# Radiation hardened temperature measurement chain based on femtosecond laser written FBGs in a specific optical fiber

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**Abstract:** a radiation resistant temperature measurement chain based on femtosecond laser written FBGs is described. First results confirm a suitable design to withstand foreseen harsh nuclear environment both in term of temperature and cumulated dose
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## 1. Introduction

Following Fukushima accident, safety standard in the nuclear industry have been increased. In this demanding context, optical technologies shall provide intrinsic advantages, in particular for remote sensing (multiplexing, long range, fast response and immunity to electromagnetic field). Based on femtosecond laser written fiber Bragg gratings (FBGs) [1] and supported by a KIC InnoEnergy funding, our consortium is currently developing a complete temperature measurement chain. Operation in nuclear harsh environment, temperature up to 350°C and cumulated gamma rays dose up to 1MGy($SiO_2$), is targeted. The sensing probe comprises one or several radiation hardened FBGs written in a specific optical fiber inserted into a stainless steel tube. Optical signals will be monitored using a compact interrogator located several hundred meters away for the hot zone thanks to a reinforced optical cable equipped with rugged connectors. Insights concerning those elements will be detailed in the following sections.

## 2. Specific radiation resistant optical fiber

A radiation resistant single mode optical fiber has been developed within the scope of this project. It comprises a pure silica core, a 2wt% fluorine doped silica cladding (dark gray in figure 1) and a metallic coating in order to withstand both maximal temperature and irradiation field specified in our system requirements. Table 1 presents some of its geometrical and optical properties. Obtained low bending loss level (compliant with ITU-G657.A2) will ease cabled fiber integration. Figure 1 presents the fiber cross section after chemical removal of the metallic coating. Radiation induced attenuation, measured at 20dB/km at 1.55µm for a $^{60}$Co gamma rays dose of 200kGy($SiO_2$) at 0.7Gy($SiO_2$)/s [3], shall be taken into account for future system safety margin calculation.

Table 1: Main fiber properties

| | |
|---|---|
| Core diameter | 7.0µm |
| Cladding diameter | 125µm |
| Coating diameter | 165µm |
| LP11 cut-off wavelength | 1.3µm |
| Mode field diameter@1.55µm | 9.0µm |
| Optical losses@1.55µm | 15dB/km |
| Bending losses@1.55µm for r=7.5mm | 0.06dB |

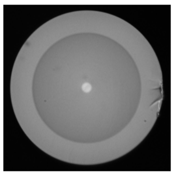

Figure 1: Fiber cross section

## 3. Radiation resistant FBGs

Radiation and temperature resistant 4mm long FBGs are written into bare fibers with a phase-mask technique using a Ti:sapphire fs-IR laser. Radiation hardness, i.e. low radiation induced Bragg wavelength shift (RI-BWS), is obtained by a thermal post-treatment at a temperature higher than 500°C for at least 15min [1]. Optimization of gratings inscription parameters allows reducing maximal RI-BWS down to ± 4pm (corresponding to a temperature error of ± 0.4°C) when exposed to a soft X-rays (40keV) cumulated dose of 1MGy($SiO_2$) delivered at room temperature [2]. Figure 2 provides a typical transmitted spectrum measured with an optical spectrum analyzer. Obtained in band depth and FWHM, respectively of ~8dB and ~0.5nm, are well suited to sensing applications.

It is worth noticing the presence of cladding modes signature. Work is ongoing to reduce their impact, in particular for some specific FBGs array configurations. Figure 3 represents the response of such FBGs when exposed to $^{60}$Co gamma rays up to 200kGy($SiO_2$) at 1Gy($SiO_2$)/s at 335°C [3]. Maximal temperature error remains in the vicinity of ± 1°C (± 10pm), except for one sensor (FBG 6) presumably suffering from a process issue.

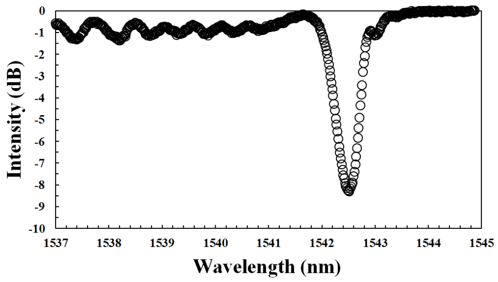


Figure 2 : Typical transmitted spectrum

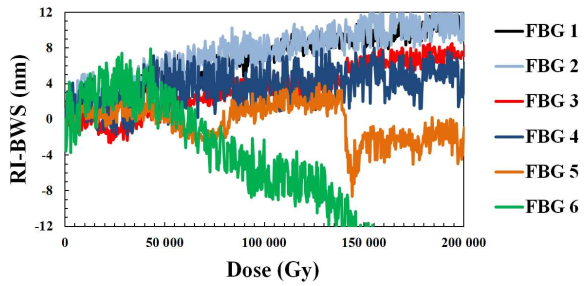


Figure 3 : RI-BWS versus cumulated dose at 335°C

## 4. Measurement chain

Figure 4 presents the complete measurement chain developed by the consortium: terminal temperature probe comprising a hardened FBG in a fiber in metal tube with connector, soft-line cable and compact interrogator. The full assembly qualification will start according to nuclear industry standards. Very first temperature cycling depicted on figure 5 are in line with expectation.


Figure 4 : Complete terminal temperature measurement chain

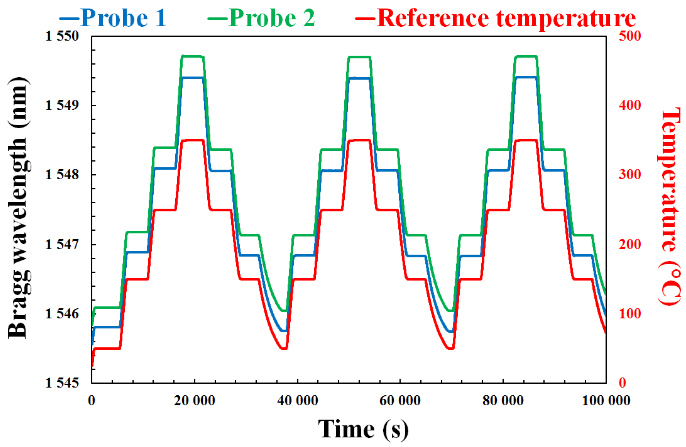


Figure 5 : Temperature calibration of two first terminal probes

## 5. Conclusion

A complete radiation hardened temperature measurement chain based on femtosecond laser written FBGs in a pure silica core fiber has been developed and tested. Work is ongoing to extend the concept to strain measurement.

## 6. References

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