Recording Bragg Gratings in Twin-hole Fiber Containing Electrodes

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Abstract

Bragg gratings have been written in twin-hole fiber filled with metallic electrodes. The pulsed ultraviolet radiation employed to record the gratings prevented local heating of the electrodes, allowing narrow reflective spectra to be obtained. The procedures to insert the electrodes and access them externally are described.

Introduction

In optical fiber communication systems, fiber devices such as lasers, amplifiers and signal multiplexers are currently integrated to the fiber transmission system. Fiber Bragg gratings (FBG) are of singular importance in these systems since they act as mirrors and dispersion compensators in fiber lasers, in optical amplifiers as gain flatteners, and as filters in wavelength-division multiplexing systems.

Electro-optical modulation in optical fiber has been considered attractive since the early nineties, when a non-zero electro-optic coefficient was induced by electro-thermal poling of silica glass [1]. Special fibers, such as twin-hole fibers (THF), offer new perspectives for the development of active optical devices such as electro-optic modulators, switches and tunable Bragg gratings. Through electro-thermal poling of a THF, electro-optic coefficient of 0.5 pm/V has been achieved and electro-optical modulation was demonstrated [2]. THF from Acreo/Sweden, with one ore two cores, have been employed in our laboratories in poling and electrooptic modulation experiments.

Inserting electrodes and writing Bragg gratings in these fibers are important steps that should be controlled. In the present work we demonstrate the possibility of recording FBG in THF filled with metallic electrodes. The procedures to insert metallic electrodes in the fiber holes and to externally access them are described. Preliminary results on the response of the FBG to the applied voltage are presented.

Experimental Procedure

In the present work, the gratings were recorded in THF containing one core and two holes, fabricated by Acreo/Sweden. The composition and diameter of the core are similar to those of standard telecommunication fibers.

Metallic electrodes are inserted in the THF using a pressure chamber (Figure1). The chamber is made of steel, with an entrance for compressed air and a small canal to insert the fiber. A metal alloy with low melting point (137^{o}C) has been chosen for the electrode composition. The chamber is filled with the metal and hermetically sealed using Teflon o-ring. The fiber is inserted through a thin canal till it touches the metal. The system is then put inside an oven and heated to the metal melting point temperature. Once the thermal equilibrium has been reached, compressed air is launched into the chamber to fulfill the twin holes with metal. After this process is completed, the fiber is slowly pulled out the oven. The continuity of the electrodes is verified with an optical microscope.

We built a fiber-polishing machine, similar to the developed by Acreo/Sweden, to access the internal electrodes. The THF filled with electrodes is glued on a microscope slice and polished until the electrodes are accessed

(Figure 1). Thin copper wires soldered to the electrodes with silver ink provide the contacts of the THF device, to which voltage and current can be externally supplied.

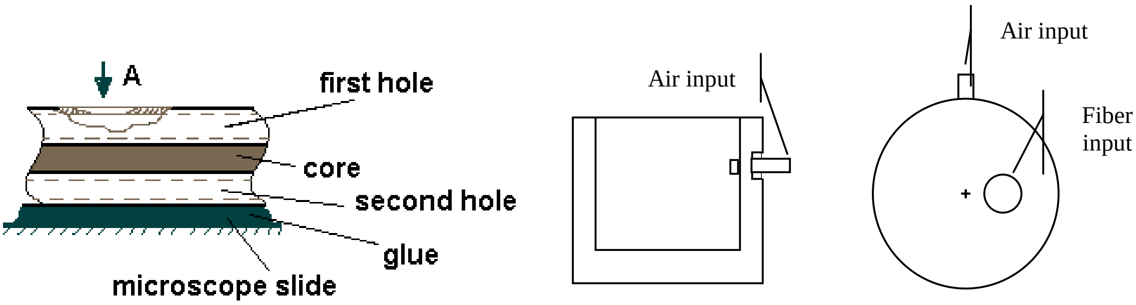

Figure 1: Scheme of the THF with access to electrode. Frontal and upper views of the pressure chamber for inserting electrodes.

Fiber Bragg gratings are obtained by exposition of the fiber core to an interference pattern of ultraviolet (UV) radiation. The absorption of UV radiation by Ge centers generates new defects in the core matrix, altering the refractive index of the illuminated regions. The refractive index can vary with respect to the core index by a factor of 10^{-3}. This periodic modulation of the core index causes a partial reflection on a propagating light. Constructive interference of the reflected light occurs for in-phase radiation, which is determined by the Bragg law: $\lambda_B=2n_{eff}\Lambda$, where n_{eff} the effective core-cladding refractive index, Λ is the index modulation period, and λ_B is the Bragg wavelength [3].

To enhance the UV absorption, the fiber core can be doped with high levels of Ge (typically around 10-20%-mol) or other dopants [3]. This kind of fiber is called photosensitive fiber. In order to increase the photosensitivity, the fibers may be loaded with hydrogen [4]. Recently, the formation of strong gratings in pure silica fibers with high hydroxyl concentration has been attained [5].

In our laboratory, the FBG are produced through the external method [3,6], by lateral exposition of the bared fiber to the forth or the fifth harmonic of a Q-Switched Nd:YAG laser (with wavelengths of 266 and 213 nm respectively), which delivers 5 ns pulses at rates up to 20 Hz. Due to the high energy delivered by the pulses (up to 10 mJ at 266 nm), the laser average power cannot be raised beyond 20 mW with the penalty of cladding burning and stopping grating growing. As a consequence, long exposition times are needed to obtain saturated gratings. The typical exposition times are 1-4 minutes for hydrogenated photosensitive fibers, and 20-40 minutes for hydrogenated standard telecommunication fibers. Gratings with reflectivities as high as 100% (70%) are obtained with hydrogen-loaded photosensitive (standard telecommunication) fibers. The bandwidths of the reflectivity spectra stay around 1 nm for gratings recorded in photosensitive fibers, and about 0.5 nm for those written in standard telecommunication fibers. Similar results were obtained for inscription with 266 nm and 213 nm. The data presented here were obtained by exposition to 213 nm.

Before inscription, the fibers are submitted to a room temperature pressurized hydrogen environment with 150 kg/cm^2 for at least one week to saturate the hydrogen level diffused into the fiber core at that pressure. Two weeks are required to saturate the hydrogen level in the core of THF with metallic electrodes at that hydrogen pressure. The results presented here were obtained with fibers hydrogenated during 3 days. Therefore, at moment of inscription, the hydrogen level was not saturated in the fiber matrix.

Results and Discussions

One of the challenges in dealing with THF filled with metallic electrodes is properly recording Bragg gratings. As a consequence of local heating by absorption of the inscription radiation, the metal may expand, causing the fiber to dilate. In this case, it becomes impossible to imprint a well-defined interference pattern in the fiber core. The result is blurred spectra, useless for practical purposes. We surpassed these difficulties using short UV pulses to record the gratings, as described in the sequence.

Using a microscope, the THF was positioned to prevent blocking of the incident UV radiation by the holes. The fiber is glued in a Teflon holder and this system is aligned at the plane of UV interference pattern. The reflectivity spectra have been monitored during the inscription process. The broadband radiation emitted by a partially polarized LED was launched into the fiber and an optical spectrum analyzer recorded the reflected portion of the spectrum. To have an approximate value for the grating reflectivity during the inscription, the reflected intensity was calibrated with respect to the intensity obtained when the fiber end was cleaved, which corresponds to 4% reflectivity. One of the sources of error in this method lies on the process of cleavage, because the hydrogenated THF is extremely fragile and difficult to cleave. The second source of error in determining the grating reflectivity arises from the fact that the LED is 30% polarized and that the THF device presents an important polarization dependent loss (PDL).

The dynamics of grating growth for THF with and without electrodes is presented in Figure 2. For both cases, the reflectivity increases monotonically with the time interval until a maximum is reached. For further exposition of the fiber to the UV pattern, we observe a rapid decrease of the grating reflectivity. The irradiation was stopped at that point. The Bragg wavelength values (not shown in the figure) also increase monotonically with the time interval but does not show any saturation or decrease for long exposition times. The growth dynamics of FBG in the hydrogenated THF is similar to those obtained in hydrogen-loaded standard and photosensitive fibers grown under the same conditions in our laboratory. For the gratings in standard fibers, a thermal treatment at temperatures up to 250^{o}C caused a decrease of 30-40% on the original reflectivity [8]. These observations are consistent with data reported in literature for Type I gratings [3]. Reflectivities as high as 40% and 25% were obtained for the fibers without, and with, electrodes, respectively. The maxima reflectivities and the lateral lobules in the spectra strongly depend on the fiber alignment at the UV interference plane, and we believe that this misalignment is the reason for the difference in growth dynamics and reflectivity maxima observed in Fig. 2. Since the THF core composition is similar to that of standard telecommunication fibers, we expect that reflectivities as high as 70% would be attained for fibers with saturated level of hydrogen.

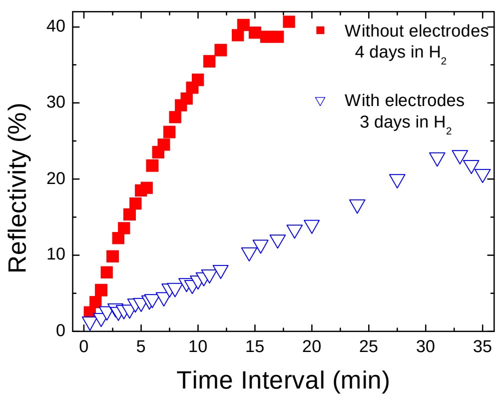

Figure 2: Growth dynamics of FBG in THF with (open triangles) and without electrodes (solid squares).

Figure 3 shows the reflectivity spectra of the FBG grown in fibers with and without electrodes.

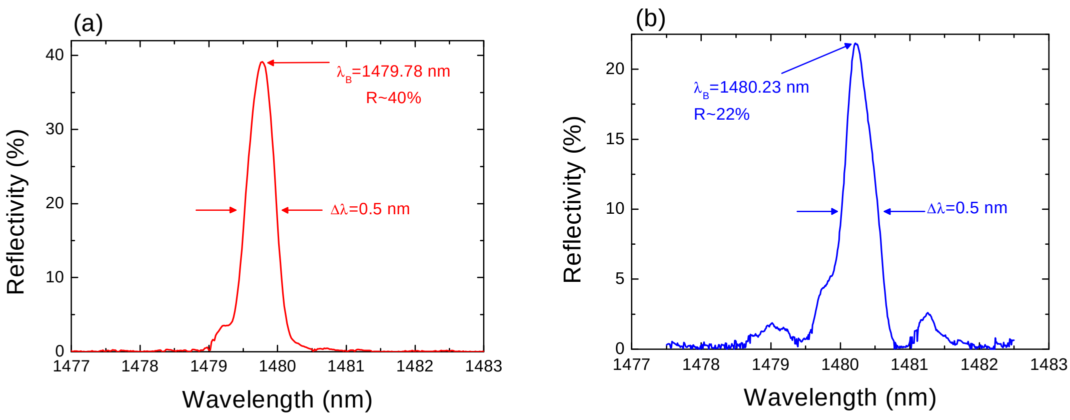

Figure 3: Reflectivity spectra of the gratings grown in THF (a) without electrodes and (b) with electrodes

As can be observed, despite the long exposure time needed to attain maximum reflectivity, clear and narrow spectra could be obtained. The lateral lobules are strongly dependent on the fiber alignment with respect to the UV interference pattern.

Contacts were made with the THF containing the Bragg grating and external voltages were supplied to the device. Figure 4 shows the reflected spectra for the three values of applied DC voltage: zero, 200 V and 400V. Up to this voltage, no remarkable change on the grating spectrum could be observed. The applied voltage could not be raised beyond 500 V because breakdown happened causing a short circuit inside the device. The fissure points were observed to be close to the contacts. The breakdown occurred most probably due to fiber fragileness during the device fabrication process.

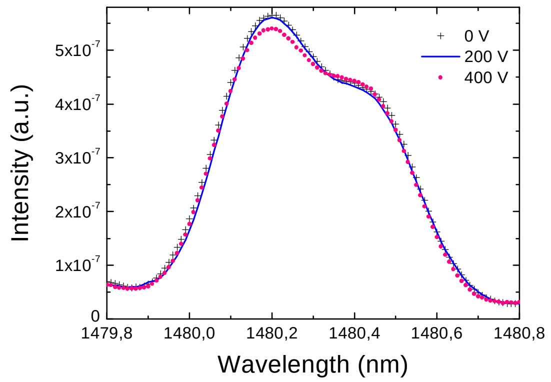

Figure 4: Reflectivity spectra of the grating grown in THF with electrodes for different applied voltages.

Conclusions

Twin-hole fiber filled with metallic electrodes has been obtained. A technique was developed to make a twin-hole fiber device, with external contacts to the internal electrodes. Bragg gratings have been successfully recorded in the twin-hole fiber filled with metallic electrodes. Using pulsed laser to record the grating prevented local heating of the electrodes, allowing narrow reflectivity spectra to be obtained. It was not observed any Bragg wavelength shift during preliminary tests, when the device was supplied with DC voltages up to 400V.

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References

[1] R. A. Myers, N. Mukherjee, S. R. J. Brueck, Opt. Lett. **16**, 1732 (1991).
[2] D. Wong, W. Xu, S. Fleming, M. Janos, K-M. Lo, Opt. Fiber Technol. **5**, 235 (1999).
[3] R. Kashyap, *"Fiber Bragg Gratings"*, Academic Press (1999); A. Othonos and K. Kalli, *"Fiber Bragg Gratings-Fundamentals and Applications in Telecommunications and Sensing"*, Artech House (1999).
[4] P. J. Lemaire, R. M. Atkins, V. Mizrahi, W. A. Reed, Electron. Lett. **29**, 1191 (1993).
[5] J. Albert, M. Fokine, W. Margulis, Opt. Lett. **27**, 807 (2002).
[6] C. J. S. Matos, P. I. Torres, L. C. G. Valente, I. C. S. Carvalho, W. Margulis, Proc. SPIE Vol. 3572, pp. 400, 3rd Ibero-merican Optics Meeting and 6th Latin American Meeting on Optics, Lasers, and Their Applications; Angela M. Guzman ed. (1999).
[7] A. L. C. Triques, C. L. Barbosa, R. M. Cazo, J. L. S. Ferreira. R. C. Rabelo, L. C. G. Valente. A. M. B. Braga, *"Thermal stability of fiber Bragg gratings recorded under different conditions"*, submitted to XXVI Encontro Nacional de Física da Matéria Condensada (2003).