GAMMA-RADIATION IMPACT ON TEMPERATURE AND RH SENSITIVITY OF FBGS IN A FEW-MODE POLYMER CYTOP FIBER

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Abstract: We characterize a fiber Bragg grating (FBG) inscribed in a few-mode polymer CYTOP® fiber for temperature and relative humidity (RH) response before and after gamma radiation treatment. The results demonstrate strong rise of RH sensitivity: from 13.3 pm/%RH for the pristine FBG up to 56.8 pm/%RH after receiving 520 kGy gamma radiation dose. Temperature response also becomes stronger and moreover, demonstrates change of sign: from 19.6 pm/°C for the pristine case down to -38.9 pm/°C after irradiation. The results show the possibility of temperature and RH response adjustment by gamma radiation, and suggest the existence of an optimal radiation dose which can eliminate temperature sensitivity.

Keywords: fiber Bragg gratings, polymer optical fiber, femtosecond inscription, gamma radiation, CYTOP optical fiber.

1. Introduction

Polymer fiber Bragg gratings (FBGs) are known to have wider strain range and stronger temperature sensitivity comparing to silica FBGs [1, 2]. Besides, they are sensitive to relative humidity (RH), so their application for RH sensing has been extensively investigated along with temperature and strain sensing [2]. A wide number of research works have been dedicated to the development of FBG sensors using CYTOP® [3], PMMA [4], polycarbonate [5], Zeonex® [6] and TOPAS® [7] POFs. Depending on the material, sensors demonstrate various sensitivities. For example, FBGs inscribed in graded-index fiber with 50-µm CYTOP® core and 490-µm polycarbonate overclad (GigaPOF-50SR, Chromis Technologies) show temperature and RH sensitivity of 37.7 pm/°C and 22.3 pm/%RH correspondingly [8]. PMMA FBGs demonstrate strong and negative temperature sensitivity (< -47 pm/°C) and strong RH sensitivity (> 35 pm/%RH) [2, 4]. Depending on sensing requirements, various fibers can be preferable for FBGs inscription. In addition, methods, such as fiber pre-strain, have been investigated for adjustment of temperature sensitivity of FBG inscribed in CYTOP® and PMMA POFs [9, 10].

In this work, we investigate the influence of gamma radiation on temperature and RH response of FBGs inscribed in a few-mode polymer CYTOP® fiber. We found that the FBG received 520 kGy dose of gamma radiation demonstrates a strong rise of RH sensitivity: 56.8 pm/%RH after irradiation versus 13.3 pm/%RH before irradiation. Moreover, temperature response shows a change of sign: temperature sensitivity changed from 19.6 pm/°C before irradiation to -38.9 pm/°C after irradiation. Thus, gamma radiation treatment of CYTOP® FBGs can serve as an effective way to improve their RH sensitivity. Besides, one can suppose that, due to the change of temperature sensitivity sign, the optimal gamma radiation dose can be found to eliminate temperature response to prevent temperature cross-sensitivity.

2. Experimental setup

For the FBG inscription, we used a graded-index few-mode POF produced by Chromis Technologies. A CYTOP® core has a 20-µm diameter and an effective refractive index of 1.34. A protective overclad (250-µm diameter) is made of a XYLEX® material (a blend of polycarbonate and an amorphous polyester). The FBG was inscribed using plane-by-plane technique and femtosecond (fs) pulses generated by HighQ laser femtoREGEN source (λ=517 nm, 220 fs pulse duration, 1 kHz repetition rate) [11]. The CYTOP® fiber sample with FBG was centered and connected with standard silica SMF-28 pigtail using UV-curing adhesive. The length of POF between the FBG and the silica pigtail was 4 cm. The short POF length was chosen to avoid excessive losses caused by the radiation-induced attenuation [12]. The FBG reflection spectra measured before and after irradiation are presented in Figure 1 (a).

We irradiated the FBG sample using the Brigitte ^{60}Co gamma radiation setup (SCK-CEN, Belgium). The radiation sources were located at a depth of seven meters in a water pool and formed a cylindrical volume. The stainless steel hermetic container with the fiber sample was placed there for a specified time according to the required dose (Figure 1 (b)). Irradiation was conducted at a dose-rate of 5.3 kGy/h and temperature of 41-44 °C. After irradiation, we stored the FBG sample at room temperature for several weeks in order to stabilize all processes in the fiber followed by irradiation [12].

We used a climatic chamber Weiss SB22/300 for temperature and RH experiments. Temperature and RH were measured by internal sensors of the chamber and were additionally controlled by the Thorlabs TSP01 sensor. The FBG sample was tested using RH cycle at constant temperature of 30 °C and temperature cycle at constant RH of 40 %. During a cycle, temperature or RH was programmed to increase and then decrease stepwise. The RH or temperature change duration was 30 min, and the stabilization time at each value was 2 hours in the case of the RH cycle and 4 hours in the case of the temperature cycle. The increased stabilization time for the temperature cycle was used taking into account the impact of temperature change on RH in the chamber. The temperature was changed in the range of 25 – 50 °C and RH was changed in the range 40 – 100 %RH. The FBG sample was characterized in the climatic chamber before and after irradiation. Temperature annealing during three hours (65°C, 40 %RH) was applied prior to experiments to enhance the stability of the results and reduce possible hysteresis. We used a standard commercial interrogator (FiberSensing FS2200) operating in 1500-1600 nm wavelength range for the FBGs reflection spectra monitoring.

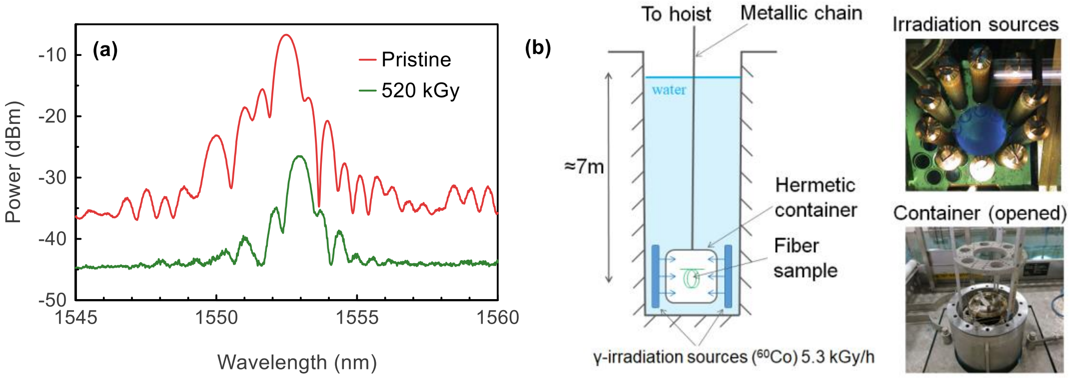

Fig. 1: FBG reflection spectra before and after irradiation (a); scheme and photographs of the irradiation setup (b).

3. Experimental results and discussion

Presented in Figure 1 (a) FBG reflection spectrum shows a strongly pronounced reflection peak corresponding to the fundamental mode of a few-mode fiber. The reflection power decreased by ≈20 dB as a result of 520 kGy dose of gamma radiation. However, the reflection spectrum, especially the peak corresponding to the fundamental mode, did not change significantly. Therefore, no difficulties occurred during the Bragg wavelength (BW) monitoring for both pristine and irradiated FBG cases. We underline that the red shift in the BW for the irradiated FBG is probably due to uncontrolled environment conditions during these spectra measurements.

The BW shift evolution during the RH cycle for pristine and irradiated cases is presented in Figure 2. It is seen that gamma radiation treatment significantly increased the RH response. The RH sensitivity is calculated to be 13.3 pm/%RH for pristine FBG and 56.8 pm/%RH for irradiated FBG. Thus, irradiated FBG demonstrates more than 4 times higher RH sensitivity than the pristine one. It should be mentioned that the stabilized BW values at the rising and the falling parts of the graph are well matched for the pristine case, while for irradiated FBG, a slight hysteresis is presented: the last BW value corresponding to RH of 40% is 110 pm less than corresponding BW value in the beginning of the cycle. This is 3.5% of the overall BW change of 3.13 nm. We also note that irradiated FBG requires approximately 2.5 times longer time to stabilize after 20% RH change comparing to the pristine one. This can be explained by the higher water absorption capacity of irradiated FBG.

Figure 3 shows the BW shift evolution during the temperature experiment. It is seen that despite two times longer stabilization time for each temperature step (4 hours comparing to 2 hours in the case of RH cycle), the BW does not stabilizes well. Nevertheless, it is clearly seen that irradiated FBG became more sensitive to temperature with the inversed sign. Temperature sensitivity was estimated to be 19.6 pm/°C for the pristine FBG and -38.9 pm/°C for irradiated one (almost twice the initial value). The ability of temperature sensitivity adjustment is attractive for temperature sensing, however, issues such as significant RH cross sensitivity and insufficient stabilization performance during the temperature cycle must be resolved. In contrast, strong and stable RH response seems prospecting for RH sensing. Moreover, since the temperature response changes its sign, one can suppose that the optimal gamma radiation dose can be found to decrease temperature sensitivity down to zero i.e. temperature cross sensitivity of the RH sensor can be potentially eliminated.

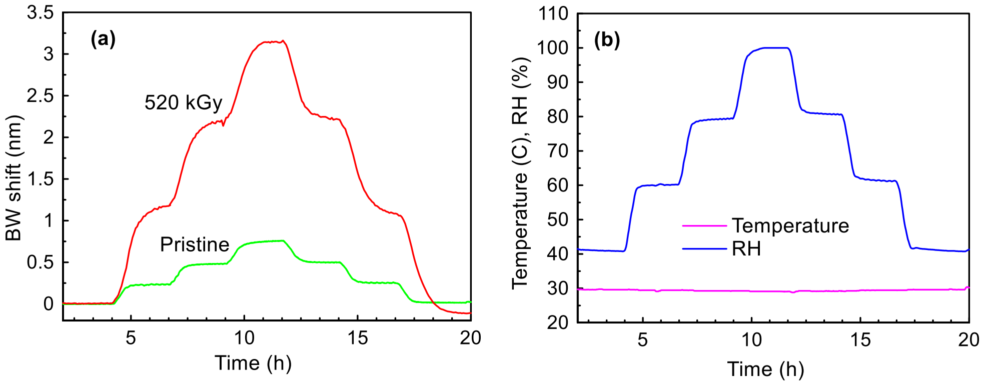

Fig. 2: Bragg wavelength shift time evolution during RH cycle for pristine and irradiated cases (a); corresponding temperature and RH evolution during RH cycle (b).

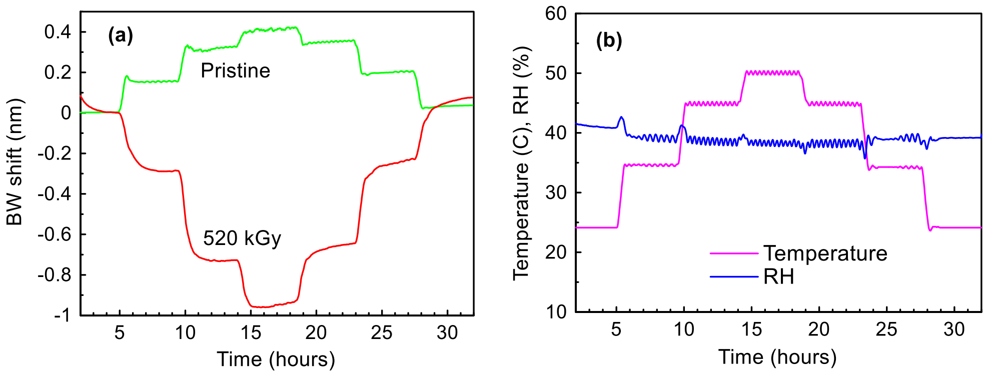

Fig. 3: Bragg wavelength shift time evolution during temperature cycle for pristine and irradiated cases (a); corresponding temperature and RH evolution during temperature cycle (b).

The RH effect observed above can be discussed taking into account the water absorptivity of the POF. As it is suggested in [9], the mechanism of RH sensitivity consists in swelling of the more hydrophilic XYLEX® overclad that leads to stretching of hydrophobic CYTOP® core. The rise of RH sensitivity after gamma irradiation can be caused by the water absorptivity increase of both CYTOP® core and XYLEX® overclad as a result of degradation or other gamma radiation-initiated processes (e.g. main chain scission, crosslinking etc.) of the materials. The temperature response is conditioned by the balance of the negative thermo-optic coefficient of CYTOP® core and the positive thermal expansion coefficient of the core and XYLEX® overclad. Therefore, possible reasons for the thermal response decrease down to negative values can be decreased thermal expansion coefficient of the core and (or) the overclad as well as an increased magnitude of the thermo-optic coefficient (or a combination of these effects) as a result of gamma radiation.

4. Conclusion

The FBG inscribed in a few-mode graded-index polymer fiber with CYTOP® core and XYLEX® overclad was investigated in this work for temperature and RH response. First, we tested the pristine FBG and then, after irradiation up to 520 kGy, the characterization was repeated. Experimental results showed an increase of RH sensitivity more than four times as a result of gamma irradiation. Also, temperature response became almost two times stronger and turned the sign from positive to negative. Thus, gamma radiation treatment can serve as an effective way to adjust the temperature and RH sensitivity of FBGs inscribed in CYTOP® fiber. Future research should be focused on applying various radiation doses aiming to find an optimal dose which can decrease temperature sensitivity down to zero. In this case, the sensors will exhibit enhanced sensitivity to RH changes and no sensitivity to temperature variations.

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