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#05-163 Fiber Bragg Grating based sensors for applications in harsh environments.

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Nowadays, the optical fiber sensors (OFSs) have attracted the interest not only of researchers but also of industries, for their applications in harsh environments characterized by high temperatures and/or radiations. The Fiber Bragg Grating (FBG) based technology is one of the most widely studied under radiation [1]. Even today it presents qualities unbeatable by other OFSs, such as its high acquisition repetition rate, that can reach at least 20 kHz with an adequate acquisition system. Even if it is not a distributed sensor, as the ones based on scattering phenomena, it is easily multiplexable, which means that several point sensors can be placed in series on a same fiber. However, the research on the radiation-response of different types of gratings is still active, since the radiation degrades their performances through two phenomena:
- Radiation-Induced Attenuation (RIA), which reduces the signal transmission,
- Radiation-Induced Bragg Wavelength Shift (RI-BWS), which introduces an error on the sensing parameter measurements.

In this work, we will compare two of the best FBG technologies that are considered for applications in severe environments with the more classical FBG type.
o The Rad-Hard type II gratings (RH-type II-FBGs) are manufactured with the patented procedure developed by Areva and the Laboratoire H. Curien [2]: these type II FBGs were written with a femtosecond laser at 800 nm in radiation-resistant fibres, having a fluorine doped or pure-silica-core. Before the irradiation they were subjected after their writing to a short thermal annealing at 750℃. The chosen manufacturing process parameters combined with this pre-treatment enable to reduce the RI-BWS below 10 pm (error of about 1℃ on the temperature measurements performed by the sensor) after MGy dose of irradiation [3].
o The regenerated gratings (R-FBGs) are obtained by treating at high temperatures (higher than 650℃) a strong type I grating inscribed in a H2-loaded Ge-doped fiber by an UV laser (continuous wave or pulsed in the nanosecond regime) [4]. The seed grating quickly disappears during the annealing and, in its place, another grating, the R-FBG, appears. The new grating is resistant to high temperatures and, preliminary results show that its radiation resistance increases at high temperatures, with a RI-BWS of only 10 pm, at irradiation temperature higher than 150℃ at 0.1 MGy dose [5].
o The type I-UV FBGs are the most classical grating type: the FBGs were written with a cw UV laser (at 244 nm) in a H2-loaded Ge-doped fiber and thermally stabilized at 120℃. Contrary to the two previous gratings, this one does not resist to high temperature or to radiations: the Bragg peak shifts with the dose; moreover, the higher is the temperature, the lower is the BWS [1].

It is worth noticing that both R-FBG and RH-type II FBG undergo a treatment at high temperature, however, the mechanisms at the origin of these gratings are very different and still under investigation. Moreover, whereas the R-FBG has to be written into a photosensitive fiber, as the Ge-doped one, the RH-type II-FBG can be inscribed into a rad-hardened fiber, as the F-doped one, which is less affected by the RIA compared to the Ge-doped one.
We report in Fig. 1 a first example of the Bragg wavelength shift induced by the gamma-rays at room temperature (RT) on the three FBGs. The experiments have been conduced at the IRMA facility of the IRSN (Saclay, France).

Fig. 1. Bragg wavelength shift, corrected for temperature fluctuation (recorded by thermocouples) induced by gamma-rays on the three types of gratings at RT, dose-rate being 1.3 kGy/h, up to TID of 500 kGy.

The BWS of the RH-type II-FBG is only few pm, as expected for this rad-hard solution. The type R and type I-UV FBGs, instead, red-shift of ~30 pm and 50 pm, at the total ionizing dose (TID) of ~500 kGy. The reported curves are a bit noisy, probably because of a non-perfect correction of the nights and days temperature fluctuations.
In the final paper, these three grating types will be irradiated under gamma- and X-rays at different temperatures up to the MGy dose level, in order to investigate the real performances of the sensors based on these

technologies. We will also investigate different pre-loadings of the Ge-doped fiber for the R-FBGs inscription, since our group recently showed the possibility to regenerate FBGs written in D2-loaded Ge-doped fibers [6].

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