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Radiation and High Temperature Effects on Regenerated Fiber Bragg Grating

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Abstract—Fiber Bragg Gratings (FBGs) are promising sensors for operation in harsh environments mixing temperature and radiation constraints. Regenerated FBGs (RFBGs) are suited to perform measurements at very high temperatures (up to 1295°C) as those encountered in nuclear reactor cores. However, only a few studies have been done regarding combined effects of radiations and temperature on RFBGs. We studied the response of such gratings under X-rays at several irradiation temperatures from 25°C to 250°C. Tested RFBGs have been inscribed on a pre-hydrogenated Ge-doped fiber with UV laser (KrF) using a phase mask and the regeneration has been done at 750°C. Our results show that RFBGs are relatively radiation tolerant at 25°C with a Bragg Wavelength Shift (BWS) of less than 50 pm (~ 5°C error) for a total dose of 100 kGy(SiO₂). However, at increased irradiation temperatures (> 150°C), the BWS is limited, remaining below 10 pm (< 1°C error). We also studied the influence of a pre-thermal treatment (300°C for 5h) on the RFBGs response as well as the influence of other irradiation parameters, such as the dose-rate (1-20 Gy/s), the pre-irradiation (100 kGy) and the total dose (2 MGy) at 25°C. Radiation Induced-BWS increases with dose rate while the pre-thermal treatment has no influence.

Index Terms—Fiber Bragg gratings, optical fiber sensors, radiation, regeneration, temperature sensors, X-rays

I. INTRODUCTION

Fiber Bragg Gratings (FBGs) technology is one of the most studied Optical Fiber Sensors (OFS) mainly for temperature or strain monitoring. Creating a periodic refractive index modulation along the fiber core leads to the creation of this in-fiber diffraction grating [1], [2]. For an injected input spectrum the transmitted spectrum after the FBG will be unchanged except for few narrow bands that are reflected. The central wavelengths of these bands are known as Bragg wavelengths and depend on the effective index of the fundamental mode

(n_{eff}) and the period modulation of the core index (Λ):

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

with m standing for the diffraction grating order. A strain or temperature variation induces a Bragg Wavelength Shift (BWS). In the case of stress-free FBG, by knowing at a given temperature (T_0) the Bragg wavelength ($\lambda_B(T_0)$) and its temperature sensitivity, it becomes possible to convert any change of the Bragg wavelength into a temperature evolution according to the following equation:

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

The BWS appears to be linearly dependent on the temperature in the 25°C to 100°C range, with a temperature coefficient (C_t) around 10 pm/°C for silica based fibers [2].

In harsh environments the optical fibers are not immune to radiation (X-rays, γ -rays...) and several phenomena can be observed. First, the fiber attenuation increases due to the generation of defects associated with absorption bands in the bandgap. This phenomenon is known as Radiation Induced Attenuation (RIA) [3]. Another effect is the Radiation Induced Emission (RIE) which is the emission of light from defects excited by radiation or Cerenkov light [2]. The RIE is generally more intense in the ultraviolet-visible spectral range and does not influence the FBGs having Bragg wavelengths in the third telecom windows (1550 nm) [3]. The Radiation Induced Compaction (RIC), and the RIA, instead, can modify the refractive index profile of the fiber as it can be demonstrated with the relations of Lorentz-Lorenz and Kramers-Krönig respectively [2].

Ionizing radiation can induce a shift of the Bragg wavelength, also called RI-BWS (Radiation Induced-BWS), since the effective index and the period of the grating can change [2]. Moreover, the Bragg peak amplitude sometimes decreases leading to the FBG erasure.

Most of FBGs are photo-inscribed with high power lasers and interferometric methods [4]. In addition, post-inscription treatments can be applied to the gratings in order to stabilize them with regards to temperature [5] or to high radiation doses [6]. The photo-inscription method but also post-inscription treatment may lead to different types of gratings [7].

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Type I gratings are inscribed in photo-sensitive fibers with UV lasers. The fibers can also be pre-hydrogenated before inscription in order to enhance their photosensitivity. At high temperature ($>300^{\circ}\text{C}$), the Bragg peak amplitude of these gratings decreases down to the grating disappearance [8]. Under radiation, these FBGs are characterized by an important RI-BWS for pre-hydrogenated fibers. For example, a RI-BWS of more than 70 pm is observed for grating inscribed on hydrogenated SMF-28e (Corning) at 100 kGy(SiO_2) under γ -rays at Room Temperature (RT) [9]. On the contrary, FBGs inscribed in non-hydrogenated fibers present a BWS of less than 20 pm under the same irradiation conditions [9].

Type II gratings are often called damaged gratings, since the energy at the focal point is above the damage threshold of silica [10]. This is achieved using light emitted from femtosecond laser. With this method it is possible to inscribe FBGs even in non-photosensitive fibers [11]. This type of gratings resists to temperature up to 1000°C [7]. Concerning their radiation responses, it has been observed that a single thermal treatment at 750°C during 15 min after the grating inscription (following the procedure described in [12]) in a pure silica core fiber increases their radiation-resistance, indeed under X-rays the RI-BWS is reduced to less than 10 pm at RT and at MGy dose level [6], [12].

Void gratings or type III FBGs are inscribed point by point by focusing the femtosecond laser inside the fiber core. This method creates void bubbles [13]. This type of grating can resist up to 1000°C [14] and under X-rays at RT, the grating inscribed in Fluorine doped fiber presents a RI-BWS of less than 5 pm to a total dose of 1 MGy [15]. However, by combining X-rays and temperature (200°C) these gratings shift more than 20 pm at 1 MGy [15] and their thermal stability is not preserved.

Another grating type is the regenerated one (RFBG) [7] previously known as Chemical Composition Grating (CCG) [16]. A type I grating is inscribed in a pre-hydrogenated photosensitive fiber (Ge-doped or Ge-F co-doped) or pure silica core fibers. The regeneration occurs when this “seed” grating is heated at temperature above 500°C until its erasure. The regenerated FBG appears a few minutes after the seed FBG erasure. These gratings are stable at temperature up to more than 1000°C with no evidence of erasure [17]. Significant Bragg wavelength shifts are observed under radiation for this class of gratings [18], [19]. For the CCGs written in a fluorine germanium co-doped fiber, a RI-BWS of more than 10 nm is observed at an accumulated dose of 2 GGy (γ -ray) and a fluence of 10^{20} neutrons/cm² with an irradiation temperature of 150°C .

For grating inscribed in pre-hydrogenated Ge-doped fibers and regenerated at 900°C , under X-rays at a total dose of 33 kGy and RT, a RI-BWS of 40 pm is observed [19]. Under irradiation, the RI-BWS is larger at RT than at high temperature, indeed a shift of only 8 pm is observed at 600°C at the same dose [19]. In our previous study, we observed a RI-BWS of 35 pm for RFBG at 100 kGy at RT [20].

In this paper, we studied the response of the RFBGs to combined temperature and X-rays constraints. After demonstrating the RFBG stability at 300°C we performed irradiations at 10 Gy/s up to 100 kGy at different temperatures: 25°C , 80°C , 115°C , 150°C and 250°C . We studied also the dose-rate effects (1 Gy/s, 10 Gy/s and 20 Gy/s) and we verified the influence of a pre-irradiation or a thermal treatment on the

gratings response to an irradiation at RT up to 100 kGy. In order to observe possible saturation effects on the RFBG response, we increased the total dose up to 2 MGy.

II. EXPERIMENTAL SETUP

During the inscription, the regeneration process and the irradiation tests the grating spectra were recorded in reflection with the Tunics/CT-400 Component Tester from Yenista. The Tunics device is a tunable laser emitting between 1500 and 1630 nm with a maximum output of 10 mW (for the experiment the output was set to 1 mW), whereas the CT-400 is a 4-channel spectrometer with a minimal resolution of 1 pm. Up to 4 FBGs were simultaneously investigated in reflection thanks to four circulators. The measurement time for each spectrum is lower than 15 s. We fit all the spectra with a 3rd order polynomial in order to extract the Bragg wavelength. At least 2 similar FBGs were used for each experiment, with an exception for the high dose rate test for which only one grating was characterized. The RFBGs were fixed stress-free on an Aluminum plate with two bridles, for the temperature/radiation tests, whereas during the regeneration process no Aluminum plate was used. Thermocouples (TCs) were used during the irradiation tests, to compensate the Bragg wavelength drift due to the temperature variations and to extract only the RI-BWS (Figure 1).

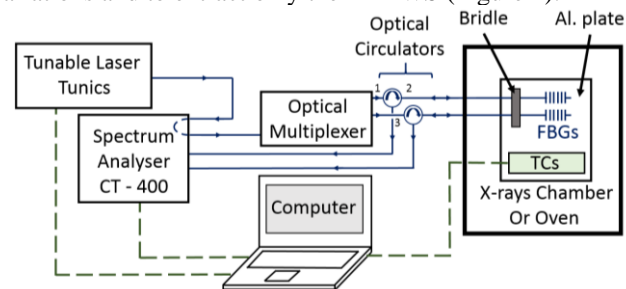


Fig 1. Experimental setup used for the experiments under X-rays and inside the oven, with an exception for the regeneration process where no Al plate was used.

The gratings were inscribed at the CEA List (LCAE) in a highly Germanium-doped fiber pre-hydrogenated at 200 bars during two weeks at RT. For these samples, a KrF pulsed laser (BraggStar M from coherent) at 248 nm with a repetition-rate of 100 Hz, a pulse energy of 9 mJ and a pulse duration of 20 ns was used. The regeneration was performed less than two days after the inscription; during this time the gratings were kept at RT.

The irradiations were performed using the Moperix machine at the LabHC in St Etienne (France). X-rays are created by Bremsstrahlung effect on a Tungsten target with a mean energy of ~ 40 keV for 100 kV in input. The dose-rate can be tuned by changing the distance between the target and the sample. In addition, a heating plate was added inside the facility to reach temperatures up to 250°C during these irradiation runs.

III. RESULTS

A. Thermal Regeneration

The seed gratings were regenerated inside a vertical oven during almost 2 hours. Fig. 2.a shows the BWS during the regeneration. During the first 18 min the temperature inside the

oven increases up to 750°C and the Bragg wavelength red-shifts. The FWHM decreases quickly and the peak amplitude varies of ~5 %. From 18 min to 32 min the oven temperature is constant at 750°C and the FBG is erased, indeed the FWHM decreases of a further 26 % and peak amplitude is reduced from 41 dB to 11 dB. From 32 min to 34 min the grating completely disappears, while the oven is still at 750°C. Between 34 min and 60 min the RFBG appears, with an increase of the peak amplitude. Furthermore, the Bragg wavelength and FWHM of the RFBG are very similar to those of the seed grating just before erasure.

The most common explanation for the regeneration process is the hydrogen presence at the core-cladding interface that generates high pressure when the temperature increases. This may lead to the creation of Cristobalite which is normally stable at 1470°C at ambient pressure, but can be metastable at lower temperature [17], [21].

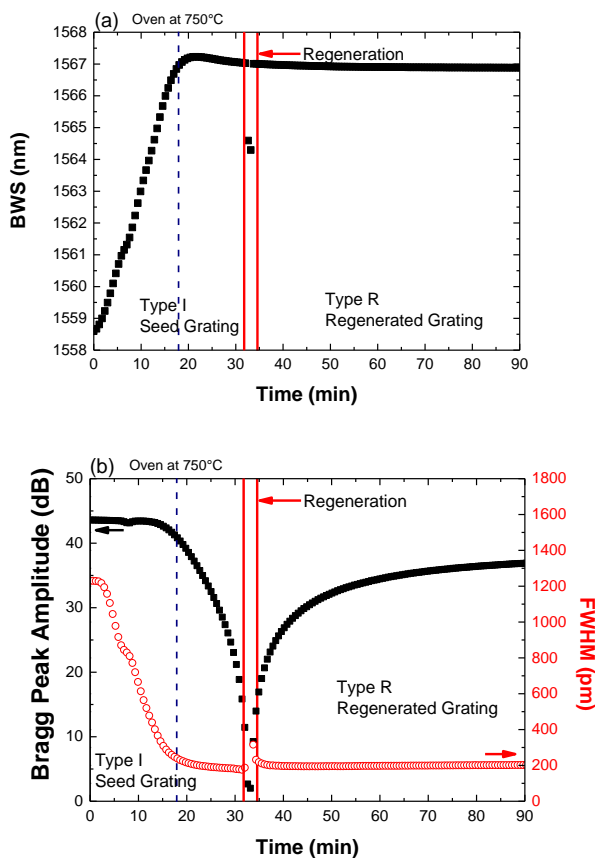


Fig 2. (a) Bragg wavelength variations induced during the regeneration process, with the seed grating erasure at 32 min. The RFBG reappears at 34 min. (b) The Bragg peak amplitude (black squares – left) and FWHM (red empty circles – Right) variations during the regeneration process.

B. RFBG Temperature Sensitivity Coefficient

In order to correct the Bragg wavelength shift during the experiments (irradiations or thermal treatments) we measured the thermal sensitivity coefficient (eq. 2) before and after the tests. We considered that the temperature coefficient remains linear on a range of 50°C. The error made on our measurement is 0.5 pm/°C. Table I reports the RFBG temperature coefficients at different temperatures.

TABLE I
TEMPERATURE SENSITIVITY COEFFICIENTS AT 25°C, 80°C, 115°C, 150°C, 250°C AND 300°C BEFORE AND AFTER IRRADIATION AT 10 Gy/s UP TO 100 kGy AT 250°C

Temperature	C_t (pm/°C)		Relative Error
	Before Irradiation	After Irradiation	
25°C	11.4	11.5	0.8 %
80°C	11.4	11.5	0.8 %
115°C	12.4	12.5	0.8 %
150°C	13.2	13.3	0.8 %
250°C	14.5	14.8	2.1 %

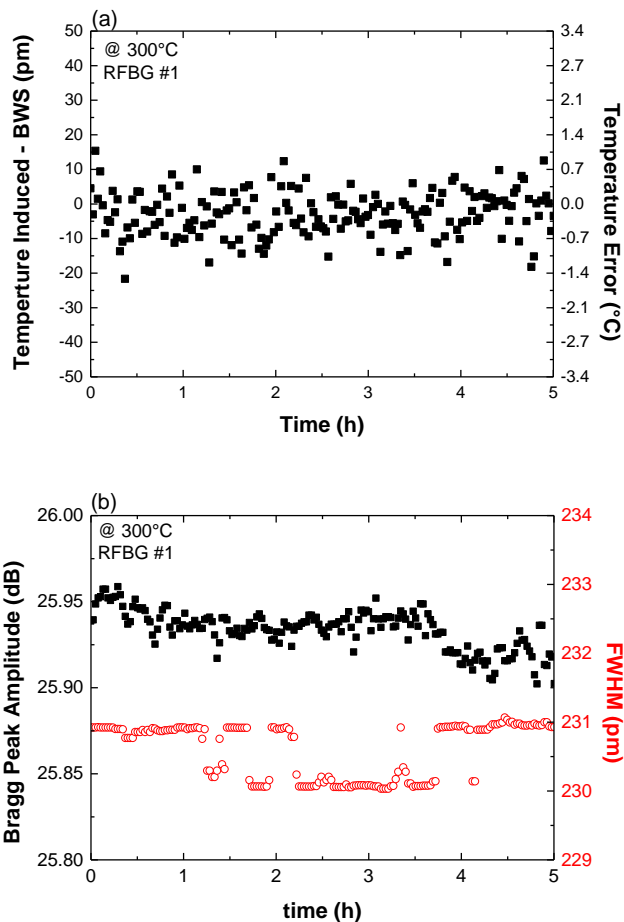


Fig. 3. Grating stability at 300°C during 5 h for RFBG #1. (a) Left-axis gives the variation of the BWS corrected in temperature, right-axis represents the temperature error for a grating used as a temperature sensor. (b) Bragg peak amplitude variations (black squares) and FWHM variations (red empty circles).

The thermal sensitivity coefficient does not change with the irradiation within an error of 2 % (obtained at 250°C).

Since the Bragg wavelength increases with temperature according to a 3rd order polynomial, it is expected that by considering the thermal sensitivity coefficient linear on a range of 50°C, this coefficient follows the same trend with temperature. Since the temperature fluctuations inside the oven or the thermal plate are less than 1.5°C, the maximal correction made on the BWS is 0.8 pm.

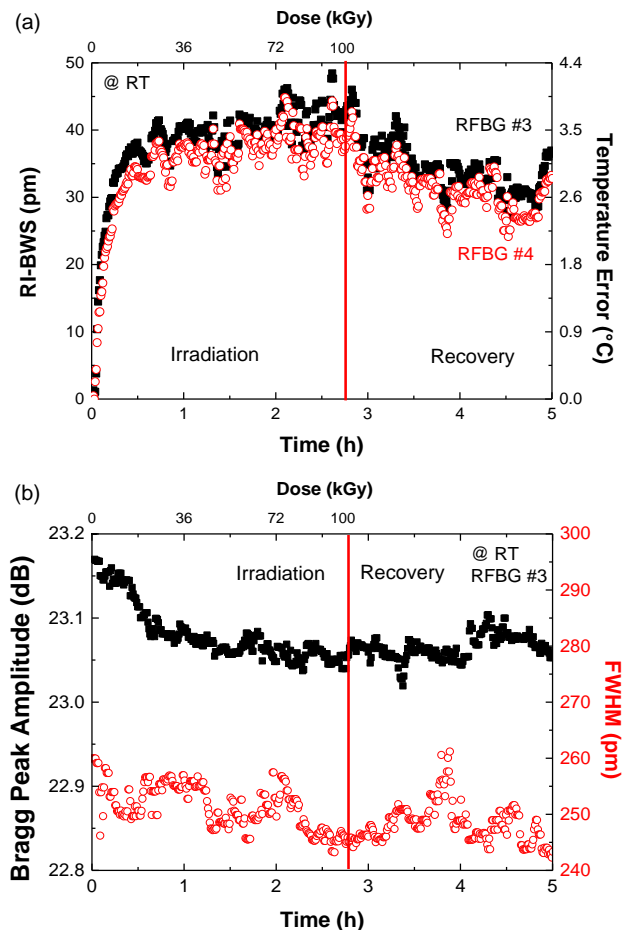


Fig. 4. Irradiation at 25°C of two similar RFBGs at 10 Gy/s up to 100 kGy. (a) RI-BWS and its recovery post irradiation. (b) Bragg peak amplitude (black square – Y-left axis) and FWHM (red empty circle – Y-right axis) recorded during and after irradiation for the RFBG #3 sample.

C. Thermal Stability

In order to check the RFBG thermal stability during an irradiation run at 250°C, we performed a thermal treatment on RFBG up to 300°C for 5 h, period exceeding the run duration.

Fig. 3.a. shows the BWS due to the thermal treatment for the RFBG #1. The gratings are stable at 300°C during 5 h, with an error of less than 15 pm on the Bragg wavelength. This noise is probably due to the temperature inhomogeneity inside the oven. Moreover the FWHM and the peak amplitude (Fig. 3.b.) are stable, indeed the peak amplitude variation is less than 0.05 dB and the FWHM one is less than 1 pm, which corresponds to the Tunics/CT-400 resolution. As other previous studies on the thermal stabilities of RFBG [7], we conclude that this type of gratings is stable in temperature, assessed in our specific case at 300°C during at least 5 h.

D. Combined Effects of Temperature and Radiation

In this section only the results at a dose-rate of 10 Gy/s up to a total dose of 100 kGy are reported at 5 different temperatures (RT, 80°C, 110°C, 150°C and 250°C). The RI-BWS is again corrected for temperature fluctuations in order to highlight only the X-ray RI-BWS. For Fig. 4, 5, 7, 8 and 9 the y-right axis entitled “Temperature Error” gives the radiation induced temperature measurement error when the RFBG is used as a temperature sensor.

1) Irradiation at 25°C

Fig. 4 compares the irradiation responses at 25°C (RT) of two identical RFBGs. RI-BWS quickly increases up to ~37 pm for doses lower than 18 kGy, followed by a slower increase (less than 5 pm for a further accumulated dose of 82 kGy). During the recovery, the Bragg peak shifts by less than 10 pm towards the “blue” wavelengths. The Bragg peak amplitude (Fig. 4.b) for the grating #3 presents a variation of less than 0.15 dB which may be due to the RIA effect. In addition, the FWHM remains constant within 20 pm. These variations can be explained by the noise level in the RFBG spectrum. Similar behavior was observed for RFBG #4 (not reported).

2) Irradiation at 250°C

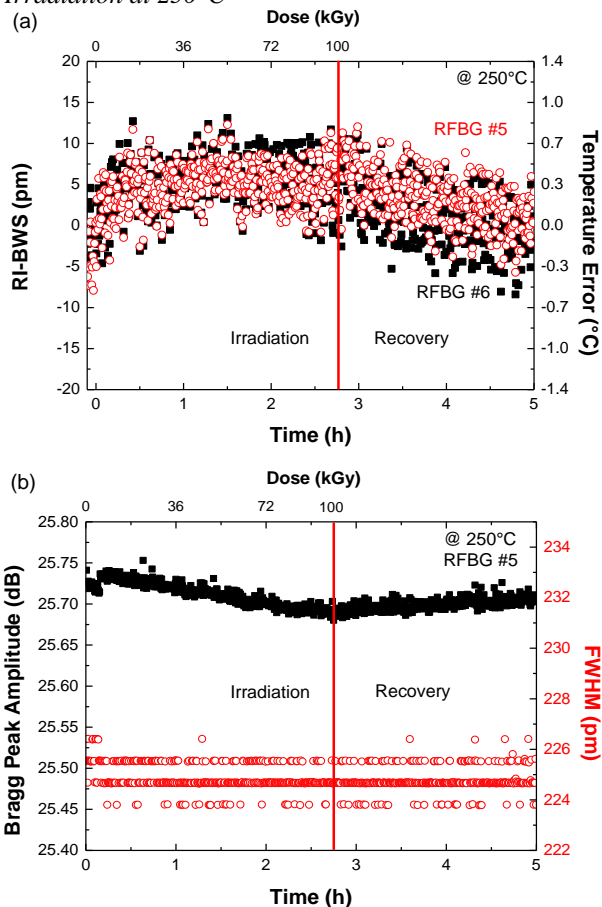


Fig. 5. Irradiation at 250°C of two similar RFBGs at 10 Gy/s up to 100 kGy. (a) RI-BWS and its recovery post irradiation. (b) Bragg peak amplitude (black square – Y-left axis) and FWHM (red empty circle – Y-right axis) recorded during and after irradiation for the RFBG #5 sample.

Two pristine RFBGs (no pre-treatment with the exception of the regeneration process) were irradiated at 250°C under the same conditions. We observed in Fig. 5a. RI-BWS lower than 10 pm. The heating plate at 250°C exhibits, in steady state, temperature fluctuations of less than 0.3 % as measured by the two thermocouples placed on the Aluminum pad, near the RFBGs. During the recovery, the Bragg wavelength blue-shifts of less than 5 pm. During all these experiments, the RFBG peak amplitude decreases of less than 0.05 dB, which is less important than the variations recorded at RT during the same

irradiation conditions (0.15 dB). The FWHM does not vary within 3 pm.

3) Comparison Between the Results at RT, 80°C, 150°C and 250°C

Fig. 6 compares the average response of two RFBGs irradiated at the same conditions (dose rate and dose) but at different temperatures: 25°C, 80°C, 115°C, 150°C and 250°C.

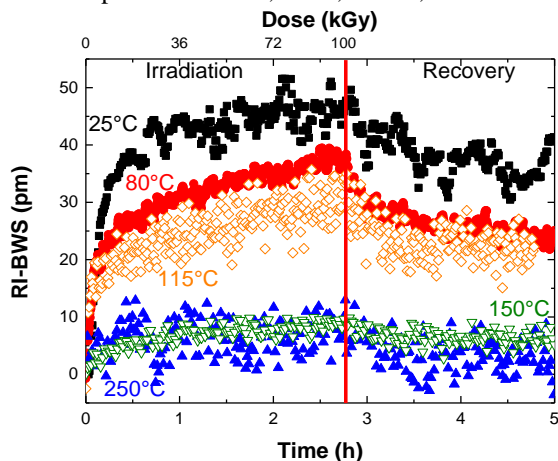


Fig. 6. Average of the radiation induced Bragg wavelength shift (RI-BWS) of two RFBGs during an irradiation at RT (Black square), 80°C (red circle), 115°C (empty orange lozenge), 150°C (empty green down triangle) and 250°C (blue up triangle) with a dose-rate of 10 Gy/s to an accumulated dose of 100 kGy.

The 100 kGy irradiations at 25°C, 80°C and 115°C are associated with RI-BWS of (45 ± 5) pm, (37 ± 10) pm and (30 ± 5) pm, respectively. During the irradiation at 150°C and 250°C, the Bragg peak shifts less than (10 ± 2) pm. In addition, no sign of erasure was observed since the FWHM and the Bragg peak amplitude did not vary significantly. In conclusion the higher is the irradiation temperature the lower is the RI-BWS. Moreover, the grating is stable under irradiation at temperature exceeding 150°C.

E. Dose-Rate Effects at RT

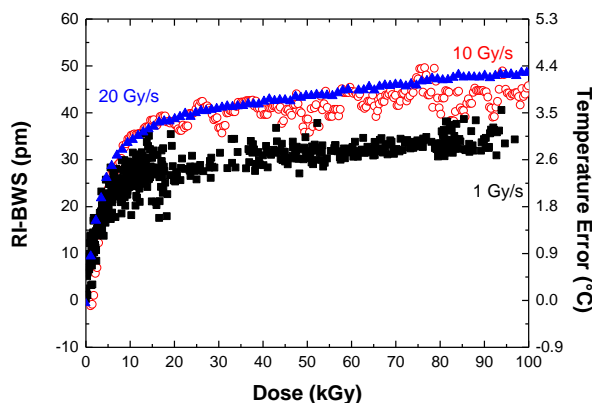


Fig. 7. RI-BWS at RT up to 100 kGy at three different dose-rates: 1 Gy/s (black square), 10 Gy/s (red empty circle) and 20 Gy/s (blue triangle).

In this section we report the response of RFBGs irradiated at RT up to a total dose of 100 kGy at three different dose rates: 1, 10 and 20 Gy/s. For the irradiation at 20 Gy/s only one RFBG

was used. For all the dose-rates no FWHM variation is observed and the peak amplitude varies by less than 0.15 dB.

From Fig. 7, a dose-rate effect is clearly visible: RI-BWS at 100 kGy is about 50 pm for the 10 Gy/s or 20 Gy/s dose-rate whereas it is only 30 pm at 1 Gy/s. The higher is the dose-rate the larger is the Bragg wavelength shift, as already demonstrated for type I FBGs [22], [23]. For void gratings no dose-rate dependence was observed [15].

F. Gratings stabilization

1) Thermal treatment influence

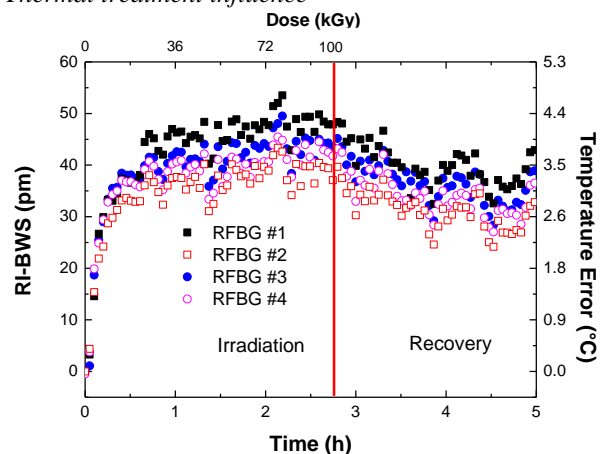


Fig. 8. Irradiation at RT at 10 Gy/s to 100 kGy of four RFBGs. RFBGs #1 (black square) and #2 (red empty circle) had a thermal treatment of 5 hours at 300°C between the regeneration process and the irradiation and RFBGs #3 (blue full circle) and #4 (pink empty circle) had no thermal treatment.

As expected from section C, to check the grating stabilization at high temperatures, we performed a thermal treatment at 300°C during 5 h after the RFBG inscription.

We irradiated (RT, 10 Gy/s up to 100 kGy) two gratings (RFBG #3 and #4) not treated after the regeneration and compare their response to two other RFBGs (#1 and #2) that have been thermally treated at 300°C during 5 h. As clearly shown by Fig. 8 results, such thermal treatment has no effect on the behavior of the RFBG under X-rays up to 100 kGy at RT.

2) 100 kGy Pre-irradiation Before MGy Dose Exposure

Since the thermal treatment performed before irradiation does not improve the grating radiation response at RT, we performed an irradiation to a total dose of 2 MGy at 10 Gy/s at RT on one of the RFBG #3 previously irradiated at 100 kGy and on a pristine one.

We observe in Fig. 9 that up to 2 MGy at RT the pristine RFBG has a BWS of more than 100 pm, which corresponds to a temperature measurement error exceeding 8.8°C. As for the other results, we observe an important RI-BWS of 40 pm at the beginning of the irradiation (18 kGy). However, the pre-irradiated RFBG shows a reduced RI-BWS during the same period (only 30 pm). At 2 MGy, the pre-irradiated grating shifts by 80 pm. From this preliminary test, we can conclude that, as observed for other FBG types, a pre-irradiation may increase the radiation resistance but a pre-irradiation at 100 kGy is not sufficient to stabilize the RFBG up to 2 MGy at RT.

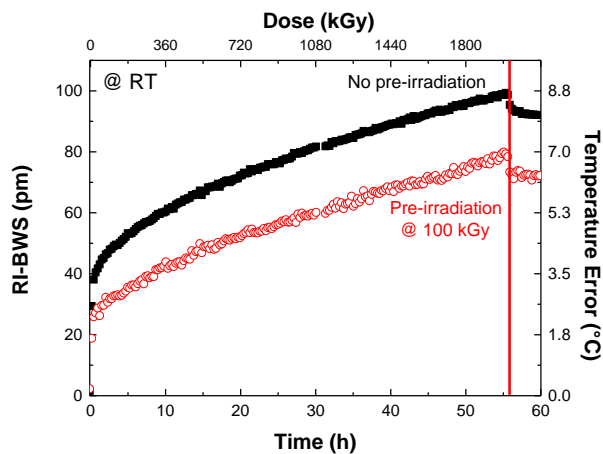


Fig. 9. Irradiation at RT with a dose-rate of 10 Gy/s up to 2 MGy: black squares give the response of a pristine RFBG whereas red empty circles give the one of the RFBG #3 pre-irradiated at 100 kGy at RT.

IV. DISCUSSION

Regenerated FBGs are stable at high temperature (assessed specifically for this study at 300°C during 5 h – Fig. 3.a.) as expected. Under X-rays the gratings are affected by radiation at RT. Indeed a RI-BWS of more than 100 pm is observed at the dose of 2 MGy (SiO_2) without saturation tendency. However, our results show that the higher is the irradiation temperature, the more radiation resistant became the RFBGs.

At temperatures more than 150°C the RI-BWS is less than 10 pm. However, Fernandez *et al.* [18] irradiated CC gratings under a mixed flux on thermal/fast neutrons and γ radiations and they observed a RI-BWS for their gratings above 12 nm at a total flux of 10^{20} neutrons/cm² and total ionization dose of more than 2 GGy for an irradiation temperature of 150°C. The results are difficult to compare since several parameters differ for the two experiments, above all the fiber composition, the inscription techniques and the regeneration temperature. Indeed, our seed gratings were written with a KrF laser emitting at 248 nm in a germanium doped fiber and the regeneration was performed at 750°C; whereas Fernandez *et al.* inscribed their gratings in a Ge/F co-doped fiber, these gratings were regenerated at 1000°C. Clearly, depending on the fiber choice and the regeneration conditions, different basic mechanisms can be involved. In our case, we supposed the creation of Cristobalite [17, 21]. Fernandez *et al.* [18], instead, explained the creation of their CCG with the migration of hydrogen from silica or germanium sites to fluorine ones. Moreover, the regeneration temperature can have an influence on the grating radiation response, as already demonstrated for type I [2], [9] and type II gratings [6].

Concerning the irradiation conditions, our RFBGs were X-irradiated up to 100 kGy, a dose at which the compaction can be neglected whereas Fernandez *et al.* [18] performed a neutron irradiation (at a flux of less than 10^{14} neutrons/(cm².s¹)), where the compaction phenomenon cannot be neglected [24], [25], as observed by Remy *et al.* [25]. An average linear compaction of 0.25% is induced at the fluence of more than 3.10^{19} neutrons/cm² (irradiation temperature being at 291°C). This compaction will induce a variation of the grating period

and consequently a BWS. However, the authors [18] supposed that their grating response was mainly due to the hydrogen diffusion from the coating leading to the grating destruction. Because of the radiations the fluorine is replaced by hydroxyl groups. In our case we suppose that more defects are created in the non-inscribed fringe than in the inscribed ones creating an increase of the effective refractive index. However, the defect center generation depends on the irradiation temperature, it can increase or decrease with temperature [28], regarding the recombination efficiency of the defects, this parameter increases with the temperature.

Another study on the RFBGs radiation response was performed by Laffont *et al.* [19]. Their seed gratings were inscribed in a germanosilicate fiber (SMT-A1310H from OFS Company) with an Argon laser (continuous wavelength at 244 nm) and a Lloyd mirror interferometer and the regeneration was performed in an oven at 900°C. Their RFBGs were irradiated with 9 MeV X-rays at RT with a dose-rate of ~ 7 Gy/s and at temperatures from 200 to 800°C with a dose-rate of ~ 1.5 Gy/s.

At a total dose of 33 kGy a RI-BWS of about 55 pm was observed at RT, and this value decreased with temperature increase down to less than 10 pm at 600°C. These gratings show a lower radiation resistance compared to those tested in our study, indeed in our case an irradiation temperature of only 150°C is enough to decrease the RI-BWS to less than 10 pm (Fig. 6). This difference can be related to both the kind of fiber used (high Ge content fiber versus a SMT-A1310H fiber) and to the regeneration temperature, which is 750°C for our gratings instead of 900°C in [19]. However, other differences between the two experiments have to be highlighted, such as the FBG inscription techniques and the irradiation conditions.

The RFBGs show the classical behavior under high temperature and radiations of type I gratings [9]. Since the used X-rays are not very energetic (~ 45 keV), we neglect the RIC contribution. As a consequence, the RFBG radiation response can be explained by the competition between the creation and recombination of defect centers [26]. Radiation creates defects in all fiber types [26], [27], but by increasing the irradiation temperature, RIA decreases for the Ge-doped ones [28], showing a similar behavior of the RI-BWS of the regenerated gratings.

At temperatures higher than 150°C, no RI-BWS was observed. Thus we can suppose that there is a new and favorable equilibrium between the creation and the recombination of the defects under such conditions.

We reported a dose-rate effect for the irradiation at RT (Fig. 7). The higher is the dose-rate, the higher is the RI-BWS. This behavior has already been observed for type I gratings under γ -rays [2], [22] or X-rays [22], [29] at RT. As before, there is a competition between creation and recombination: at higher dose-rate more defects will be created, with a lower efficiency of the recombination effect [2].

V. CONCLUSION

We performed X-ray irradiation and temperature tests on several Fiber Bragg Gratings (RFBGs) regenerated at 750°C. We verified their thermal stability for at least 5 h at 300°C. Under irradiation at RT up to 2 MGy, the RFBGs are shown to be quite radiation sensitive. Even a pre-irradiation (100 kGy)

nor a thermal treatment (5 h, 300°C) did not improve the grating response under X-rays at RT.

At irradiation temperatures lower than 115°C the grating presents a RI-BWS as important as those observed at RT. For temperature above 150°C, the grating becomes more radiation resistant and a RI-BWS of less than 10 pm is observed. This is suggested to be due to a more favorable equilibrium between the creation and recombination of radiation induced defects at these temperatures.

In addition, we observed a dose-rate effect: the higher is the dose-rate the larger is the Bragg wavelength shift, as for type I gratings. In all the tests no significant variations of the Bragg peak amplitude or FWHM were observed confirming the grating stability. However for the integration of such devices inside nuclear power plants further experiments have to be performed as investigating the responses of these gratings under γ -ray at higher temperatures (600°C). Their response to high neutron fluence has also to be investigated in the future.

To conclude, type R gratings appears as quite radiation resistant and promising devices for operation in harsh environments combining high temperature (150°C) and high doses.

VI. REFERENCES

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