# Bragg Gratings with Enhanced Temperature Sustainability Written in a High-Germanium-Doped Fiber

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***Resumo*** **- Nesta contribuição apresentam-se redes de Bragg com elevada estabilidade às variações de temperatura, resultantes de regimes de exposição do tipo IIA e de um novo tipo especial, comparando-se os resultados de estabilidade com os de outras redes, obtidas a partir de diferentes mecanismos de crescimento, nomeadamente de tipos I e IA. Espera-se que as redes de tipo IIA, e a referida como especial, conduzam a uma melhoria da fiabilidade de aplicações sensoriais a temperaturas elevadas, bem como de dispositivos para comunicações ópticas baseados em redes de Bragg.**

***Abstract*** **- In this contribution we report the achievement of fiber Bragg gratings exhibiting high temperature sustainability, resultant from type IIA and a new abnormal exposition regimes, and compare their thermal stability with other gratings obtained from different growth mechanisms, namely type I and IA. It is expected that type IIA and the designated as abnormal gratings improve the reliability of high-temperature grating-sensing applications and grating-based components for optical communication systems.**

## I. INTRODUCTION

Fiber Bragg gratings (FBGs) are widely used for numerous applications in optical communications, and as sensing elements of various physical quantities. For a number of such applications, FBGs should withstand heating to high temperatures, and therefore the optimization of gratings' thermal stability has received considerable attention during the last few years [1]-[3].

The thermal stability of gratings depends on numerous factors such as the doping material, the pre- or pos-fabrication treatment used, and the exposition regime considered. Until recently, FBGs have been found to exhibit three distinct structural types according to their different growth mechanisms, the most commonly observed type I, and two other regimes, type II - arising from physical damage - and type IIA - most often observed in non-hydrogenated high Germanium (Ge) doped optical fibers [4]. Recently, Liu *et al.* have reported a new regime they termed type IA [5], obtained in hydrogenated germanosilicate fibers, which has been further studied [6].

In this letter we report a new FBG with high temperature sustainability, obtained from an abnormal growth mechanism (different from the presented), and compare its thermal stability with other FBGs, resultant from the three referred regimes.

## II. FBGS FABRICATION

The FBGs used in this investigation were written in a commercial high Ge doped optical fibre (Fibercore SM1500 4.2/125), hydrogenated or not, by exposing it to an interference pattern originated from a UV beam through a phase-mask.

The type IIA $FBG_1$ was written using KrF excimer laser (248 nm), with a fluence of 300 mJ/cm$^2$ per pulse and a pulse repetition rate of 30 Hz, after 100 minutes irradiation. Type I $FBG_2$ was obtained by stopping a potential type IIA regime, after only 7.5 minutes (reflectivity ~0.7). To obtain the type IA $FBG_3$ first we have hydrogenated the fiber, keeping it under high-pressure hydrogen atmosphere (100 bars) during four weeks. After the UV exposure - continuous wave from a $Ar^+$ laser (244 nm) - the hydrogenated grating without coating was annealed for 4 h at 80 °C, to remove unreacted hydrogen. $FBG_4$ was written considering the same UV source conditions as $FBG_3$, but using the non-hydrogenated fiber instead.

In Fig. 1 [7] we present the measured maximum reflectivity ($R_{max}$) and mean refractive index perturbation ($\Delta n_{mean}$) - obtained from the Bragg wavelength shift - as a function of the irradiation time, for the referred FBGs.

Observing Fig. 1 we notice that, as regards the evolution of $FBG_4$ perturbation (mean value and amplitude - related to $R_{max}$), it cannot be associated to any of the indicated regimes. Clearly it is not a type I regime. The $R_{max}$ variation could suggest the growth of a type IIA grating, with UV exposure resulting in the grating erasure, followed by a new spectral formation. However, we do not observe the typical Bragg resonance blue shifting ($\Delta n_{mean}$ decrease), associated to that new formation (instead, $\Delta n_{mean}$ continuously increases with UV exposure) [4]. On the other hand, it is not observed the characteristically large red shift of the Bragg wavelength that accompanies type IA grating formation [5][6]. In order to conclude about this abnormal regime, in the next section we will study its thermal behaviour, comparing it with the other mechanisms.

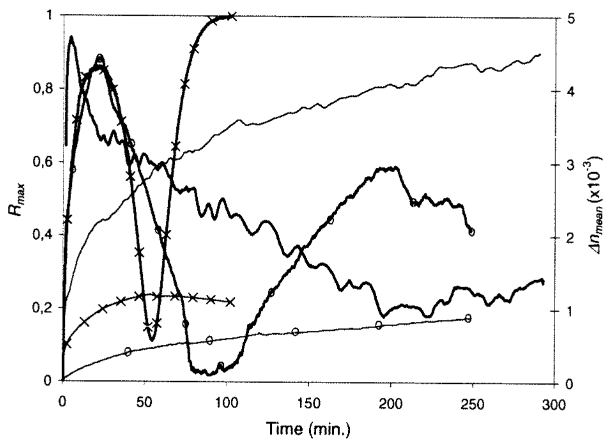


Fig. 1. Measured parameters during the gratings ($FBG_{1,2}$ -x-, $FBG_3$ —, $FBG_4$ -o-) formation: $R_{max}$ (heavy lines) and $\Delta n_{mean}$ (hair lines) [7].

## III. EXPERIMENTAL RESULTS

Following gratings fabrication, we now evaluate the temperature performance (stability) of the four described FBGs.

To observe their thermal decay characteristics, the gratings were placed in a tubular stove and the temperature was increased till 800 °C, with step of 100 °C. The measured reflectivities are presented in Fig. 2 [7]. Considering as a limit a 10% decrease on the reflectivity (relatively to the initial one), the acceptable temperatures are approximately 550 °C, 150 °C, 200 °C and 350 °C, respectively for $FBG_1$ (type IIA), $FBG_2$ (type I), $FBG_3$ (type IA) and $FBG_4$ (abnormal).

The highest/lowest temperatures are sustained considering respectively type IIA/type I FBGs, following the results presented in the literature [4]. Type IA $FBG_3$ presents a slightly higher temperature limit than type I $FBG_2$. On the other hand, the grating obtained from the abnormal regime ($FBG_4$) has been shown to sustain considerably higher temperatures than both of them (type I and IA), although lower than the type IIA one. Additionally, when performing the reflectivity measurements, we observed that the variations on the reflection spectrum bandwidth as the temperature increased were much more evident for type I and IA FBGs. For the other FBGs (abnormal and type IIA), those variations are negligible.

The observed temperature dependencies for the different FBGs, may indicate several potential applications for them, within optical communications and sensing.

Indeed, type IIA FBGs can sustain high temperatures, and therefore may find application in sensing heads for industrial environments where large temperature variations occur [8]. FBGs like the obtained from the regime we considered abnormal, may also be used in such applications, although for a lower temperature range.

Also, this observed high stability (for both type IIA and abnormal FBGs) may result in optimized thermo-tunable

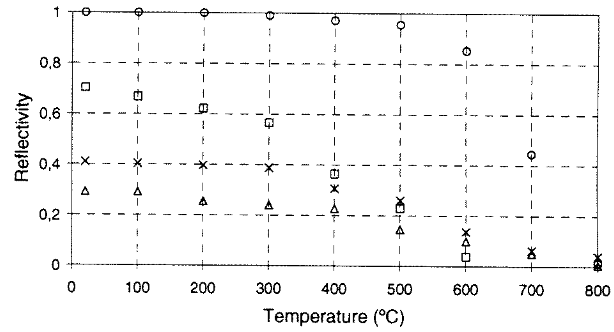


Fig. 2. The evolution of the reflectivity for the different gratings, $FBG_1$ (o), $FBG_2$ (€), $FBG_3$ ($\Delta$), $FBG_4$ ($\times$) as the temperature is increased [7].

(central wavelength and/or dispersion) optical filters for lightwave systems [9].

## IV. CONCLUSIONS

We have compared the thermal stability of FBGs obtained from distinct exposition regimes, namely type I, IA, IIA and a new regime we designated as abnormal, written in a high-Ge-doped fiber. The highest temperature stability is achieved for the type IIA FBG. The grating obtained from the abnormal regime presents a lower temperature limit, although higher than the achieved for type I and IA FBGs. Therefore, it is envisaged that type IIA and the referred as abnormal FBGs improve the reliability of high-temperature grating-sensing applications and FBG components for optical communication systems.


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