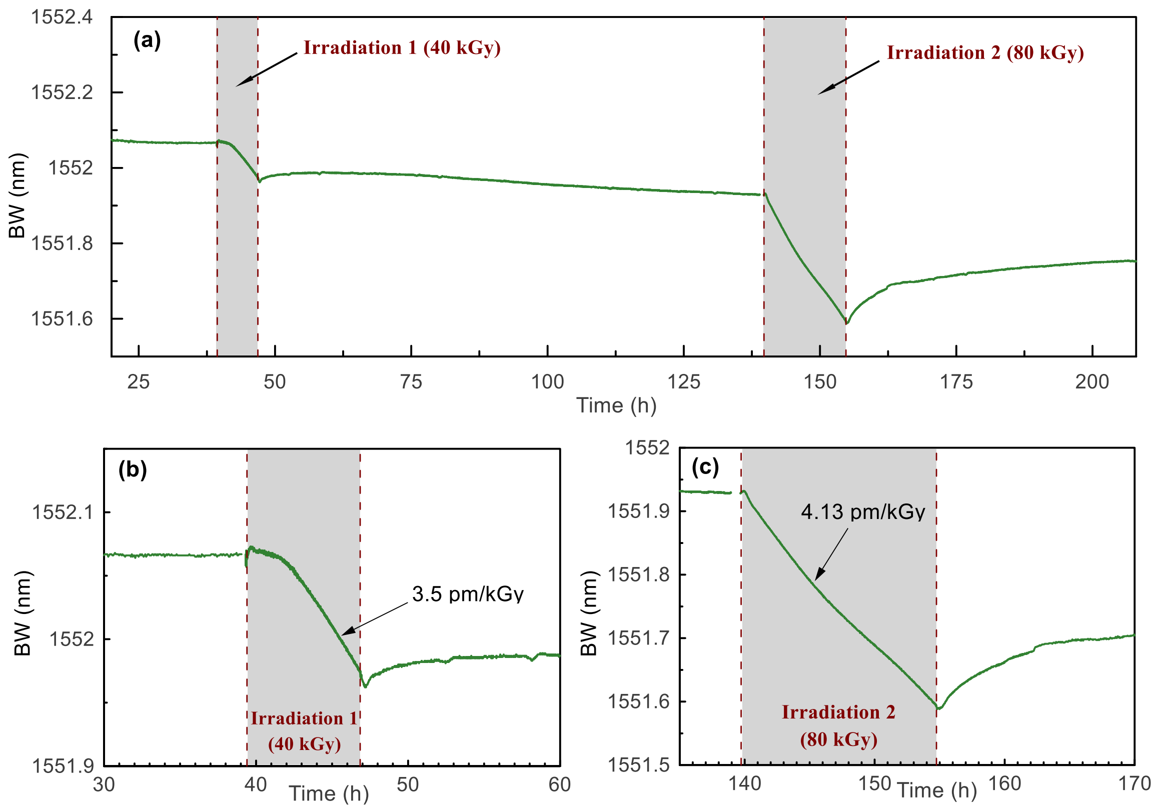

Fig. 2 Bragg wavelength evolution over time during two sessions of gamma radiation: general view (a), detailed graph of the first irradiation session of 40 kGy (b), and detailed graph of second irradiation session of 80 kGy (c).

Fig. 2(b) shows the first irradiation in more detail. A slight BW rise of ≈10 pm during 20 min is seen after the start of irradiation. Then, the BW turned to a slow decrease during another 1.5-2 hours, and finally, it reached stronger, linear decreasing part of the graph with a slope of -3.5 pm/kGy. The total BW shift during irradiation is -95 pm. It should be mentioned that the BW experienced another 10-pm decrease immediately after irradiation. After that, the BW recovery process was observed.

The BW evolution during the second (80-kGy) irradiation (Fig. 2(c)) demonstrates very weak initial BW rise of ≈5 pm. Then, the BW decreased linearly with the slope of -4.13 pm/kGy. The total BW change during the second irradiation is -340 pm. The recovery BW shift is 130 pm at the end of the experiment (53 hours after the end of irradiation 2), i.e. 38% of the second irradiation BW shift.

The possible reason of the non-linear response during the beginning part of the first irradiation could be not ideally stabilized temperature. It changed by ≈3℃ in the beginning of the first irradiation. Therefore, the BW could react simultaneously to the temperature and radiation. Before and during the second irradiation, the temperature was well stabilized, and the FBG demonstrated linear response to the irradiation dose.

Reference [6] presents the investigation the gamma radiation response of FBGs inscribed in a standard POF with 120-μm CYTOP core and 490-μm polycarbonate overclad. The blue shift of the BW was also demonstrated, however significantly higher sensitivity of -29.9 pm/kGy was obtained. There could be several possible reasons that could affect sensitivity: temperature during irradiation, different fiber lateral dimensions, and even the history of the fiber's climatic conditions (especially the absence of temperature annealing). The latter can result in the additional shrinkage effect (and therefore additional blue shift of the BW) due to increased temperature during irradiation. However, the most significant reason, in our opinion, is different dose rates: 5.3 kGy/h in our experiment versus 635 Gy/h in [6].

Conclusion

In this work we investigated the BW evolution under gamma radiation of the FBG inscribed in a few-mode CYTOP fiber. The CYTOP FBG seems prospective for gamma radiation dosimetry since it demonstrated a linear response to the received dose with a sensitivity of -4.13 pm/kGy at 42℃. Future research should be focused on the effect of dose rate, temperature and total received dose on the FBG response to gamma radiation.

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