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Femtosecond Void-based Fiber Bragg Gratings Responses under both X-rays and High Temperature

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Abstract: Type III (void) femtosecond Fiber Bragg Gratings inscribed with the point-by-point techniques in the SMF-28 fiber and thermally annealed were irradiated under both X-rays and temperature ranging from -75°C up to 150°C. © 2022 The Author(s) (35 mots max)

1. Introduction

Optical Fiber Sensors (OFSs) present numerous advantages as their small size and weight, an immunity to almost all the electromagnetic perturbations, ... From all of these sensor types, Fiber Bragg Gratings (FBGs) in singlemode fibers are periodic perturbation of the effective refractive index of the guided mode giving rise to a diffraction grating which reflects a narrow spectral band located at the Bragg wavelength proportional to the mean fundamental mode effective refractive index and to the grating's pitch. Wavelength multiplexing can be achieved by simply writing FBG with different periods along a single fiber. Any change of the measurand (e.g. temperature, strain, ...) observed by a given "sensing" FBG induces a spectral shift of its Bragg wavelength [1]. The measurand is spectrally encoded in the form of a spectral shift while the sensor identity is given by the absolute Bragg wavelength.

If the temperature increases, the Bragg wavelength shifts (BWS) toward the higher wavelengths. The relation between the temperature and Bragg wavelength can be approximated by a linear equation over moderate temperature ranges where the slope corresponds to the thermal sensitivity coefficient (C_t), which is about 10 pm/°C at 1550 nm and around Room Temperature (RT). Type III gratings also called void-gratings are written using femtosecond lasers and can withstand temperature up to 1000°C [2]. The periodic modulation of the core index consists of micro-void bubble with a densified shell [3]. Radiation Induced-Bragg Wavelength Shift (RI-BWS) is the main phenomena, which occurs when a grating is irradiated, and it will cause an error on the temperature measurement if the FBG is used as a temperature sensor. Type III gratings inscribed in Ge-doped fiber present a RI-BWS of about 15 pm (1.5°C) at a total dose of 1 MGy(SiO₂) with a dose-rate of 40 Gy/s at RT and almost 20 pm (2°C) when the irradiation temperature is set at 200°C with the same irradiation parameters [4].

In this abstract, we have inscribed type III FBGs using the Point-by-Point (PbP) method in an uncoated SMF-28 fiber from Corning and a part of them were annealed during 30 min at 750°C. Then the gratings were irradiated at -75°C, 25°C and 150°C with a dose-rate of 10 Gy/s up to a total dose of 100 kGy.

2. Experimental Setup

Type III FBGs have been written in an uncoated SMF-28 fiber using the PbP technique and a femtosecond laser at CEA List LCFO facilities. FBGs, 5 mm long, were inscribed per sensing line and half of these lines were annealed during 30 min at 750°C in a similar process than the radiation-hardened treatment used for type II gratings and described in [5]. Then the FBGs were placed stress free on an aluminum pad, similar to our other experiments on regenerated or type R FBG [6], inside the so-called Moperix X-ray chamber (LabHC, St Etienne) delivering X-ray with a mean energy of 40 keV. The dose-rate was set at 10 Gy/s up to a total dose of 100 kGy at temperatures of -75°C, 25°C and 150°C. The spectra were recorded using an external cavity tunable laser (Tunics) and an associated Component Tester CT-400 from Yenista (EXFO) achieving a spectral resolution of 1 pm. The Bragg wavelength was extracted from the spectrum with a 3rd order polynomial fitting method. During the irradiation, the Bragg peak shift was corrected from the temperature fluctuations for the irradiation tests at RT and 150°C, with temperature fluctuations of ±0.5°C in the second case, while in the third case at -75°C, the Bragg wavelength was not corrected and the variations are estimated to be ±1°C. Also during this experiment, only one grating per group was irradiated. For the other two irradiations, the Bragg wavelength corresponds to the mean of five Bragg peak shifts.

3. Results and discussion

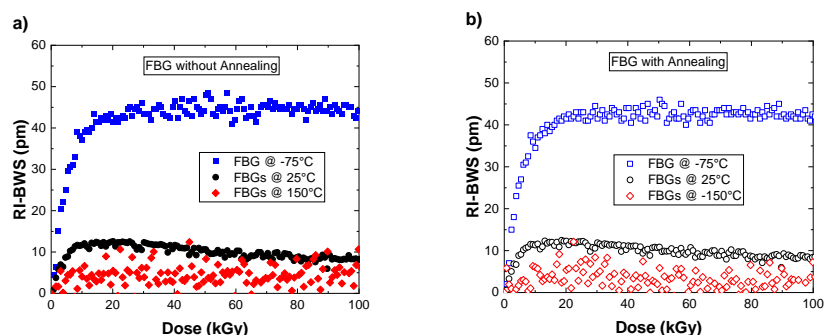


Fig. 1. Irradiation at a dose rate of 10 Gy/s up to 100 kGy at temperature of -75°C (blue square), around 25°C (black circle) and 150°C (red lozenge) for the non-thermally annealed grating (a) and thermally treated ones (b)

The two grating groups were irradiated to a total dose of 100 kGy at a dose rate of 10 Gy/s at three distinct temperatures (-75°C , 25°C and 150°C). The first group of gratings with no thermal treatment present a RI-BWS of 45 pm at -75°C , 9 pm at 25°C and around 5 pm at 150°C (Fig. 1.a). At the lowest temperature, two phases are observed with an initial Bragg peak shift up to 45 pm at 20 kGy and a second phase where the Bragg wavelength did not shift anymore. At the irradiation temperature of 25°C , the same phases are observed, with an initial BWS around 12 pm at 10 kGy and a stabilization of the Bragg peak shift afterward. At the highest temperature, the Bragg wavelength shift of around 4 pm but due to the temperature variations, the uncertainties are estimated to be about 5 pm. For the second group of gratings with the thermal treatment at 750°C during 30 min, the RI-BWS at 100 kGy are the same as for the gratings without any thermal annealing (Fig. 1.b).

The thermal annealing, similar to the ones performed to obtain Radiation-resistant type II FBGs as described in [5], did not modify the type III behavior under X-ray radiation. Since the micro-voids are written in the fiber core, only the core material (Ge-doped silica) around the bubble contributes to the radiation sensitivity of the component. As the annealing temperature is too low to modify the core material structure, this explains the similar results between the two FBG groups.

4. Conclusion

We have inscribed 5-type III FBGs per line in a SMF-28e fiber. Half of the lines were submitted to a pre-annealing at 750°C during 30 min. Then all the gratings were irradiated up to 100 kGy at temperatures of -75°C , 25°C and 150°C . We did not observe any behavior modifications between the gratings with regards to their thermal pre-treatment. At the lowest temperature, the Bragg peak shift corresponds to about 6°C of error at 100 kGy. When the temperature is increasing the Bragg peak shift is less important and when the irradiation temperature reached 150°C , the temperature error measured by the grating is less than 1°C which corresponds to our measurement error. For the conference, we will compare the grating reflectivity on the radiation responses as well as the influence of a pre-irradiation treatment or radiation influences on the grating thermal response.

5. References

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