Production and Characterization of Broad Fibre Bragg Gratings for Photonic Devices

Hypolito J Kalinowski[a], Fabiano Kuller[a], Jean C Cardoso da Silva[a],
Rogério N Nogueira[b], José L Fabris[a], Alexandre A P Pohl[a]
and Paulo S B André[b]

[a]Centro Federal de Educação Tecnológica do Paraná,
Av. Sete de Setembro 3165, 80230-901 Curitiba, Brazil

[b]Instituto de Telecomunicações – Polo de Aveiro
and Departamento de Física, Universidade de Aveiro,
Campus Universitário de Santiago, 3810-193 Aveiro, Portugal

ABSTRACT

We succeeded in recording broad FBG in standard single-mode fibre optic, using saturated hydrogen loading and over-exposure to the UV beam. The reflection spectra of the obtained gratings presents a FWHM line-width between 3 nm and 10 nm, and peak reflectivity in the range from 20 dB to 25 dB. The dispersion of the gratings is also measured and the dispersion coefficient results values about 2.5 ps/nm, at least 10 times smaller than that of conventional broad gratings recorded with chirped refractive index profiles.

Keywords: Fibre Bragg grating, Bragg grating recording, grating line-width

1. INTRODUCTION

Fibre gratings have several applications as a key device in fibre optic sensors and optical communication components.[1,2] Usually the fibre Bragg grating (FBG) for such applications requires narrow line-width in order to select a specific spectral band in the available spectrum. Broad transmission filters can be based on long period gratings (LPG), but their high sensitivity to temperature and strain imposes also tighter requirements in the packaging and conditioning of devices. FBG present (as compared to LPG) lower sensitivities to that parameters and their recording is also easily achieved, so their choice is usually preferable for most applications.

There are applications, however, for which FBG with broad line-width have particular interest, like their use as sensor and fixed reference filters for intensity demodulated sensors[3] with large dynamic range. One potential application of those FBG for optical coomunication devices resides in the gain equalization of Erbium Doped Fibre Amplifiers with a single grating, mid-cavity configuration.[4]

The conventional procedure for obtaining a very broad FBG (with FWHM in the order of several nanometers) is their recording through a chirped phase-mask. The process can be easily accomplished by direct writing the grating under the phase-mask illuminated with a wide UV beam. With lasers of small beam diameters (commonly used in phase-mask interferometers), the recording can be accomplished by translating the writing beam along the phase-mask, such that each section of the grating has a different spatial period. In principle, gratings with any line-width can be obtained in this way, only limited by the phase-mask characteristics (chirp rate, lenght). However, the strong dependence of the grating period with the longitudinal position also imposes a strong chirp to the grating, which can be undesirable for some applications, particularly in high data rate optical communications.

We succeeded in recording broad FBG in standard single-mode fibre optic, using saturated hydrogen loading and over-exposure to the UV beam. We also recorded broad gratings in single-mode photosensitive fibre optic with high Germaniun contents.

Correspondence author: H. J. Kalinowski
e-mail: hjkalin@cpgei.cefetpr.br

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2. EXPERIMENTAL DETAILS

The process used to obtain the Bragg gratings is standard in laboratories working on the same subject. Both conventional communication's grade single-mode fibre (provided by ABC Xtal Ltd.) and commercial photosensitive fibre (Thorlabs, Fibercore) are used in the experiments. Fibres are hydrogen loaded (typically $100-150$ atm, room temperature) for $2-4$ weeks prior to grating recording.

Most of the gratings are recorded using standard UV-illuminated phase-mask interferometers, whose details were described elsewhere.[5,6] The experimental set-up to write the gratings uses phase-mask interferometers illuminated by CW (Ar+, 244 nm) or pulsed (Nd:YAG, 266 nm) UV laser beams.[5] The use of a phase-mask interferometer permits to record gratings at diferent spectral positions, as well as to impose a suitable apodization to the refractive index longitudinal profile. Because of the uniform phase-masks, the obtained gratings present lower chirp. The main diference from conventional Bragg grating recording is the use of over-exposure to the UV pattern. The gratings described in this work are recorded using exposure times from several tens of minutes to several hours.

Usually the grating growth is similar to the standard one described in literature,[1,2] until the reflectivity saturates. From that point on, the grating has saturated reflectance but its FWHM increases with the illumination time.

For comparison, some gratings are recorded using a chirped phase-mask and UV beam scanning with constant velocity, with the fibre positioned just below the phase-mask. This procedure, as previouslly mentioned, is very simple but has the drawback of imposing a high chirp to the grating.

Gratings were kept at room temperature in the laboratory in between the characterisation measurements.

The obtained gratings are characterised in terms of their optical reflection spectrum and dispersion. The optical spectrum is measured during the recording process using commercial Optical Spectrum Analysers (OSA). The dispersion coefficient is calculated from the measurements of group delay for a modulated signal reflected by the grating. Fig. 1 describes the experimental set-up used to record the grating spectrum and group delay as a function of the wavelength. A network analyser is used with an externally modulated tuneable laser to determine the magnitude and group delay or the reflected signal.

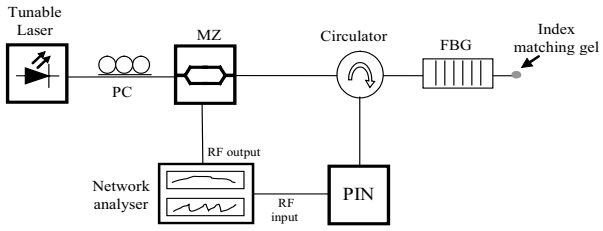

Figure 1. Schematics of the experimental set up used to characterize the gratings.

The narrow line-width (in this case less than 100 kHz) output of the external cavity tuneable laser is intensity modulated by the Mach-Zehnder modulator and applied to the FBG under test, through an optical circulator. The reflected signal is detected and the relative phase, $\Delta\phi$, between the injected electrical wave and the detected one is evaluated and averaged over a short period. This process is repeated at several intervals across the

wavelength range of interest. Since the relative phase of the wave is nothing more than a delay measurement, only missing the conversion factor (as the phase is determined in degrees), the relative group delay, τ, can be obtained by:

$$\tau = \frac{\Delta\phi_{mod}}{360^\circ f_{mod}} \tag{1}$$

where f_{mod} is the electrical modulation frequency. By scanning this factor over the wavelength, the relative group delay versus wavelength can be obtained. The dispersion is defined as the rate of change of the group delay with wavelength, therefore from the retrieved data this parameter can also be obtained.

From Eq. 1 it is clear that the resolution is improved with the increase of the modulation frequency; on the other hand, the increase in frequency will increase the spectral width of the optical signal, decreasing the spectral resolution. Therefore, a compromise between these two factors is considered for each particular characterization. A few measurements are also obtained by the use of commercial Optical Network Analysers (ONA).

Figure 2 presents the results for one of the obtained gratings, recorded with the phase-mask (uniform pitch) interferometer. The FWHM of the depicted grating is 6.9 nm. The magnitude of the reflected signal presents an almost flat top spectrum, an indication that the strength of the grating is very high. This is caused by the saturated hydrogen loading and by the over-exposure to the UV-beam. The measured group delay permits to observe that the dispersion coeficient of the grating is -2.81 ± 0.04 ps/nm, calculated by a linear best-fit to the group delay. This is a relatively small dispersion coefficient, well below the obtained for a grating written by direct recording under a chirped phase-mask. Soon after the recording, the optical spectrum shows an almost periodic ripple on the longer wavelength side, but the ripple has almost vanished after a few weeks (the grating was kept at room temperature in the lab). It is probable that the vanishing of the ripple can be due to leaking of hydrogen from the glass, that helps to smooth the refractive index modulation profile. The changes in the center position of the reflection band are negligible after a few weeks, close to the resolution of the experimental apparatus. However, some gratings present a small narrowing, the FWHM line-width decreases by about ≈ 0.5 nm in a time-span of several weeks after the inscription.

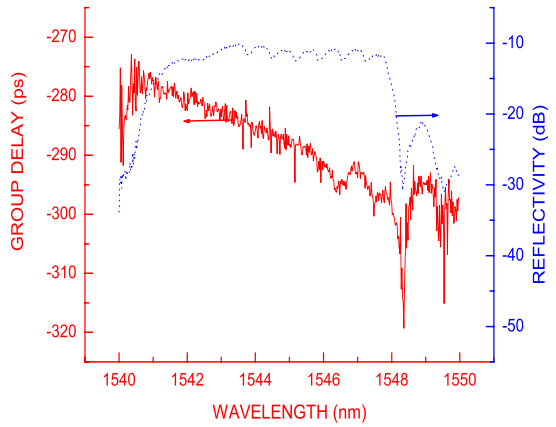

Figure 2. Reflection spectrum and dispersion (group delay) of a broad FBG recorded in a phase-mask interferometer with UV over-exposure.

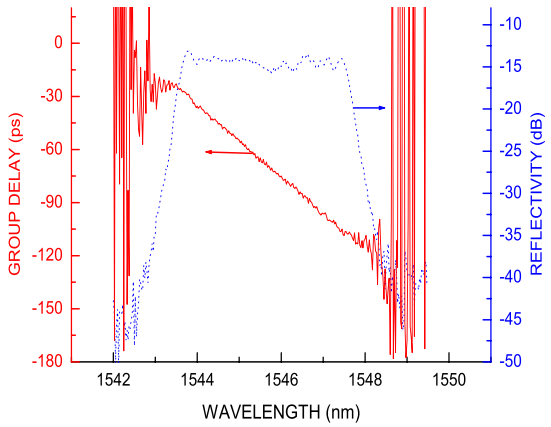

Figure 3. Reflection spectrum and dispersion of a FBG directly recorded with a chirped phase-mask using beam translation.

For comparison, Fig. 3 presents a broad grating recorded using direct exposure under a chirped phase-mask, with the UV beam scanned over the entire length of the mask. Because of the length of the used phase-mask, the observed FWHM is only half of that obtained for the grating depicted by Figure 2. The main difference, as

compared with Fig. 2 is the high value of the dispersion. The grating used for the experiment has a chirp of nm/cm and this imposes a dispersion coefficient of 20 ps/nm, almost 10 times higher than that of the previous grating. On this later process it is possible to see the effect of a small apodization to the refractive index profile, obtained directly from the UV beam power profile and from the beam scanning.

Several gratings were obtained, showing FWHM higher than 10 nm and dispersion coeficients around $2-3$ nm. However, some tricks have to be taken in account during the recording process. One important point is the spatial stability of the beam position. We observed in some gratings the strong development of side lobes, whose number and relative strength increased with the exposure time. Other samples start to present a transmission band in the middle of the spectrum after long irradiation time. It is possible that the DC change to the refractive index in the middle of the grating (where the beam fluence is higher) lead to a phase shift causing the transmission band. Further studies are under way to clarify these points. Fig. 4 shows the spectrum and dispersion curve of a Bragg grating recorded in hydrogenated fibre, using a uniform phase-mask and CW Ar^+ doubled UV light (244 nm). The main lobe is flanked by the series of side-lobes at higher frequencies (smaller wavelengths). Notice the change in the sign of the delay scale, due to a reference phase setting.

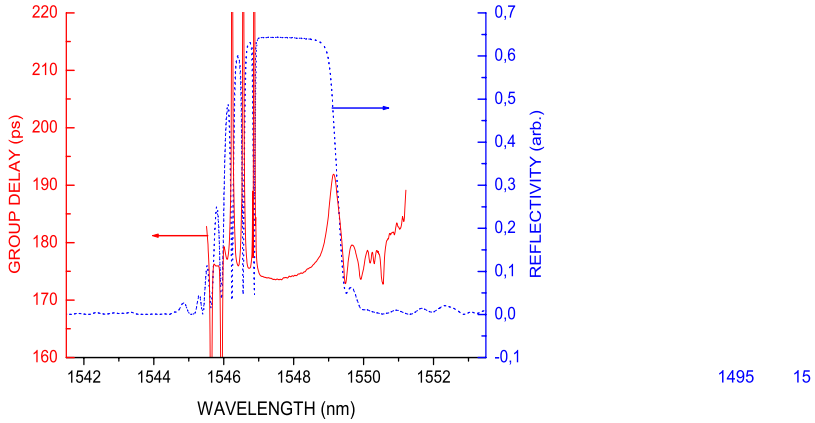

Figure 4. Reflection spectrum and dispersion (group delay) of a broad FBG recorded in an uniform pitch phase-mask interferometer, CW 244 nm UV light.

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