CHARACTERIZATION OF FIBER BRAGG GRATINGS WRITTEN IN LARGE MODE AREA FIBERS

Ioana R. IVASCU[1], Regina GUMENYUK[2], Samuli KIVISTÖ[3], Oleg G. OKHOTNIKOV[4]

In această lucrare se prezintă fabricarea rețelelelor Bragg foto-inscripționate în fibre optice cu o arie largă a modului (ALM) şi monomod standard folosind tehnica măştii de fază şi un laser KrF cu lungimea de undă de 248 nm. Rețelele Bragg obținute au o reflectivitate de peste 90% şi au fost testate din punct de vedere al sensibilității lor funcție de temperatură, respectiv tensiune. Rezultatele obținute evidențiază o mai bună stabilitate în tensiune a rețelelor Bragg inscripționate în fibre ALM în comparație cu a celor inscripționate în fibre monomod standard, de aici şi avantajul utilizării rețelelor Bragg inscripționate în fibre ALM ca senzori de temperatură.

In this paper we report on strong fiber Bragg gratins (FBGs) photo-written in a large mode area (LMA) fiber and in a standard single-mode fiber using a conventional phase-mask technique and 248 nm KrF excimer laser. The obtained FBGs had the reflectivity over 90% and they were tested regarding their sensibility in temperature and in strain respectively. The measurement results show that FBGs written in LMA fiber are more stable under strain than FBGs written in single-mode fiber, hence the advantage of the FBGs written in LMA fibers for temperature sensor applications.

***Keywords*:** large mode area fiber, fiber Bragg grating, Bragg wavelength, phase mask technique, hydrogen loaded fiber, temperature and strain sensor.

1. Introduction

Since optical fiber was asserted by its great advantages as main transmission medium for light, many applications on communications and sensing areas were derived based on it during the years. Among these, the fiber Bragg

[1] Assist., Physics Dept., University POLITEHNICA of Bucharest, România, e-mail: ivascu_ioana@physics.pub.ro.
[2] Eng., Researcher with Ultrafast and Intense Optics Laboratory, Optoelectronics Research Centre, Tampere University of Technology, Tampere, Finland
[3] PhD, Researcher with Ultrafast and Intense Optics Laboratory, Optoelectronics Research Centre, Tampere University of Technology, Tampere, Finland. Currently with Corelase Oy, Tampere, Finland
[4] Prof., Ultrafast and Intense Optics Laboratory, Optoelectronics Research Centre, Tampere University of Technology, Tampere, Finland

gratings (FBGs) have opened the opportunity for the development of a large variety of optical fiber sensors and of fiber telecommunication devices, also [1].

A FBG consists of a periodic change in the refractive index of a fiber core caused by exposure of an interference pattern of an UV laser beam [2].

The FBG written in single mode fiber became one of the most commonly used device in optical fiber communications, signal processing and optical sensing [3, 4]. Many times it was considered as a reference in characterization of the FBGs written in other types of optical fibers [5, 6]. Among these, the large mode area (LMA) fibers have been extensively developed in order to make transmitting of a high power signal through the optical fiber possible. The LMA fiber is characterized by a large core diameter in order to avoid the nonlinear effects and by a very low numerical aperture which limits the permitted modes number to a few modes or only to the fundamental mode. Particularly, a single-mode behavior of the LMA fiber is very desirable in high power fiber lasers design, in order to get a high quality output beam [7].

The FBGs written in LMA fiber have been largely studied and used in communication systems, being mostly employed in fiber laser designs [8, 9] and in characterization of modal coupling of the FBG in LMA fiber [10]. However, the FBGs written in LMA fiber could be also attractive as sensing elements grace to the LMA fiber easy coupling with light sources and due to the robust fiber characteristics.

The most tempting way to characterize a FBG for sensing purpose is basically related with its well known sensitivity on strain and temperature reflected in Bragg wavelength shift of the FBG under test. In practice it is difficult to distinguish between Bragg wavelength shifts caused by the temperature change or by the applied strain, because in most of the real situations the FBG supports the environmental changes of the both parameters (temperature and strain) at the same time. Hence, it is simply desirable to get FBG having either high temperature sensitivity, while its strain sensitivity is low or vice versa, according with the target parameter to be measured.

In this paper we report on strong uniform FBGs, photo-written in a LMA fiber and in a standard single mod fiber (as reference) using a conventional phase-mask technique [11] and 248 nm KrF excimer laser. All optical fibers were hydrogen loaded prior the inscription process [12] to increase their photosensitivity. We obtained gratings with high reflectivity of 92% for FBG written in LMA fiber and of 93% for FBG written in single mode fiber. All gratings imprinted in these fibers were rigorously tested. The temperature and strain sensitivity of the FBG in LMA fiber have been derived and compared it with those of the FBG written in a standard single mode fiber. The temperature coefficients for FBGs written in LMA fiber and standard single-mode fiber were similar. However, the strain coefficient of LMA fiber FBG was by one order of magnitude smaller than that one corresponding to FBG written into single-mode fiber. These characteristics show the advantage of using the FBG written in LMA fiber for temperature sensor applications without needing a strain compensation. The LMA fibers are robust, could use cheap and powerful light sources, therefore the FBGs in LMA fiber are attractive as sensor elements in a harsh environment.

The paper is organized as follows: in Sect. 2 we present the experimental conditions including materials used and experimental setup. In Sect. 3 we show the relevant results and in Sect. 4 we draw the conclusions of this work.

2. Experimental conditions

A. Materials

The LMA fiber employed in experiment had the core diameter of 20 µm, the clad diameter of 400 µm, and the numerical aperture of 0.06.

The OFS single-mode fiber used as reference had the following main properties: core diameter of 4.4 µm, 125 µm clad diameter, numerical aperture of 0.16, and a cutoff wavelength of 960 nm ensuring that light propagation in the fiber core in the 1060 nm region would be single mode.

To increase their photosensitivity both types of fibers were highly hydrogen loaded prior inscription by placing them into a pressure controlled hydrogen chamber under pressure of 130 atm and room temperature, for 4 weeks (LMA fiber) and 1 week (OFS fiber) respectively.

B. Set-up for writing FBGs

All gratings were written using phase-mask technique. In Fig. 1 the schematical set-up used for inscribing FBG in LMA fiber case is presented. A similar arrangement was used in the case of writing FBG in OFS fiber. The photo-printed process was carried out using a 248 nm KrF excimer laser with a repetition rate of 30 Hz. The UV laser beam was focused over a perpendicular direction to the phase-mask surface. The optical fiber was placed parallel and close behind to the phase mask surface within a few microns distance. The LMA fiber was exposed for 2 min to the beam laser of 25 mJ energy. The phase-mask employed in the photo-imprinting process of the FBG in LMA fiber had the uniform period of 744.51 nm and was manufactured by Ibsen. The OFS fiber was exposed to a 20 mJ laser beam energy of through a phase mask with a constant period of 730.69 nm (supplied by Stocker Yale). The exposure time in the OFS case was approximately of 40s. The length of all gratings was of 1 cm.

During the photo-inscription process the optical fibers where connected to a broadband spectrum of an Yb-doped fiber ASE source and to an optical spectrum analyzer (OSA) – ANDO AQ6317B with the resolution of 0.01 nm, in order to monitor the gratings growth.

The piece of LMA fiber in which we have written the FBG was connected to the interrogation light source and to the OSA using two pieces of LMA fiber spliced with OFS. The ends of the LMA fiber pieces which were spliced with OFS fiber were tapered prior to fusion splice (Fig. 1 inset). The fusion splicing between the two pieces of LMA fiber or between OFS and LMA fibers, was carried out by using a commercial splicing machine (Ericsson FSU 995 FA Fusion Splicer). The tapered end of LMA fiber was fabricated by heating a short region of the LMA fiber up to approximate 1450 ^{o}C and then slowly pulling the fiber in opposite direction [13] till the fiber diameter in the heated region became close to OFS diameter. Finally the tapered fiber end was obtained by transversal cutting of the fiber within the waist area of the tapered fiber.

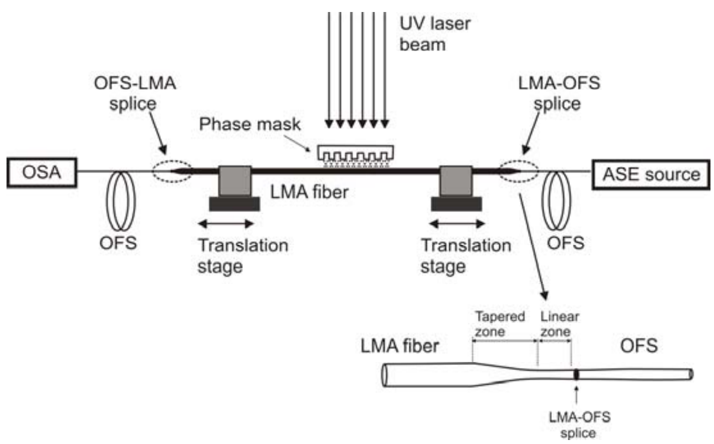


Fig. 1. Schematic of the setup used for writing FBG in LMA fiber using phase mask technique; OSA - optical spectrum analyzer, OFS - standard single mode fiber, LMA fiber – large mode area fiber, ASE source - amplified spontaneous emission source; in inset the splice between LMA and OFS fibers is presented.

After the photo-imprinting process, the fibers containing FBG were annealed by leaving them into an oven for 48 hours at 60 ^{o}C for hydrogen out-diffusion.

The reflection and transmission spectra of the obtained FBGs in the region of their Bragg wavelengths were measured with the same OSA, using as interrogation light the same broadband spectrum supplied by the Yb-doped fiber

ASE source. The FBGs spectra were normalized with respect to the source spectrum.

C. **Characterization of the obtained FBGs on strain and temperature sensitivity**

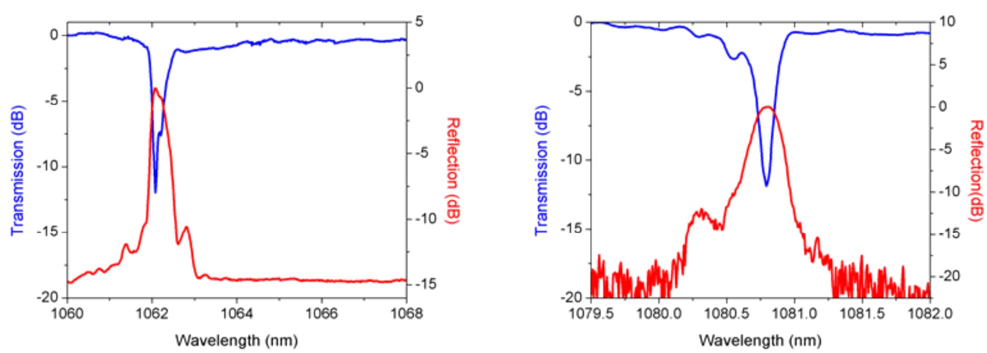
The characterization of the strain sensitivity of the obtained FBGs was carried out by applying longitudinal tension to the grating using a fiber handling device and a computer control similar to that shown in Fig. 1. The tension range varied from 0 N to 5 N for FBG in OFS, or up to 6 N for FBG in LMA fiber. The tension values applied to the FBG were rigorously set each time by a dedicated LabView program.

The temperature measurements were made using an oven with a temperature accuracy of 0.1 °C. Each fiber containing FBG was placed inside the oven, while the temperature was linearly varied from 25 ^{o}C to 150 ^{o}C.

In both cases of measurements, the FBGs under test were interrogated by connecting them to the Yb-doped fiber ASE source, and the Bragg wavelength shift was measured using the same OSA as we described above.

3. Results and discussion

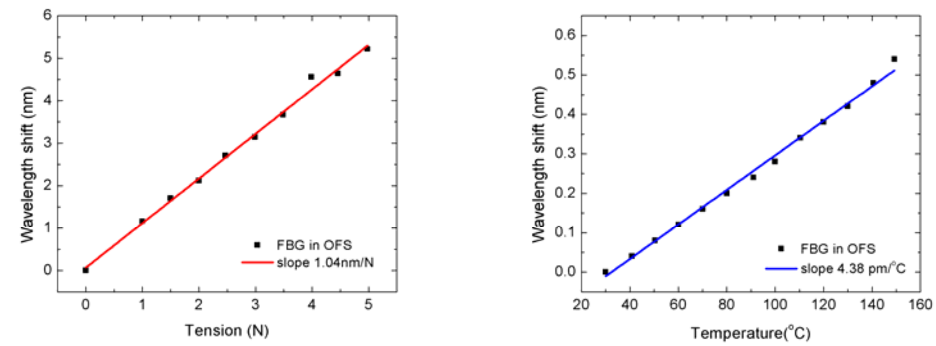
The measured FBG spectra corresponding to both types of fibers are shown in Fig. 2-a) for OFS fiber and in Fig. 2-b) for LMA fiber, respectively. The FBG inscribed in OFS had the reflectivity of 93%. For the FBG written in LMA fiber, the fundamental Bragg resonance had a reflectivity of 92%.



a) b)

Fig. 2 The spectra of the FBG written a) in OFS fiber and b) in LMA fiber.

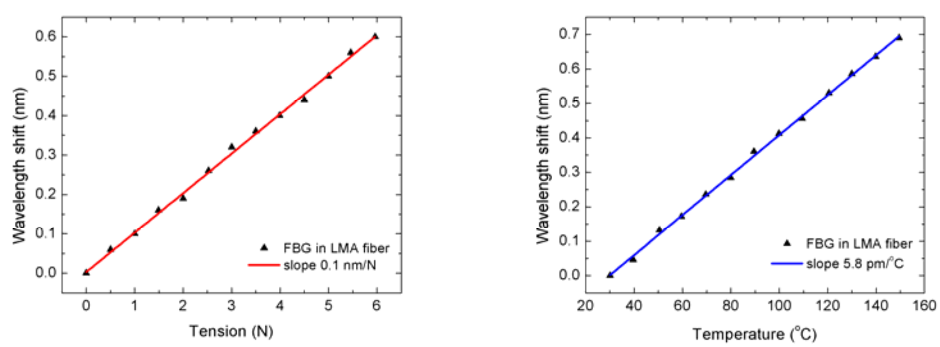
The wavelength shifts of the fundamental Bragg resonance for the applied tension and temperature are presented for the OFS fiber in Fig. 3 a) and b). For the FBG written in the OFS fiber the strain and temperature coefficients were measured to be 1.04 nm/N and 4.38 pm/^{o}C respectively.



a) b)

Fig. 3 Dependence of the wavelength shift of the FBG written in OFS fiber on a) applied tension and b) temperature.

In Fig. 4 a) and b) the wavelength shifts of the fundamental Bragg resonance for the applied tension and temperature are presented for the LMA fiber. For the FBG written in the LMA fiber the strain and temperature coefficients were measured to be 0.1 nm/N and 5.8 pm/^{o}C respectively.



a) b)

Fig. 4 Dependence of the wavelength shift of the FBG written in LMA fiber on a) applied tension and b) temperature.

It is observed that the temperature coefficients for FBGs written in LMA fiber and standard single-mode fiber are close to each other. The strain coefficient of the FBG inscribed in LMA fiber core is by one order of magnitude smaller than the FBG written into single-mode fiber. These characteristics show the advantage of FBG written in LMA fiber for temperature sensor applications.

4. Conclusions

Strong FBGs in LMA and OFS fibers, having the reflectivity over 90% were fabricated by phase mask technique. The fibers were highly hydrogen loaded prior to photo-inscription process in order to increase their photosensitivity. All gratings imprinted in these fibers were rigorously tested. Particularly, the temperature and strain sensitivity of the FBG in LMA fiber has been derived and compared it with those written in a standard single mode fiber. The sensitivity level in temperature of the FBG written in LMA fiber was comparative with that of the FBG inscribed in OFS fiber core, while the strain coefficient of the FBG inscribed into LMA fiber core was by one order of magnitude smaller than the one written into single-mode fiber. These characteristics demonstrate that FBGs written in LMA fiber are more stable under strain than FBGs written in single-mode fiber, hence the advantage of FBGs written in LMA fiber for temperature sensor applications. Furthermore, LMA fibers are robust, could use cheap and powerful light sources and, therefore, FBGs written in such a fiber are attractive as sensor elements in harsh environment.

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R E F E R E N C E S

[1] A. *Othonos, K. Kalli,* Fiber Bragg Gratings - Fundamentals and Applications in Telecommunications and Sensing, Artech House Inc., Boston-London 1999.
[2] *K. O. Hill, G. Meltz*, Fiber Bragg Grating Technology Fundamentals and Overview, Journal of Lightwave Technology **15**(8), 1997, p.1263-1276.

[3] *T. Erdogan*, “Fiber grating spectra”, J. Lightwave Technol. **15**(8), 1997, p. 1277-1294
[4] *R. Kashyap*, Fiber Bragg Grating, Academic Press,London, 1999.
[5] *I. R. Ivascu, R. Gumenyuk, S. Kivistö, A. N. Denisov, A. F. Kosolapov, Y. P. Yatsenko, S. L. Semjonov, O. G. Okhotnokov,* Fiber Bragg gratings written in photosensitive photonic crystal fibers and its sensing applications, Optoelectron. Advan. Mat. – Rapid Communications, **5**(7), 2011, p. 704 – 708.
[6] V. *Beugin, L. Bigot, P. Niay, M. Lancry, Y. Quiquempois, M. Douay, G. Mélin, A. Fleureau, S. Lempereur, and L. Gasca,* Efficient Bragg gratings in phosphosilicate and germanosilicate photonic crystal fiber, Appl. Opt. **45**, 2006, p. 8186-8193.
[7] N*. G. R. Broderick, D. J. Richardson, R. A. Sammut, J. Caplen and L. Dong*, Large Mode Area Fibers for High Power Applications, Optical Fiber Technology **5(2**), 1999, p. 185-196.
[8] *M. Dubinskii, J. Zhang, and V. Ter-Mikirtychev*, Highly scalable, resonantly cladding-pumped, Er-doped fiber laser with record efficiency, Opt. Lett. **34**, 2009, p. 1507-1509.
[9] *W. Mohammed and X. Gu*, "Fiber Bragg grating in large-mode-area fiber for high power fiber laser applications," Appl. Opt. **49**, p. 5297-5301 (2010)
[10] *A. Iho, A. Tervonen, K. Ylä-Jarkko, S. Tammela, and S. Honkanen*, Characterization of Modal Coupling of Bragg Gratings in Large-Mode-Area Fibers, J. Lightwave Technol. **29**, 2011, p.2031-2038.
[11] *K. O. Hill, B. Malo, F. Bilodeau, D. C. Johnson, J. Albert,* Bragg gratings fabricated in monomode photosensitive optical fiber by UV exposure through a phase mask, Appl. Phys. Lett. **62**, 1993, p. 1035–1037.
[12] *B. Malo, J. Albert, K.O. Hill, F. Bilodeau, and D.C. Jonson*, Effective index drift from molecular hydrogen diffusion in hydrogen-loaded optical fiber and its effect on Bragg grating fabrication, Electron. Lett. **30**, 1994, p.442-444.
[13] R*.Gumenyuk, C. Thür, S. Kivistö, and O. Okhotnikov*, Tapered Fiber Bragg Gratings for Dispersion Compensation in Mode-Locked Yb-Doped Fiber Laser, Journal of Quantum Electronics **46**(5), 2010, p. 769-773.

A fiber Bragg grating is a periodic or aperiodic perturbation of the effective refractive index in the core of an optical fiber (see Figure 1). Typically, the perturbation is approximately periodic over a certain length of e.g. a few millimeters or centimeters, and the period is of the order of hundreds of nanometers, or much longer than that for long-period fiber. gratings (see below).Â The fabrication of fiber Bragg gratings typically involves the illumination of the core material with ultraviolet laser light (e.g. from a KrF or ArF excimer laser or other type of ultraviolet laser), which induces some structural changes and thus a permanent modification of the refractive index.Â B.-O. Guan et al., â€œHighly stable fiber Bragg gratings written in hydrogen-loaded fiberâ€, IEEE Photon. Technol. Lett. 6. Tilted fiber Bragg grating (TFBG) and its transmission spectrum in optical fiber. . 6 Fig. 7. Transmission spectrum using LPG in optical waveguide.6 Fig.Â 13. Ray-optic illustration of core-mode Bragg reflection by a fiber Bragg grating .28 Fig. 14. Schematic representing fiber Bragg gratings. . 29 Fig.Â The cladding modes are excited in this project by strong FBG written in a photosensitive fiber. The scheme has been used as refractometer to measure the SRI leading up to the TFBG-SPR sensor presented in chapter 4. Chapter 4 presents the second article based on interrogating the SPR in reflection by capturing the cladding modes by DCFC with TFBG. Keywords: Fiber sensor, tilted fiber Bragg grating (TFBG), mode coupling, temperature cross sensitivity, biochemical sensing, interrogation. 1. Introduction.Â Some researchers also presented holographic method, by which performances of fiber gratings could be improved to a large extend although the grating period is normally dependent on tilt angle.Â In 2006 M. C. P. Huy et al. proposed a TFBG refractive index sensor written in PCF, which has better performances in comparison with the FBG sensor written in PCF because of the optimized mode coupling between core mode and high order cladding modes [53].Â 5, it could be seen that effective area. of cladding mode envelope in the transmission. spectrum gradually decreases.