Thermally Tunable Bragg Grating Filtrers for Wavelength-Multiplexed Systems

M. J. N. Lima, O. Frazão, A. L. J. Teixeira, P. S. B. André, J. R. Ferreira da Rocha

***Resumo* - Nesta contribuição compara-se a capacidade de sintonia por variação de temperatura de duas redes de Bragg do tipo I, considerando fibra hidrogenizada ou não, e uma rede do tipo IIa. Estudamos a estabilidade das respostas com a temperatura, analisando o seu potencial como filtros ópticos em sistemas com multiplexagem no comprimento de onda. Conclui-se que todas elas têm eficiências de sintonia semelhantes, contudo, à medida que varia a temperatura, as redes do tipo I em fibras não hidrogenizadas apresentam maiores variações na reflectividade, largura de banda e atraso de grupo, do que os outros dois casos, desaconselhando a sua utilização como filtro termo-sintonizável em sistemas com multiplexagem no comprimento de onda. O melhor balanço gama de sintonia/variação da resposta do filtro é conseguida para as redes do tipo IIa.**

***Abstract* - In this contribution we compare the thermal tuning capabilities of two type I gratings, considering an unloaded and a hydrogen-loaded fiber, and a type IIa grating. We further study their responses stability with temperature, analyzing their potential as optical filters in wavelength division multiplexing systems. We conclude that all of them have similar tuning efficiencies, however, as the temperature is changed, the type I grating written in the unloaded fiber presents much higher variations on its reflectivity, bandwidth and group delay than the other two cases, misadvising its utilization as thermo-tunable optical filter for wavelength-multiplexed systems. The best tuning range/filter response variation balance is achieved for type IIa gratings.**

I. INTRODUCTION

Fiber Bragg gratings (FBG) are nowadays extensively used on several devices of wavelength division multiplexed (WDM) optical networks.

One of the main applications in such systems is as tunable optical filters to perform the demultiplexing operation. In such applications, tuning can be achieved either by modifying the fiber refraction index or by changing the grating period. These changes can be induced thermally or by mechanical stress [1].

Although the later approach has typically a broader tuning range and a higher tuning speed, the first allows higher reproducibility and reversibility of the tuned frequencies [2], which is important for WDM applications.

As the WDM filter is tuned, it is crucial that its response characteristics, reflection spectrum and group delay, remain stable.

In previous works, it has been studied the reflectivity thermal decay, considering gratings in fibers and in planar waveguides, using different fiber co-dopants and treatments, and writing laser sources with distinct characteristics [3-5].

In this contribution we compare the thermal tuning capabilities of the referred types of gratings, type I and type IIa, written in unloaded and hydrogenated germanosilicate fibers, and analyze their stability, observing not only the maximum reflectivity, but also other characteristics of the FBG response, like the bandwidth and group delay, critical for their performance as WDM filters.

II. FBGS FABRICATION

As referred, for this study we consider type I and type IIa gratings. This later behavior is most often observed in highly germanium doped fibers, and only in non-hydrogenated ones [6]. We considered two type I gratings written in hydrogen-loaded and unloaded fiber, and one type IIa grating.

We have used the same fiber in all cases, and the same writing conditions, so that the observed behaviors depend exclusively on the type of grating used. The FBGs were written in a germanosilicate optical fiber, exposed to a phase-mask spatially modulated UV (248 nm) beam, originated from a KrF excimer laser, with a fluence of 300 mJ/cm^2 per pulse, and a pulse repetition rate of 30 Hz. The phase-mask period was 1067 nm and its length 10 mm.

To hydrogenate the fiber, we kept it under high-pressure hydrogen atmosphere (120 bars) during one week, in order to enhance its photosensitivity, due to hydrogen diffusion into the glass matrix. After the UV exposure the hydrogenated grating without coating was annealed for 60 h at 60 ºC to increase its stability.

In Fig. 1 we present the measured maximum reflectivity (R_{max}) and mean refractive index perturbation (Δn_{mean}) as a function of the irradiation time, relative to the formation of type I and type IIa gratings, using respectively the hydrogen loaded and the unloaded germanosilicate fibers. In this later case, we have considered the FBG after 100 minutes irradiation (~54 kJ/cm^2), FBG1 (type IIa), and after only 7.5 minutes

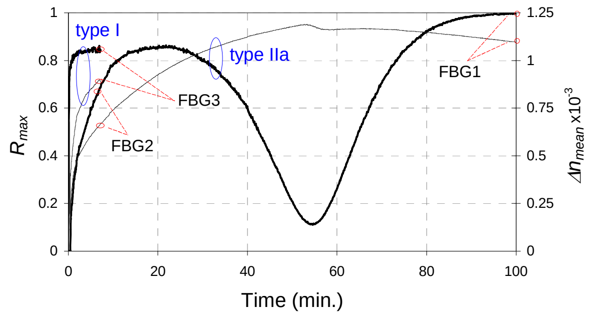


Fig. 1 - Measured parameters during the gratings formation: maximum normalized reflectivity, R_{max} (heavy lines), and mean refractive index perturbation, Δn_{mean} (hair lines).

(~4.05 kJ/cm^2), FBG2 (type I). For the first case, due to the hydrogen loading, there is no type IIa behavior and another type I grating of higher reflectivity than FBG2 can be achieved just after irradiating for 7 minutes (~3.78 kJ/cm^2), FBG3.

III. EXPERIMENTAL RESULTS

In this section we analyze the measured responses of the three referred FBGs, as we vary the temperature. We observe the thermal tuning efficiency, that is the central wavelength shift with temperature (pm/ºC), and analyze other consequent thermal alterations on the gratings response, important for their performance as optical filters in WDM systems, namely the maximum reflectivity, the bandwidth and the group delay variations.

The measuring setup for characterizing the FBGs is based on the phase-delay technique, but using a lightwave component analyzer (LCA) instead of a vector-voltmeter [7], and is presented in Fig. 2. The light from a tunable laser is modulated using a Mach-Zehnder interferometer (MZI) and launched into the input port of the FBG. The amplitude and phase of the reflected signal are compared with the input modulated signal in a lightwave component analyzer. As the wavelength of the laser is tuned, with step 0.01 nm, the reflectivity and group delay are averaged over 128 samples. The chosen modulation frequency was 1 GHz, thus one degree of phase change is equivalent to a group delay of 2.77 ps, and the measurements precision is ~22 fs.

To vary the gratings temperature we first assembled them, involved with thermal conductive glue, over a thermoelectric Peltier element, so that the temperature could be easily set and controlled. The temperature was then varied from 30 ºC to 75 ºC (with a 15 ºC step) and the gratings characteristics measured for each case.

In Fig. 3 we present the superimposed central wavelength centered reflection spectra and group delay variation of the three gratings, for the minimum and maximum temperatures considered (30 ºC and 75 ºC), and in Fig. 4 are presented the central wavelengths (λ_{cent})

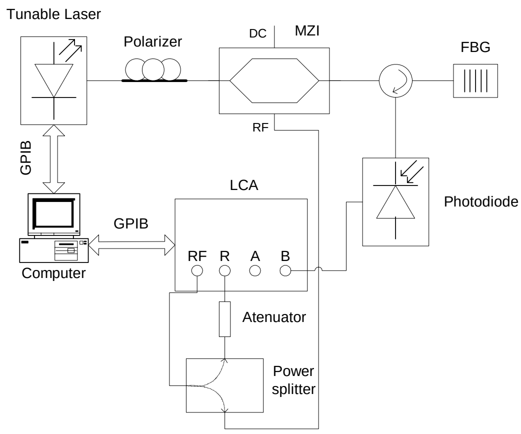
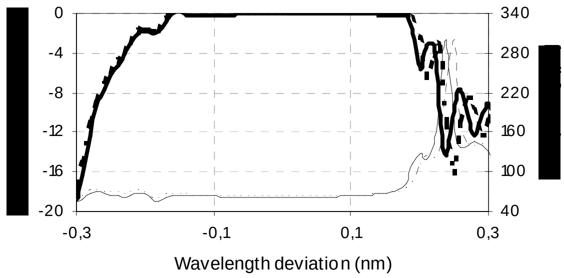
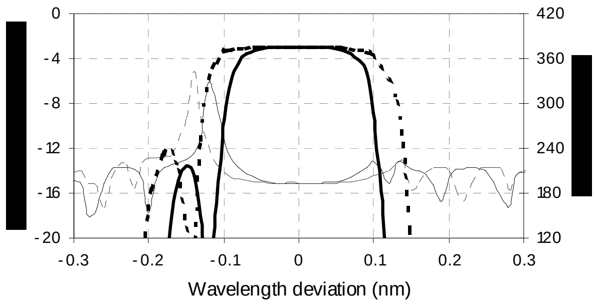


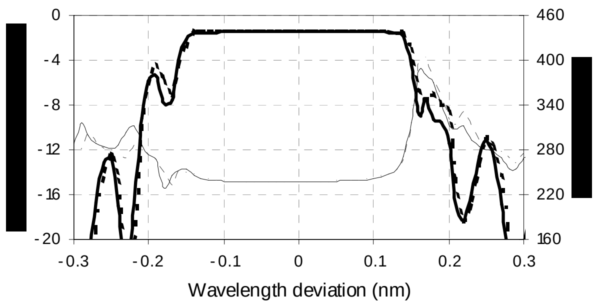
Fig. 2 - Measuring setup.



(a)



(b)



(c)

Fig. 3. Measured reflection spectra (heavy lines) and group delay variation (hair lines) of the studied gratings, FBG1 (a), FBG2 (b) and FBG3 (c), for the minimum (solid lines) and maximum (dashed lines) temperatures analyzed, respectively 30ºC and 75 ºC.

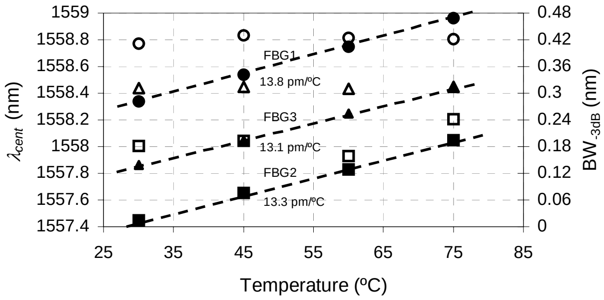


Fig. 4. Measured central wavelengths (filled shapes) and -3 dB bandwidths (empty shapes) of the three gratings, FBG1 (circles), FBG2 (squares) and FBG3 (triangles), for temperatures from 30 ºC to 75 ºC with step 15 ºC.

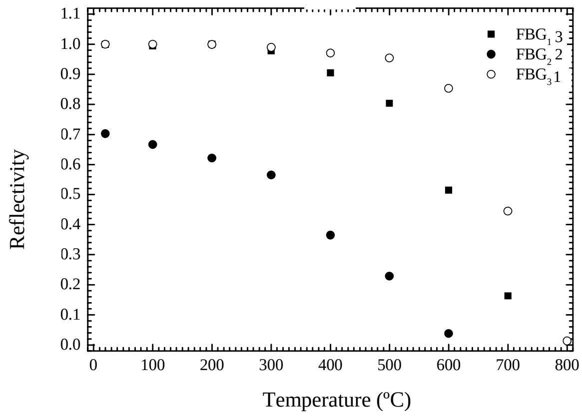


Fig. 5. Measured maximal reflectivities for different temperatures.

and the -3 dB bandwidths (BW$_{-3dB}$) of the gratings for each temperature. Then, we placed the FBGs in a tubular stove and increased the temperature till 800 ºC, with step of 100 ºC, in order to analyze the thermal decay for the three FBGs. The measured reflectivities are presented in Fig. 5.

With respect to the thermal tuning efficiency they present similar values, 13.8 pm/ºC, 13.3 pm/ºC and 13.1 pm/ºC, respectively for FBG1, FBG2 and FBG3 (see Fig. 4). Nevertheless, the highest value is obtained for the type IIa grating, FBG1, allowing a higher tuning range for the same temperature variation.

Analyzing Fig. 3 we also realize that the variations in the bandwidth and group delay of FBG2 are much more evident than for the other two studied FBGs. The measured FBGs bandwidth variations in Fig.4 confirm that. For FBG3 are within ±0.64% of the filter mean bandwidth (0.313 nm), for FBG1 (type IIa) are within 2.35% of 0.42 nm and for the FBG2, the worst result, within 25% of its bandwidth (0.19 nm), for the first temperature range considered (30 ºC to 75ºC).

From these results, it is clear that one should avoid the use of similar gratings to FBG2, as thermo-tunable optical filters. The reflectivity decay is also more evident for this grating (FBG2) and it starts around 150 ºC. For FBG3 the referred decay begins at higher temperatures, about 300 ºC, and for FBG1 at 500 ºC, thus leading to considerably higher tuning ranges than the other two cases. However, these gratings present higher bandwidth variations when thermally-tuned than gratings similar to FBG3. Thus, for a specific WDM filtering application, we will choose one of these options, depending on the critical issue addressed: the tuning range or the bandwidth variation.

IV. CONCLUSIONS

We have studied the thermal behavior of three different grating types, written in germanosilicate fibers, and analyzed their most relevant characteristics for using them as optical filters in WDM systems. It was concluded that type I gratings, resultant from the ending of the writing process of a potential type IIa, in a non-hydrogenated fiber, are the worst option, due to its bandwidth and group delay sensibility to temperature. Those variations were almost negligible for the type I grating written in hydrogenated fiber, properly stabilized. Nevertheless, the best tuning range/response variation balance is achieved for the type IIa grating.

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