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Thomas Blanchet, Guillaume Laffont, Romain Cotillard, Emmanuel Marin, Adriana Morana, et al..
Radiation effects on type I fiber Bragg gratings: influence of recoating. 25th International Conference
on Optical Fiber Sensors, Apr 2017, Jeju, South Korea. pp.103232E, 10.1117/12.2263290 . hal-
01621128

HAL Id: hal-01621128

<https://hal.science/hal-01621128>

Submitted on 23 Jun 2022

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Radiation effects on Type I Fiber Bragg Gratings: influence of recoating

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ABSTRACT

We investigated the Bragg Wavelength Shift (BWS) induced by X-rays in a large set of conventional FBGs up to 100kGy dose. Obtained results give some insights on the influence of irradiation parameters such as dose, dose rate as well as the impact of some writing process parameters such as thermal treatment or acrylate recoating on the FBG radiation tolerance.

Keywords: fiber Bragg gratings, radiation, coating, annealing

1. INTRODUCTION

Since the last decades, Fiber Bragg Gratings (FBGs) have been studied for nuclear industries to measure external parameters such as temperature or mechanical strain. FBGs present many advantages like small size, light weight, electromagnetic immunity, short interrogation time response (compared with other fiber sensors), and wavelength multiplexing capabilities. A FBG consists in a periodic modulation of the refractive index along the core which causes the reflection of a narrow range of wavelengths, centered around the so-called Bragg wavelength (λ_B). This resonance wavelength is defined by two parameters *via* the relation:

$$\lambda_B = 2 n_{\text{eff}} \Lambda \quad (1)$$

with n_{eff} , the effective index and Λ the grating period. The spectral position of the Bragg wavelength is shifted when temperature or mechanical strain are applied to the fiber and can be used to monitor these changes. For example, for temperature sensing, in the range 20 - 100°C, λ_B linearly shifts with the temperature, according to the following relation:

$$\lambda_B(T) = \lambda_B(T_0) + \alpha(T - T_0) \quad (2)$$

where T_0 is a reference temperature and α is the temperature sensitivity coefficient, whose value is typically around 10 pm/°C at 1550 nm for silica fibers. Radiation can modify the grating response through two main processes: the creation of point defects and the compaction. The first process is responsible for an increase of the optical attenuation [1]. As a consequence, the signal intensity at the fiber output decreases as the signal-to-noise ratio. In some cases, the signal can be totally lost. Both the radiation-induced attenuation and the compaction can cause a modification of the refractive index and the grating period, which induce a shift of the Bragg wavelength peak [2, 3] hence causing a direct error on the temperature or strain measurements. Furthermore, other effects have to be considered as the possible influence of the fiber recoating on the Radiation Induced BWS (RI-BWS). Until now, only a few papers discussed the coating influence on the FBG radiation response. [4]

In this work, we characterize the X-ray induced BWS in Type I FBGs written in Telecom-grade fiber with and without acrylate coating at different dose-rates up to a total dose of 100 kGy that covers the environments associated with space, high energy physics and some nuclear industry needs.

2. EXPERIMENTAL PROCEDURE

The 5 mm long FBGs have been written at Laboratory H. Curien in Saint Etienne (France), using a cw Argon Laser at 244 nm and Lloyd's mirror interferometer in the Ge-doped SMF-28 manufactured by Corning. In order to increase the fiber photosensitivity, H₂ loading was performed at 150 bars and room temperature for one week [5].

Three type I FBGs have been written per fiber at different Bragg wavelengths (1548, 1554 and 1559 nm) to study the repeatability in the FBG radiation response. The gratings are separated spatially by a few millimeters.

After the inscription, a thermal treatment was applied to the gratings. The gratings were separated on two groups, the first one was annealed at 100 °C during 4 days, and the second one at 300°C for 1 h [6]. After the thermal treatment, half of all the gratings were recoated with acrylate No-61 (from Norland Products Incorporated) with a mini-coater from Nyfors. Table 1 resumes all the treatments performed on the FBGs.

FBG	Annealing		Acrylate re-coating
	Temperature (°C)	Time	
FBG 100	100	1 hour	No
FBG 300	300	4 days 15 hours	No
FBG 100 Co	100	1 hour	Yes
FBG 300 Co	300	4 days 15 hours	Yes

Table 1. Parameters of the FBGs studied under X-rays

The irradiation was performed using an X-rays machine (MOPERIX - at the Lab. H. Curien) up to a total dose of 100 kGy(SiO₂) at three dose-rates (0.5, 5 and 50 Gy/s) at room temperature (RT). As shown in figure 1, an Aluminium plate with bridles maintains the gratings inside the X-rays machine without any constraint. A thermocouple was integrated on the plate in order to measure the temperature variations and to separate the temperature effects on the BWS from the RI-BWS.

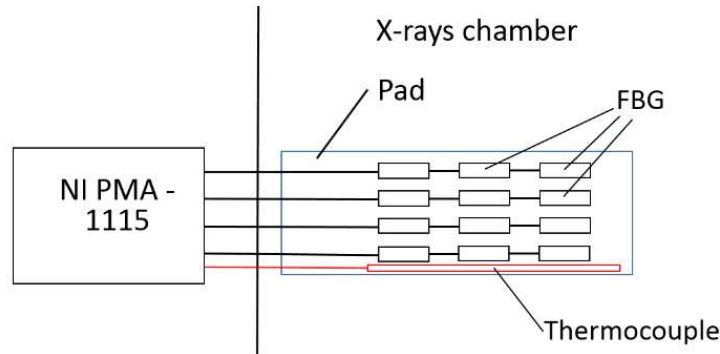


Figure 1. Experimental setup

The reflection spectra of the FBGs were recorded with a NI PMA-1115 optical sensor interrogator. This system has four optical channels operating between 1510 and 1590 nm, with a resolution of 30 pm at a 10 Hz frequency rate.

3. RESULTS AND DISCUSSION

In Figure 2, we report the radiation test results obtained for a group of 3 FBGs at the three studied wavelengths (1548, 1554, and 1559 nm). Those FBGs were uncoated and annealed at 100°C before irradiation at 5 Gy/s and RT. All the three FBGs show the same behavior during and after irradiation within a variation of 5%. In the following figures we will report only the average of the three curves obtained from the 3 FBGs of each group.

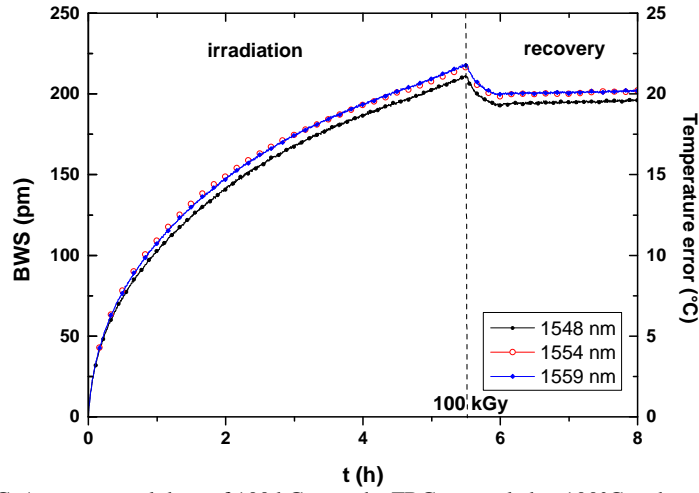


Figure 2. BWS induced at 5 Gy/s up to a total dose of 100 kGy, on the FBGs annealed at 100°C and non-recoated for 3 different wavelengths: full black dots: 1548nm; red dots: 1554 nm and blue lozenges 1559 nm. On the right the y axis corresponds to the error induced by the radiation on the temperature measurement when the FBGs are used as temperature sensors.

Figure 3 shows the results obtained on the four types of FBGs during X-rays irradiation at a dose rate of 5 Gy/s to a total of 100 kGy. The FBGs annealed at 100°C were more stable than those annealed at 300°C. This can be due to the different annealing durations. More studies will be performed for the conference.

Moreover, the recoated FBGs show a smaller BWS than the uncoated gratings for the 2 annealing temperatures, with a difference at the end of the irradiation of 70 pm for the FBGs annealed at 300°C and 20 pm for the FBGs annealed at 100°C.

The results reported in the literature by Gusarov *et al* [4] are however different. They suggest that the acrylate coating induces stress on the grating during gamma-rays irradiations. As a consequence, the FBGs without coating are less influenced by radiation than the ones with the acrylate coating. The difference might come to the radiation type: we used X-rays in our case. Since the γ -rays are more energetic than X-rays, we hypothesize that a part of the X-rays can be stopped by the coating. More tests and simulation will be performed to verify this hypothesis.

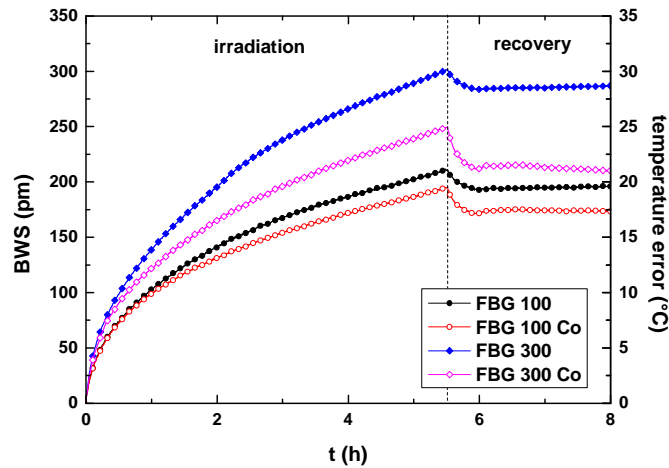


Figure 3. BWS at 5Gy/s up to 100kGy for the 4 types of FBGs full black dots: FBG 100, red dots: FBG 100 Co, full blue lozenges: FBG 300, pink lozenges: FBG 300 Co. On the right the y axis corresponds to the error induced by the radiation on the temperature measurement when the FBGs are used as temperature sensors.

Finally, figure 4 highlights the dose-rate effect by reporting the BWS induced by X-rays on the 3 uncoated FBGs annealed at 100°C at the three dose-rates, in order to reach 100 kGy accumulated dose. All the gratings exhibit a red shift as already observed on other type I FBGs [2]. Moreover, the BWS induced at 100 kGy is about 300 pm at 50 Gy/s and 120 pm at

0.5Gy/s. The higher is the dose-rate the larger is the RI-BWS, indeed at lower dose-rate the recovery process is more efficient. These results agree with those reported in literature [7].

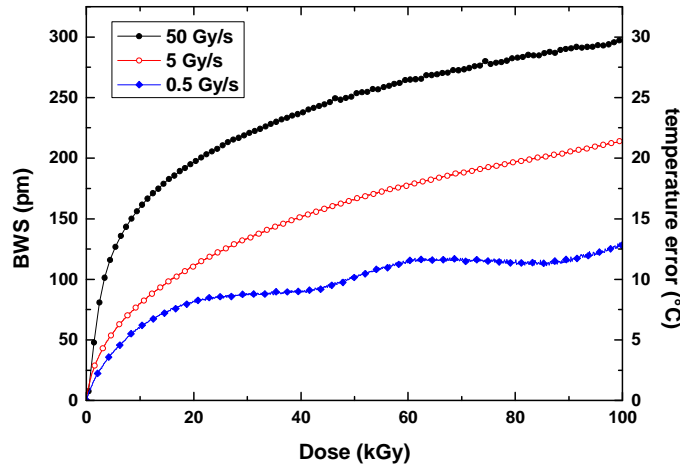


Figure 4. 3 FBGs annealed at 100°C without recoating at 3 dose rates 0.5, 5 and 50 Gy/s. On the right the y axis corresponds to the error induced by the radiation on the temperature measurement when the FBGs are used as temperature sensors.

4. CONCLUSION

In this work, we have studied the behavior of different type I FBGs under X-rays at different irradiation conditions. Preliminary results suggest that FBGs with acrylate recoating maybe slightly more tolerant to X-rays. Additional experiments will be done to support this hypothesis for the conference and further results on polyimide coating impact will be presented too as for some applications, FBGs have to operate in mixed high temperature/high radiation levels environments, eg. in nuclear power plants.

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