Sensing Characteristics of Long-Period Fiber Grating Inscribed in Double Cladding Fiber

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***Abstract*—We demonstrate the sensing characteristics of high-order cladding mode by inscribing long-period fiber grating and helical long-period grating in double-cladding fiber. Torsion and surrounding refractive index characteristics were investigated experimentally. The maximum torsion sensitivity is 0.3404 nm/(rad/m).**

Keywords—high-order cladding mode, long period fiber grating, torsion sensor

I. Introduction

The long period fiber gratings (LPFGs) have been widely used in the field of optical fiber sensing and optical communication [1-4], due to the advantage of simple manufacturing process, low insertion loss, polarization independent and backward reflection. Helical long period grating (HLPG) is a new type of fiber grating, which has periodic helical refractive index modulation along the fiber both longitudinal and azimuthal direction [5]. Owing to high sensitivity of cladding mode to change in environment, LPFG-based sensors have been widely applied in various filed to detect properties like temperature [6], torsion [7], surrounding refractive index(SRI) [8]. In addition, due to being away from the fiber core, the high-order cladding mode is more easily influenced by the external environment, resulting in higher sensing sensitivity.

In this work, LPFGs and HLPGs with the high-order cladding mode (LP_{18} mode) were fabricated in double cladding fiber (DCF) using CO_2 laser. The torsion, SRI sensing characteristics were investigated experimentally. The maximum torsion sensitivity of DCF-HLPG is about 0.3404 nm/(rad/m) in the range of -36~36 rad/m, which is much higher than DCF-LPFG. And the maximum SRI sensitivity is 1500 nm/RIU in the RI range 1.435 to 1.454. The proposed DCF-HLPG has a promising application as high sensitivity directional torsion sensor.

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II. Experimental Result and Discussion

A. Fabrication

The fiber used in the experiment is fluorine-doped double-cladding fiber (DCF, Corning Clear Curve, ZBL), which has a four-layer waveguide structure, including fiber core, inner cladding, fluorine-doped zone and outer cladding. The diameters of these four layers are 9 μm, 19 μm, 36 μm and 125 μm, respectively. The RI of inner and outer cladding is the same, which is slightly higher than the fluorine-doped region.

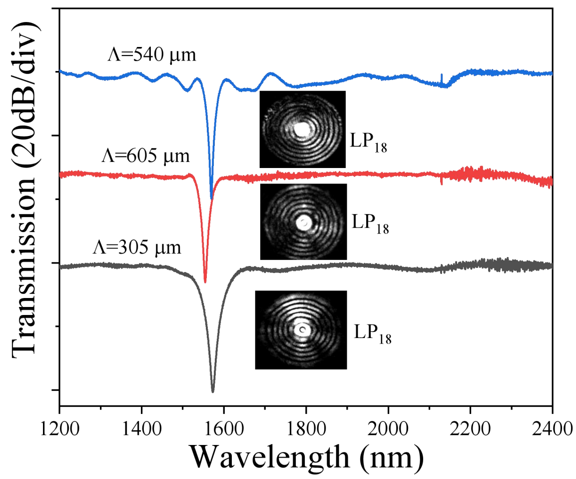

Fig. 1. The transmission spectra and mode pattern of LPFGs with period of 305 μm, 605 μm and HLPG with period of 540 μm, the period number is 60 and 50.

The fabrication system consists of CO_2-laser (CO_2-H10, Han' Laser), an attenuator, and a tuning mirror used to control the scanning power and direction of the laser. The laser beam exposed on the fiber was generated by a CO_2 laser with a spot diameter of ~ 50 μm. The fiber control systems consist of a fiber holder and a fiber rotator holder controlled by a step motor. The schematic diagram of the experimental setup was described in Ref. [7]. To fabricate the helical structure, the fiber is rotated by the rotator holder during the heating.

The transmission spectra of the gratings have been recorded in the experiment by the optical spectrum analyzer (AQ6375, YOKOGAWA) with a wavelength resolution of 0.1 nm. Figure 1 shows the transmission spectra of DCF-LPFGs with period of 305 μm and 605 μm, and DCF-HLPG with period of 540 μm. The resonance dip have a wavelength of about 1550 nm, a grating contrast of about 20 dB. To determine the mode order of gratings with different periods, a tunable laser (Agilent 81600B) and CCD (InGaAscamera, Model C10633-23 from Hamamtsu Photonics) were used to observed the mode pattern. The patterns of the DCF-LPFG and DCF-HLPG with different periods were shown in the inset of Figure 1. The resonance can be identified to be the LP_{18} cladding mode. To determine the mode order diffraction, a series of LPFGs with periods ranging from 290 to 580 μm and HLPGs with periods ranging from 410 to 580 μm have been fabricated.

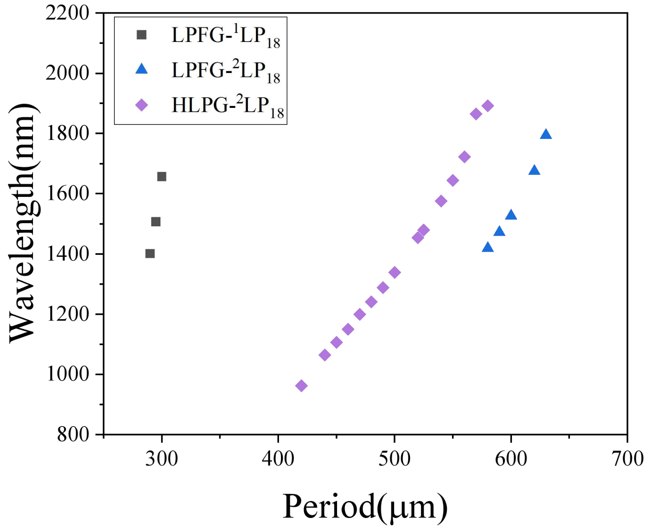

Fig. 2. Dependence of resonance wavelength on grating period for the coupling of fundamental core mode to cladding mode with diffraction order N = 1 and 2.

As a result, the DCF-LPFGs with period of 305 μm and 605 μm were confirmed to the $^1LP_{18}$, $^2LP_{18}$, representing the first and second order diffraction of LP_{18} cladding mode. The DCF-HLPG with period of 540 μm was confirmed to be $^2LP_{18}$. Therefore, the phase-matching curves between the core mode and LP_{18} cladding modes of different diffraction orders for the DCF-LPFGs and DCF-HLPGs can be attained, as shown in Figure 2.

B. Sensing characteristics

The torsion and SRI sensing characteristics were investigated experimentally. The two DCF-LPFGs with periods of 305 μm and 605 μm and DCF-HLPG with period of 540 μm were selected because their resonance dips of the same cladding mode at different diffraction orders have similar resonance wavelength.

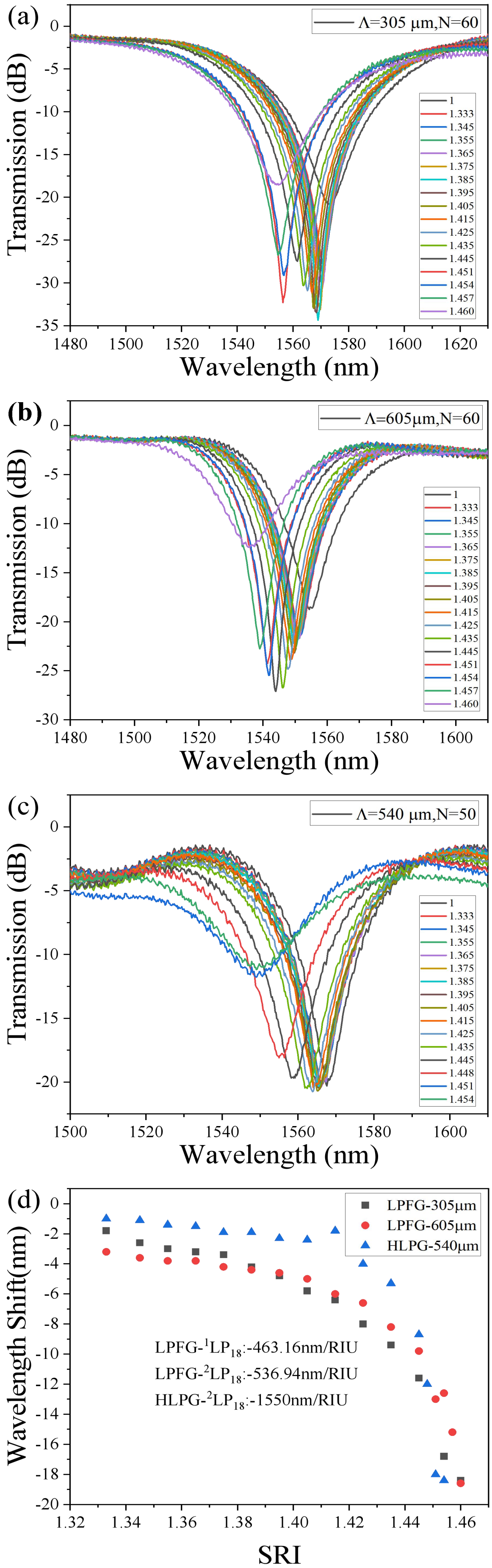

Fig. 3. The SRI characteristic of DCF-LPFGs and DCF-HLPGs.

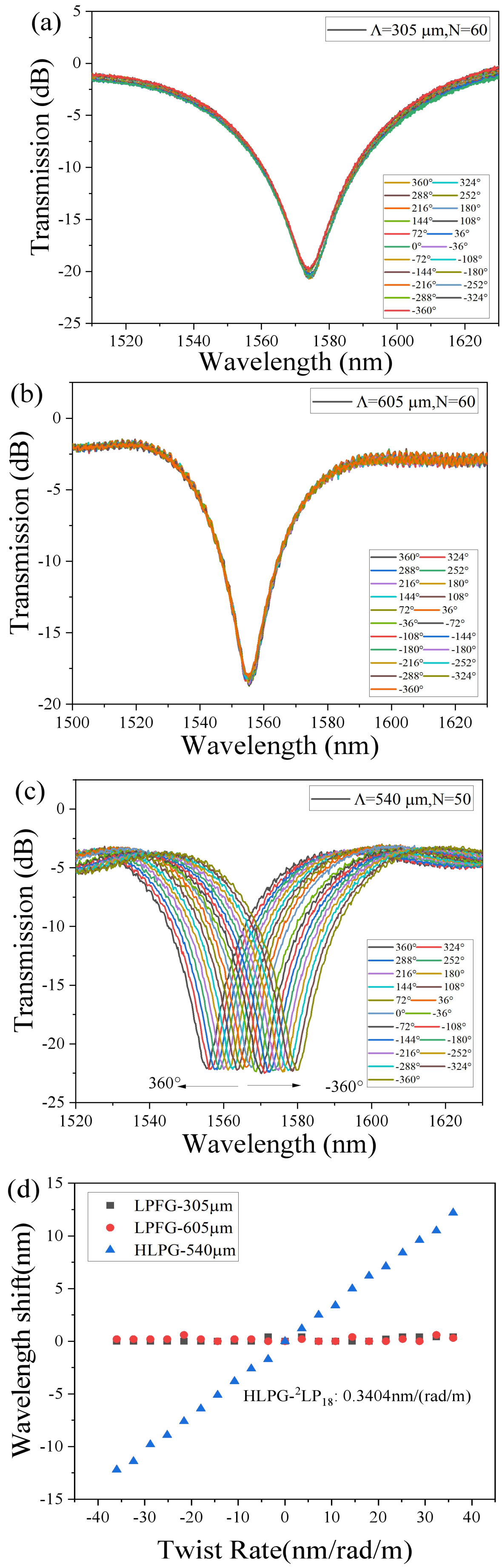

Fig. 4. The twist characteristic of DCF-LPFGs and DCF-HLPGs.

Figure 3 shows the resonance wavelength shift with the refractive index changing from 1.333 to 1.46. With the increase of refractive index, the wavelength shift to shorter wavelength. The sensitivity of $^1LP_{18}$, $^2LP_{18}$ of DCF-LPFG and $^2LP_{18}$ of DCF-HLPG is -463.16 、 -536.94 and -1550 nm/RIU respectively, in the RI range of 1.435 to 1.454. The sensitivity of $^2LP_{18}$ is slightly higher than $^1LP_{18}$ for DCf-LPFG , and the sensitivity of DCF-HLPG is three times higher than DCF-LPFG.

The torsion characteristic was also investigated. As shows in Figure 4, the DCF-LPFGs are insensitive to the torsion when the twist rate changing from -36 rad/m to 36 rad /m (-360°~360°). However, for the DCF-HLPG, the wavelength shifts to longer wavelength when the twist rate changing from 0 to 36rad/m, and the wavelength shifts to shorter wavelength in the twist rate changing from 0 to -36 rad/m. The torsion sensitivity of DCF-HLPG is 0.3404 nm/(rad/m), which is much higher than the DCF-LPFG. Thanks to the helical structure, the period of DCF-HLPG will be increased or decreased when the torsion was applied in grating, resulting in the shift of the resonant wavelength. In addition, the high- order diffraction cladding mode has a higher sensitivity [9].

III. Conclusion

In conclusion, the sensing characteristics of high-order cladding mode (LP_{18}) by inscribing LPFGs and HLPGs in double-cladding fiber have been investigated experimentally. The DCF-HLPG has a higher SRI and torsion sensitivity than DCF-LPFG. The torsion sensitivity of the DCF-HLPG is high to be 0.3404 nm/(rad/m), while the DCF-LPFG is insensitive. And the maximum SRI sensitivity is 1500 nm/RIU. Compare to conventional LPFG, the HLPG has a more extensive application prospect. The proposed HLPG can be used as high sensitivity twist sensor and wavelength tunable fiber filter.

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