Two-photon long-period grating inscription in pure-fused-silica photonic crystal fiber

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Abstract: Photochemical inscription of a long-period grating in a pure fused silica photonic crystal fiber (PCF) is reported. The inscription in PCF is found to be ten times more efficient than in a standard telecom fiber.

OCIS Codes: (060.2340) Fiber optics components; (220.4610) Optical fabrication

The first photochemical inscription of a long-period fiber grating (LPFG) in a photonic crystal fiber (PCF) was made as early as 1999. However, in this work the core of the PCF was doped with germanium and the linear absorption of the germanium dopant was used for inscription by the single-photon mechanism [1]. In this paper, we report on the photochemical fabrication of LPFGs in a pure fused silica PCF, which is based on two-photon absorption (TPA) of high-intensity femtosecond 264 nm pulses [2].

In the experiments, we used an endlessly single mode photonic crystal fiber ESM-12-01 from Blaze Photonics (now Crystal Fibre A/S) and for comparison the standard Corning telecom fiber SMF-28 (supplied by Elliot Scientific). The ESM-12-01 has a 12 µm core diameter surrounded by 4 rings of holes (hole diameter is 3.7 µm, hole pitch is 8 µm, number of holes is 54), and its outside diameter is 125 µm. The telecom SMF-28 fiber has a core diameter of 8.2 µm and a cladding diameter of 125 µm. Both fibers were sensitized under similar conditions (in a hydrogen atmosphere at 150 bar, at 70 °C, for 2 weeks). For LPFG inscription, we applied femtosecond 264 nm laser pulses with an incident UV irradiation intensity in the 300–400 GW/cm^2 range [3]. The fibers were exposed point by point with a period of 500 µm. The length of the LPFG in both cases is 1 cm.

Figures 1(a), 1(b) and 1(c) present the typical spectrum of transmission loss, and the peak wavelength and amplitude dependencies versus the incident fluence, respectively, for an LPFG inscribed in a hydrogenated ESM-12-01 fiber. Figures 2(a), 2(b) and 2(c) present the corresponding graphs for an LPFG inscribed in a H_2-loaded SMF-28 fiber. The first statement to be made is that the LPFG spectrum created in the PCF by high-intensity 264 nm femtosecond light pulses shows very strong resonance peaks with up to ~ 20 dB grating strength (Fig. 1(a)). As the band-gap energy value of pure fused silica is about 9.3 eV, this band-gap could only be bridged by two 264 nm light quanta with an energy of 4.7 eV. The loss spectrum, shown in Fig. 1(a), demonstrates an excellent LPFG quality (regular form of the peaks and absence of out-band losses). All the transmission loss peaks shift monotonically towards the longer wavelengths with the increase in incident fluence (Fig. 1 (b)). From Fig. 1(c) it follows that at an incidence fluence of 10 J/cm^2 the peak A reaches its maximum (coupling factor is equal to $\pi/2$). Such an effect is common for LPFG inscription with a high value of excitation energy and has never before been demonstrated in a PCF. But the most striking feature of the data presented in Fig. 1 (c) is the *extremely low value of fluence* necessary for the recording of an LPFG in a hydrogenated PCF. For LPFG fabrication in PCF, only 10 J/cm^2 fluence is enough to record a 20 dB peak (Figs. 1 (a), 1 (c)) in comparison with ~120 (160) J/cm^2 fluence value necessary for the inscription of the ~24 dB K (or L) peak in SMF-28 (Figs. 2 (a), 2 (c)).

The much smaller fluence value necessary for inscription in a photonic crystal fiber in comparison with a standard telecom fiber points to a much stronger resonance between the cladding and core modes in the LPFG-PCF case. Such coupling enhancement could be related to the specific mode structure in the ESM-12-01 corresponding to the hexagonal symmetry of this PCF, significantly different from the circular-symmetric mode distribution in SMF-28. Our recent measurements of the polarization properties of an LPFG recorded in ESM-12-01 confirm the importance of this factor for the strong resonance between the fundamental and core modes. Another possible cause of coupling enhancement is related to the presence of the non-absorbing holes in the PCF and the absence (regarding to SMF-28) of a highly-UV-absorbing fiber core (by the TPA mechanism), which may increase the efficiency of LPFG fabrication due to a higher uniformity of PCF illumination. It should also be noted that the mechanical stress associated with the PCF hole structure could significantly enhance the fiber photosensitivity in the given case.

The LPFG spectrum of losses recorded in PCF is more complicated than in SMF-28 (cf. Fig. 1(a) and Fig. 2(a)). The peaks A, B, C, and D in a PCF correspond well to peaks K, L, M, and N in SMF-28, though the latter cluster occupies a wider wave region. The peak E is specific to our PCF. It should be emphasized that all photo-chemically-inscribed peaks in the PCF LPFG spectrum are very sensitive to any change of irradiation parameters or external conditions. From figures 1 (b) and 2 (b) (1 (c) and 2 (c)), it follows, that transmission loss peaks in LPFG spectrum change their positions (amplitudes) with an increase in the irradiation fluence quicker in PCF than in SMF-28.

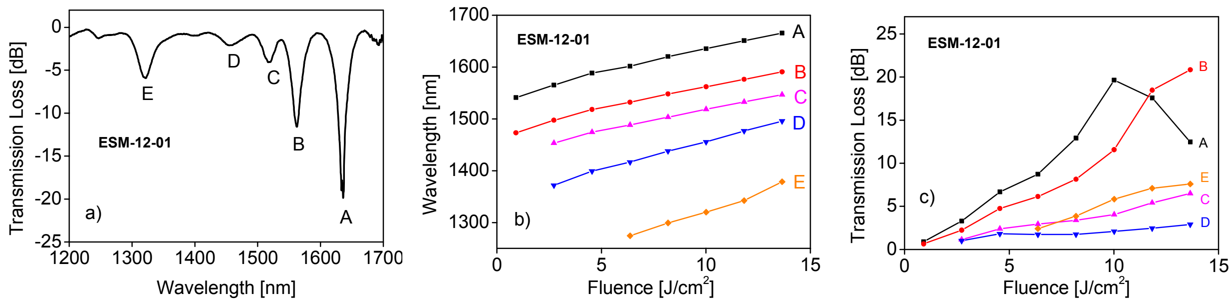

Fig. 1. The experimental graphs related to an LPFG inscribed in hydrogenated ESM-12-01 fiber with high-intensity 264 nm femtosecond pulses: (a) transmission loss spectrum recorded with an irradiation intensity of 300 GW/cm^2 and total incident fluence of 10 J/cm^2; (b) shift of wavelengths corresponding to the transmission loss peaks A, B, C, D, and E (designated in the spectrum above) versus the total incident fluence; (c) transmission loss amplitudes for the peaks A, B, C, D, and E versus the total incident fluence.

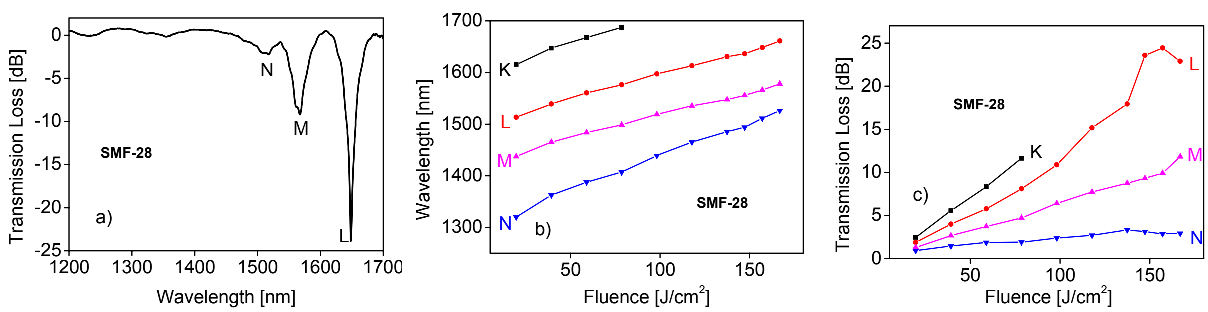

Fig. 2. The experimental graphs related to an LPFG inscribed in H2-loaded SMF-28 fiber with high-intensity 264 nm femtosecond pulses: (a) transmission loss spectrum recorded with an irradiation intensity of 310 GW/cm^2 and total incident fluence of 157 J/cm^2, the peak K at this fluence value moved beyond 1700 nm; (b) shift of wavelengths corresponding to the transmission loss peaks K, L, M, and N versus the total incident fluence; (c) transmission loss amplitudes for the peaks K, L, M, and N versus the total incident fluence.

Concluding, the two-photon high-intensity UV femtosecond approach allows us to produce LPFGs in PCF made of pure fused silica using very low fluences in comparison with standard telecom fiber [4].

We are indebted to Prof. Philip St. J. Russell for his continuous support and useful discussions. A. Fotiadi is supported by the Interuniversity Attraction Pole program of the Belgian Science Policy.

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