Fibre Bragg Gratings for dose estimation in BR2 nuclear reactor installation

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We describe a case study where FBGs are used as dosimeters to determine the dose-rate in a rig installed in the BR2 nuclear reactor pool, Mol, Belgium.

Introduction

At SCK-CEN the POSEIDON facility is used for neutron transmutation doping, see https://www.sckcen.be/en/Services_Consulting/Silicon_doping. Recently an urgent request was made to perform dose estimation at the location of the POSEIDON rotation motor, Figure 1. Theoretical estimations give a very uncertain values for the gamma-dose expected at this location, ranging from kGy to MGy dose accumulated during one operation cycle. This uncertainty had to be resolved.

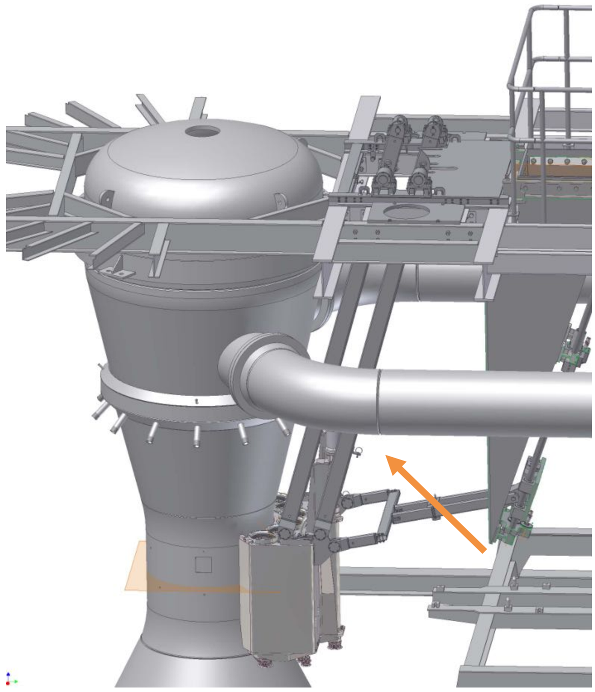

Figure 1 Poseidon facility at BR2. The rotation motor compartment is indicated by the arrow. It is located in the pool ~1.8 m above the reactor mid-plane.

The routine dosimetry system used at BR2 is based on Harwell PMMA dosimeters with the range 1 – 50 kGy. However, at ~MGy doses, considered as an upper limit, the PMMA decompose with release of gases, which include H_2 and O_2. In view of this gas release the use of PMMA dosimeters was deemed not possible.

The decomposition of PMMA under radiation was confirmed by performing gamma-irradiation of a PMMA block, Figure 2. Cracks due to formation of gas bubbles are visible at 1 and 2 MGy. After some storage these blocks spontaneously broke in small part.

(a) (b) (c) (d)

Figure 2 PMMA block (a) before irradiation, (b) after 250 kGy, (c) 1 MGy, (d) 2 MGy.

In this situation, it was decided to attempt making a dose estimation using fibre Bragg gratings (FBGs) written in silica fibres. Such components present no environmental hazard at high doses. Silica can sustain GGy dose levels. The acrylate coating usually became brittle after several MGy, making manipulation of the exposed fibres difficult.
The idea of using FBGs for dosimetry is based on the detection of the Bragg wavelength shift (BWS) as a result of irradiation [1]. It is discussed in literature for a decade [2] but without practical implementation. The main problems are: a low resolution in a kGy range, temperature cross-sensitivity, dependence of the BWS on the fabrication procedure, high cost, and a need of accurate and delicate measurement equipment. In the present case all these limitations were not critical and no other option for solution of the acute problem could be proposed on a short term.

Experiment

The FBGs for the experiment were fabricated at the University of Mons. A summary of the properties of the gratings is given in Tab. 1. The gratings were characterized at UMons before irradiation, Figure 3.

Ref	Type of optical fiber	# FBG	FBG length (mm)	Inscription method	Laser/ Wavelength	Recoated	λ_B before, UMons	λ_B after, SCK
G1	Draka Bendbright	2	2,5	Lloyd	CW / 244nm	No	1532.212	
G2	POFC UVTC1	3	5	Lloyd	CW / 244nm	through coating	1544.123	
G4	Corning SMF28	1	6	Phasemask	Femto / 800nm	through coating	1547.856	
AG5	Nufern PS-PM980	2	10	Phasemask	CW / 244nm	No	1548.879	1548.915
AG7	Corning SMF28	1	6	Phasemask	Femto / 800nm	through coating	1548.000	1548.040
AG9	HighWave EDF750	1	8,5	Phasemask	Nano / 193nm	No	1548.982	1549.025

Tab. 1 Summary of exposed gratings. All gratings were uniform.

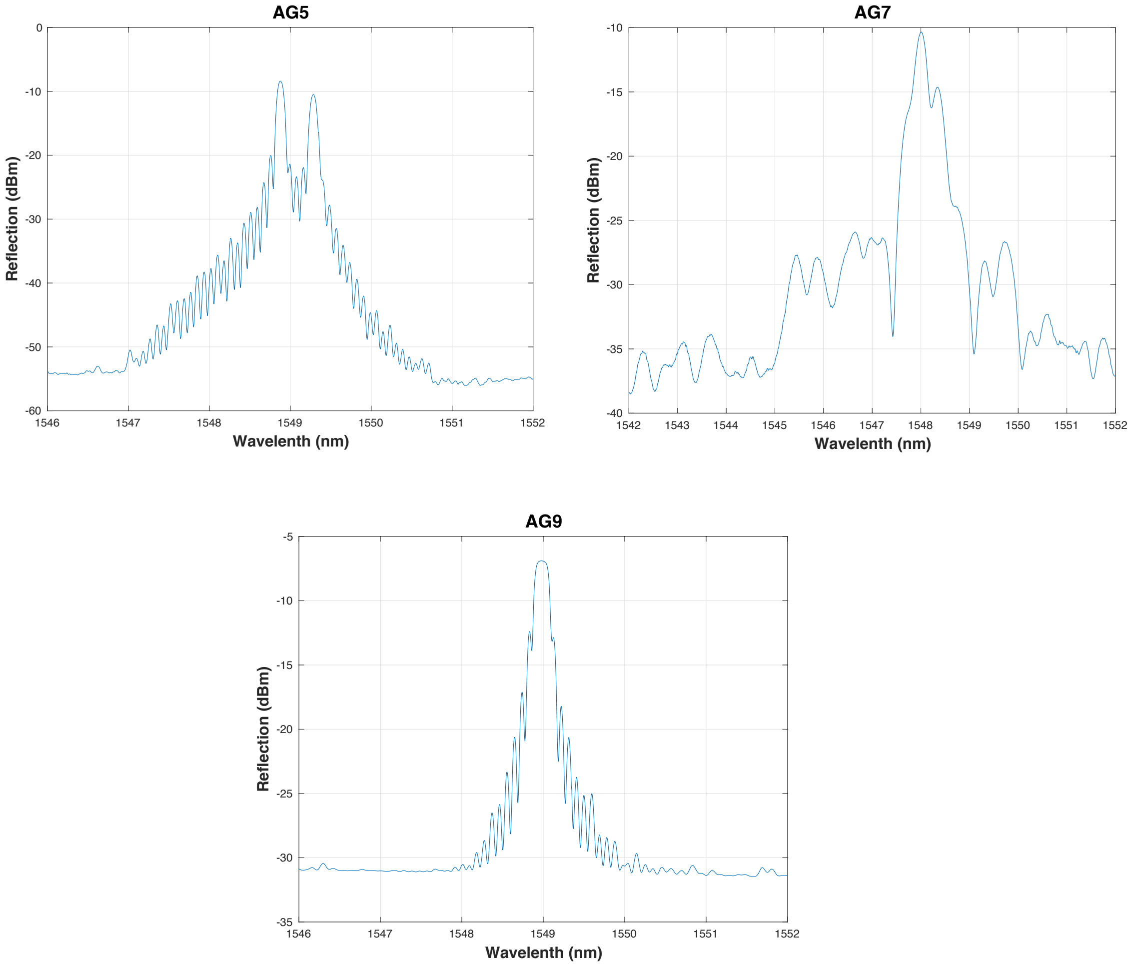

Figure 3. Reflection spectra of the gratings before the exposure.

Due to a shortage of time cross-characterization at SCK was not possible. The gratings were exposed from 03/07/2019 (full power at ~14h) till 11/07/2019 (~22h), which correspond to 200 h of exposure. The estimated temperature during exposure is ~37°C.

Post-Irradiation Control

Post-irradiation measurements were performed about a month after the exposure, on 07/08 using Micron Optics si720 interrogation system. It allows measurement of the gratings spectra both in transmission and reflection. The measurements were performed on three gratings, AG5, AG7, AG9. Software built-in in the device was used to define the peak/notch wavelength. Measurements in transmission and reflection gave similar results. For the reflection spectra the central wavelength was also defined as the average of the wavelength at a –3 dB level as compared to the peak. It was nearly the same as the peak wavelength.

For all three gratings measured at SCK the Bragg peak shift was ~40 pm with the laboratory temperature at 25°C. The measurements at UMons were performed at 22-23°C. Correction for the temperature-induced shift gives an estimation of 20 pm for the radiation-induced effect.

The radiation sensitivity of the exposed gratings was not known at the time of measurements. Therefore, we used literature data [3-6] to make an estimation, were

BWS of gratings written in different types of fibres was studied. According to [3] the post-radiation recovery of the peak shift saturates after several hours and is up to 20% at ~10h. In our case the annealing was four weeks and the irradiation temperature was slightly higher than during experiments in [3]. Therefore, the annealing effect should be stronger. As a conservative estimation of the annealing effect ~30% was taken, which means that directly after the irradiation the shift was ~30 pm. According to the data given in Figure 6 of [3] this corresponds to a dose in a range of 5 – 15 kGy. Taking into account the exposure duration of 200 h, this means that the exposure was made at a dose-rate of 25 – 75 Gy/h. These dose and the dose-rate are well within the measurement range of the Harwell PMMA dosimeters and the standard dosimetry could be safely performed. In practice, the standard dosimetry was postponed to a suitable moment because the FBG measurements effectively ruled out radiation as a cause of the exploitation problems, which allowed to discover the actual root.

Conclusion

We have described a case study when FBGs were used as dosimeters to determine the dose-rate in the POSEIDON rig installed in the BR2 nuclear reactor, Mol, Belgium. The measurements gave an estimation of the exposure dose in a range 5 – 15 kGy. In many cases such broad range may be seen as not good enough. However, in our particular situation it allowed to obtained useful information and to open the possibility to perform more accurate standard dosimetry.

Acknowledgment

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