Surface-core fiber gratings

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ABSTRACT

In this paper, we report, to our knowledge, the first demonstration of the induction of long-period and Bragg gratings on surface-core optical fibers. Surface-core fibers described herein were fabricated from commercial silica tubes and germanium-doped silica rods by employing a very simple procedure. Being the core on the fiber surface, it can be sensitive to refractive index variations in the environment in which the fiber is immersed. Thus, results concerning the sensitivity of these gratings to environmental refractive index variations are presented. Besides, simulation data are presented for comparison to the experimental behavior and for projecting future steps in this research.

Keywords: long-period grating, Bragg grating, refractive index sensor, surface-core fiber

1. INTRODUCTION

Building up fiber optics sensors based on long-period (LPG) and Bragg (FBG) gratings is very interesting since these gratings can provide means for probing a great variety of physical parameters of interest. Refractive index variations, temperature, strain, curvature and vibration are examples of parameters which can be monitored by the use of fiber gratings.[1, 2]

Both long-period and Bragg gratings consist of longitudinal periodic modulation of the refractive index of an optical fiber which can be achieved, for instance, by UV and CO_2 laser irradiation and electric arc application. This refractive index modulation, which has a period of hundreds of microns in long-period gratings and of hundreds of nanometers in Bragg gratings, allows the existence of coupling, at determined wavelengths, between, in general, the fundamental core mode to co-propagating cladding modes in LPGs and between the fundamental core mode to a counter-propagating core mode in FBGs.[1,2]

Eq. (1) and Eq. (2) describes the wavelengths λ_{LPG} and λ_{FBG} at which coupling will happen in LPGs and FBGs, respectively. In these equations, n_{co} indicates the effective refractive index of the core mode and n_{cl} the one associated to the coupled cladding mode. Λ_{LPG} and Λ_{FBG} mean the LPG and FBG refractive index modulation periods.[1, 2]

$$\lambda_{LPG} = (n_{co} - n_{cl})\, \Lambda_{LPG} \quad (1)$$

$$\lambda_{FBG} = 2\, n_{co}\, \Lambda_{FBG} \quad (2)$$

In order to obtain gratings based sensors, one has to evaluate physical parameters whose variation alters the effective refractive index values of the considered modes or the grating period. These changes imply on spectral variations in the measured LPGs and FBGs optical response. In this paper, LPGs and FBGs induced on surface-core optical fibers are studied as platforms for refractive index sensing. Employing gratings induced on this kind of fiber is appealing since the core mode can easily probe the external environment without the need of tapering the fiber or removing the silica cladding with chemical attack or polishing, for example.

In the subsequent sections, fiber fabrication, grating inscription and sensing results are presented. Besides, simulated data are shown for comparison to the observed experimental behavior. To our knowledge, this is the first demonstration of induction of long-period and Bragg gratings in surface-core fibers.

24th International Conference on Optical Fibre Sensors, edited by Hypolito José Kalinowski, José Luís Fabris, Wojtek J. Bock, Proc. of SPIE Vol. 9634, 96340V · © 2015 SPIE
CCC code: 0277-786X/15/$18 · doi: 10.1117/12.2194299

2. FIBER FABRICATION AND GRATINGS INDUCTION

The fibers used in the study reported herein were produced from standard cylindrical silica tubes with inner diameter of 12 mm and outer diameter of 18 mm and from a germanium-doped silica rod 21 mm thick. Initially, the germanium-doped silica rod (Figure 1a) was pulled in a fiber drawn tower in order to reduce its diameter to 0.8 mm. In sequence, it was merged to the tube by using a flame from a blowtorch (Figure 1b). The resulting preform was drawn to a 150 µm diameter fiber whose cross section is exposed in Figure 1c – a zoom of the core region is provided in Figure 1d. Brighter regions in Figures 1c and d identify the fiber core. Its major and minor axes measure 7.3 and 3.4 microns respectively.

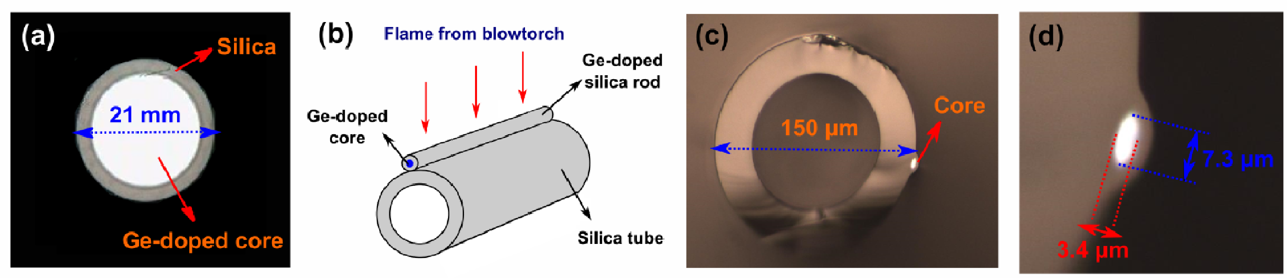

Figure 1. (a) Germanium-doped silica preform used for obtaining the fiber core. (b) Schematic diagram for merging procedure. (c) Cross-section of the 150 microns diameter surface core fiber. (d) Zoom of the fiber core.

The approach proposed in this paper is similar to some previous reported papers, where D-type and embedded-core fibers gratings were studied[3, 4]. Using surface core fibers is advantageous over D-type fibers because they are fabricated from commercial silica tubes and doped silica rods by employing a very simple technique. Their advantage on embedded-core fibers is centered on the fact that a surface-core fiber is sensitive to external environment refractive index variations. They have, however, the drawback of offering difficulties for fiber splicing. Also, the fiber reported herein resembles the near-surface-core fibers whose characteristics were recently reported[5, 6].

In order to provide the longitudinal refractive index pattern for obtaining the LPGs, radiation from a CO_2 laser was shone on the fiber. The employed setup is computer assisted and allows the user to choose the desired grating period (by controlling the space between two consecutives incidences of the laser on the fiber). For the reported experiments, a period of 1000 microns was used. For inducing the FBGs, an industrial-LN excimer laser (KrF Bragg Star™), with 248 nm operating wavelength, was used. The phase mask method was employed to create an interferometric pattern on the fiber and generate the grating on the fiber core. Laser parameters were set to be 500 Hz, with 3mJ and the phase mask pitch was 1075.34 nm, suited to produce Bragg gratings in the infrared region. Moreover, prior to the Bragg grating production, the fiber was hydrogen loaded at 70 bar during one week in order to enhance its photosensitivity to UV light.

Figure 2 shows the spectra of the obtained gratings – Figure 2a is a transmission spectrum of the LPG and Figure 2b consists of a reflection spectrum of the FBG. In Figure 2a, the dips at 689 nm, 764 nm and 895 nm correspond to the wavelengths at which coupling between core and cladding modes was attained. In Figure 2b, there are three reflection peaks (at 1560 nm, 1564 nm and 1569 nm) at which coupling between forward and backward core modes was satisfied. The existence of more than one peak in the Bragg grating reflection spectrum reveals the few mode nature of the fiber.

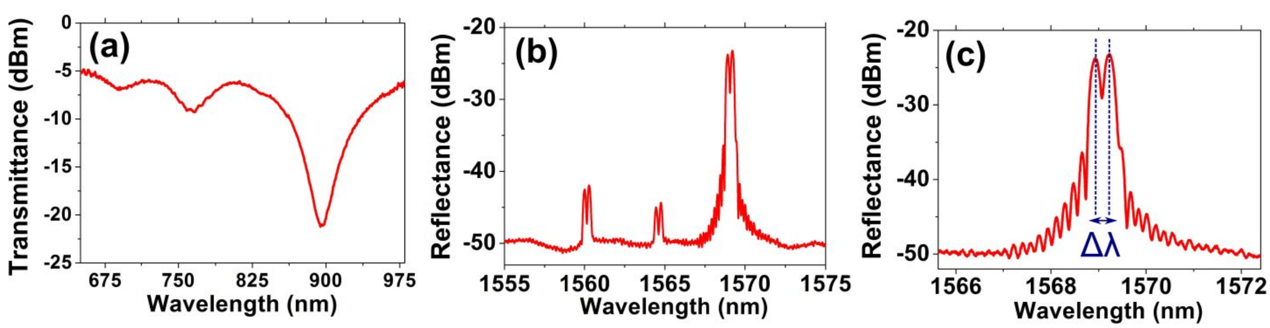

Figure 2. (a) LPG transmission spectrum. (b) FBG reflection spectrum. (c) Zoom of the interval between 1566 nm and 1572 nm for visualization in detail of the Bragg peak at 1569 nm; Δλ = 0.29 nm.

Nevertheless, a closer look to each of the reflection peaks shows two Bragg peaks separated by a spectral distance $\Delta\lambda$. Figure 2c is a zoom of the FBG spectrum around 1569 nm. Here, it can be clearly seen the peak separation (measured as 0.29 nm) due to fiber birefringence. From $\Delta\lambda$, fiber phase birefringence (B) can be easily calculated from $B = \Delta\lambda/2\Lambda_{FBG}$, giving a value of 2.7 x 10^{-4} at 1569 nm.

3. ENVIRONMENTAL REFRACTIVE INDEX VARIATIONS PROBING

As both LPG and FBG were induced on a fiber whose core is located on its surface, it is straightforward to use these gratings as platforms for refractive index sensing experiments. The sensitivity for performing environmental refractive index variation probing arises from the fact that both core and cladding modes effective refractive index are dependent on the refractive index of the medium in which the fiber is immersed. This dependency affects the spectral location of the dips and peaks in LPG transmission and FBG reflection spectrum causing them to shift.

In order to perform refractive index sensing experiments, the sections of the fibers where the LPG and the FBG were induced were immerged in baths of different refractive indexes Cargille® oils and aqueous glycerin solutions respectively. For each immersion situation, corresponding to a different environmental refractive index, a spectrum was taken and the wavelength shifts of dips and peaks were monitored.

Figure 3 presents the obtained results for the LPG sensitivity to external refractive index variations. In Figure 3a, one can observe that as the external refractive index increases, the resonant wavelength blueshifts. A plot of this shift versus the external refractive index is shown in Figure 3b. For the refractive index interval between 1.33 and 1.40, the refractive index sensitivity is calculated to be 95 nm/RIU and, for the interval between 1.38 and 1.45, a sensitivity value of 210 nm/RIU is attained.

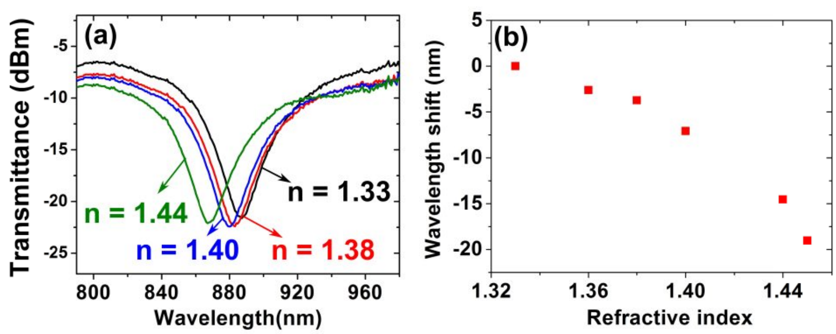

Figure 3. (a) LPG transmission spectrum for different external refractive index values n. (b) LPG resonance wavelength shift as a function of the external refractive index.

Analogously, the Bragg wavelength shift of the fundamental mode was monitored as the environmental refractive index was altered. Results concerning the Bragg wavelength shift as a function of the external refractive index change are shown in Figure 4a. For the refractive index interval between 1.33 and 1.40, a sensitivity of 0.5 nm/RIU was obtained and, for the interval between 1.43 and 1.45, a sensitivity of 2.7 nm/RIU was estimated.

Besides, simulated results for the wavelength shift as a function of the environmental refractive index change are also shown. Simulations, which were performed by using a commercial finite element-based software, indicate a higher refractive index sensitivity (1.2 nm/RIU for the refractive index interval 1.33 to 1.40 and 7.5 nm/RIU for the refractive index interval 1.42 and 1.45). This discrepancy between simulated and experimental can be due to the fact that the fiber structure employed in simulations was idealized.

The obtained sensitivity results are comparable to the ones obtained for non-etched D-fibers Bragg gratings (2.5 nm/RIU)[3] but are lower than the ones reported for other fiber processing technologies such as interferometric LPG setups (930 nm/RIU)[7], multimode interference sensors (2946 nm/RIU)[8] and birefringent microfibers configurations (30000 nm/RIU)[9]. If it is desirable to enhance the presented Bragg gratings sensitivity, the fiber can be made with a thinner silica cladding around the doped core or can be tapered down. Due to the fact that a higher fraction of the evanescent field of the core mode will permeate the external medium, the effective refractive index of the fundamental core mode will be more dependent on environmental refractive index variations. Simulations results for the expected wavelength shift of a Bragg grating induced on a 112.5 μm thick surface core fiber (25% diameter reduction) are shown in Figure 4b. A 5-fold sensitivity increase is observed in the refractive index range between 1.43 and 1.45. The possibility of inducing Bragg gratings on tapered surface-core fibers will be explored in our future experiments.

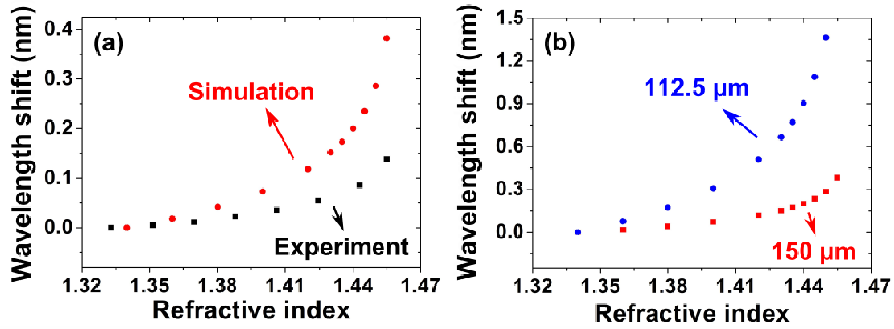

Figure 4. (a) Bragg wavelength shift versus the external refractive index plot. Black dots identify experimental data and the red ones simulation results. (b) Simulation results of the Bragg wavelength shift versus external refractive index for 150 µm and 112.5 µm diameter fibers.

CONCLUSIONS

In this paper, LPGs and FBGs induced on surface-core fibers were studied for the first time. Surface core fibers were fabricated from commercial silica tubes and germanium-doped silica rods by employing a very simple technique. As the core of this kind of fibers is on the fiber edge, the evanescent field of the propagating modes permeates the external medium. Thus, changes in the environmental refractive index cause the effective refractive index of these modes to alter.

Both LPG and FBG sensitivity to refractive index changes was measured. Maximum sensitivity values of 210 nm/RIU and 2.7 nm/RIU were obtained respectively for the LPG and FBG for refractive indexes around 1.43. FBG response was simulated and the results showed good resemblance to the experimental behavior. Furthermore, simulated data provided the information that a tapered fiber presents an enhanced sensitivity to refractive index variations. Future experiments will test this prediction.

Ergo, one can observe that a new configuration was studied aiming the performance of sensing measurements. Results are appealing due to its novelty and improvement possibilities shows up as an important route to be followed. Moreover, authors would like to acknowledge G. Chesini for his help in fiber fabrication and CNPq, São Paulo Research Foundation (Fapesp, grant #2014/50.632-6) and Fundação para a Ciência e Tecnologia (FCT, under projects UID/EEA/50008/2013, PEst-OE/EEI/LA008/2013, and scholarship SFRH/BD/88472/2012) for financial support.

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