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Long Period Fiber Grating Fabricated by Defocused CO_2 Laser for Refractive Index Sensing

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Abstract. Long period fiber grating (LPFG) has many applications in optical fiber communications and optical fiber sensors. It can be fabricated by many methods. Recently, an edge written LPFG with large resonant peak loss and apparent asymmetric cladding mode coupling has been produced by focusing the high frequency CO_2 laser pulses directly on the fiber cladding surface. Such a LPFG exhibits only a small area of refractive index change on the fiber cladding surface without any physical deformation. In this work, we developed a new LPFG fabrication method by use of defocused CO_2 laser pulses, i.e. to move the laser beam focus slightly away from the fiber cladding surface. No apparent physical damage is observed after the LPFG fabrication. With the increase of the moving distance from the fiber cladding surface, the induced average refractive index change in the fiber cladding becomes smaller, which also leads to a decreased polarization dependent loss when compared with the LPFG made by the focused CO_2 laser pulses. The LPFG developed in this work also shows a higher sensitivity of the resonant wavelength to the external refractive index around the fiber cladding than that made by use of focused CO_2 laser pulses. It is expected that this new type of LPFGs have important applications in refractive index sensors.

Keywords: Edge written Long Period Fiber Grating, Defocused CO_2 Laser Pulses, Refractive Sensor

PACS: 41.85.-p, 42.25.BS, 42.40.Eq

1. INTRODUCTION

Long period fiber grating (LPFG) has been widely used in various kinds of optical communication devices due to its feature of performing power coupling between core mode and cladding modes. [1]. Recently, by use of focused high frequency CO_2 laser pulses on the fiber cladding, an edge written LPFG is reported with a high sensitivity to the refractive index (RI) change [2]. This method is based on the thermal shock [3] and the rapid cooling [4] effects during the exposure of the laser pulses.

In this paper, we report a novel method to fabricate LPFG by use of defocused CO_2 laser pulses, i.e. to move the laser focus away from the fiber surface for a small distance. The experimental results show that this method processes a higher RI sensitivity and much smaller polarization dependent loss (PDL) compared with those made by the focused CO_2 laser beam.

2. EXPERIMENTAL RESULTS

2.1 Edge Written LPFG with Focused Laser Pulses

The LPFG we made with SMF-28 fiber by using focused laser pulses has a grating pitch of 625μm and a grating length of 2.5cm. The microscope image shows that, no physical deformation is created during the fabrication process however, a small RI change area exists near the fiber cladding surface. The maximum depth of this area is about 12μm, as shown in Fig. 1. The LPFG fabricated is denoted as LPFG1.

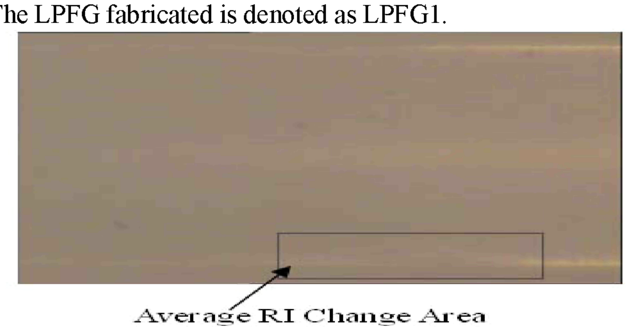

FIGURE 1. Microscope image of LPFG1

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During the fabrication process, the insertion loss of LPFG1 was ~ 0.33dB and the three main resonant peaks (RPs) were observed to grow simultaneously in the wavelength range between 1400 and 1600nm. The transmission spectrum of LPFG1 is shown in Fig. 2 where the three RPs are located at 1582.5, 1495.9 and 1458.9nm, respectively, corresponding to the RP loss of -26.95, -17.36 and -15.82dB, respectively. The largest resonant loss obtained is larger than that reported in [2].

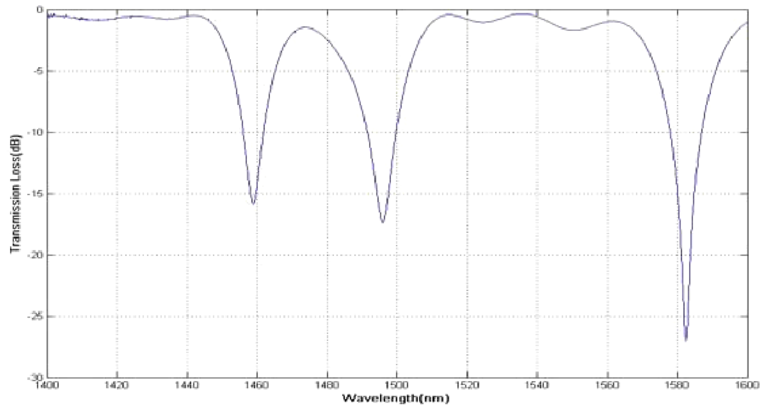

FIGURE 2. The transmission spectrum of LPFG1

Since the two small RPs grew simultaneously during the fabrication and we had chosen a large grating pitch, they should be the result of different cladding mode coupling rather than over-coupling. From the calculation results, the three RPs come from the coupling of cladding mode LP03, LP11 and LP02, respectively. According to [5] and [6], the asymmetric cladding mode coupling is the result of birefringence in the fiber, which is induced by the asymmetric index change profile obtained during the fabrication. The results of PDL test for the RP around 1582nm are shown in Fig. 3 where the two PDL peaks of LPFG1 are 9.73dB at 1584.2nm and 7.62dB at 1582.6nm, respectively.

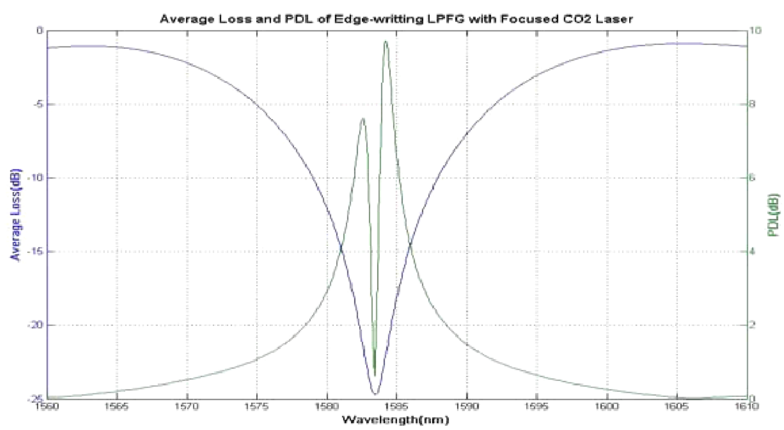

FIGURE 3. PDL of LPFG1

2.2 LPFG Fabricated by Use of Defocused Laser Pulses

By moving the laser focus away from the fiber cladding surface for a small distance, LPFG with only small average RI change in the fiber cladding ($\delta nclad$) can be obtained as the laser energy exposed into the cladding becomes small. The small distance away from the fiber cladding was set as 1mm by use of a translation stage. The LPFG fabricated in this method is denoted as LPFG2. The microscope image in Fig. 4 shows neither physical deformation nor apparent average RI change is observed in the fiber cladding.

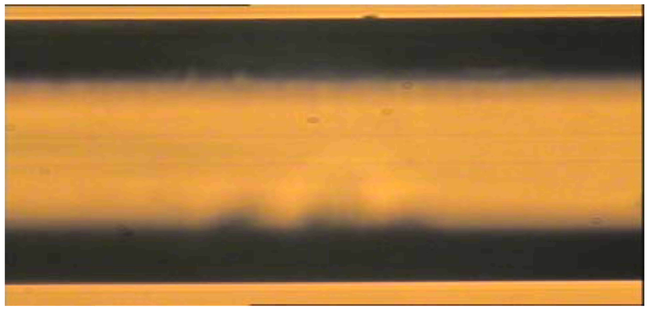

FIGURE 4. Microscope image of LPFG2

The PDL test also reveals that the LPFG made by defocused laser pulses has a smaller asymmetric RI change profile. As mentioned in section 2.1, the smaller asymmetry of RI profile in the fiber cladding will reduce the birefringence, thus lead to a smaller PDL. As shown in Fig. 5, the two peaks are 1.85dB at 1584.5nm and 1.56dB at 1589.95nm, which are much smaller compared with those in Fig. 3.

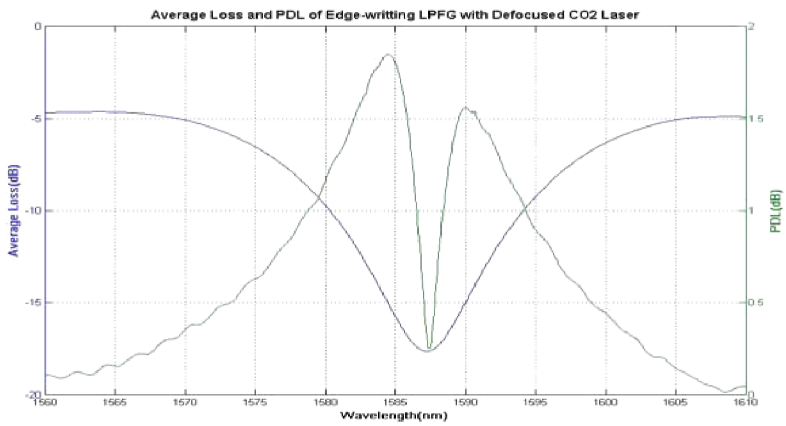

FIGURE 5. The PDL of LPFG2

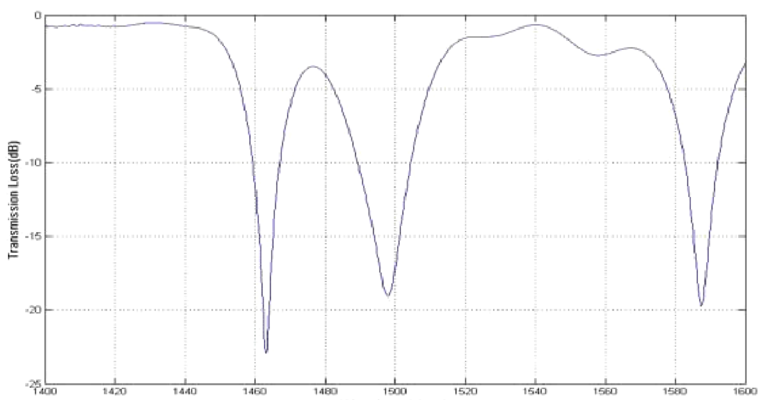

FIGURE 6. The transmission spectrum of LPFG2

Besides the PDL, the growth of the three RPs also proves that the $\delta nclad$ in the fiber cladding decreases when the laser focus is moved away from the fiber cladding surface. According to the expression of resonant wavelength growth [7], a small $\delta nclad$ will lead to a large resonant wavelength $\lambda \max$. The transmission spectrum of LPFG2 is shown in Fig. 6. The three RPs are located at 1587.6, 1498.0 and 1463.2nm, with resonant loss 19.71, 19.05 and 22.91dB, respectively. The RPs in LPFG2 are red shifted when compared with LPFG1. However, the insertion loss of LPFG2 is ~ 0.47dB, similar to that of LPFG1.

2.3 Comparison of LPFG Made by Focused and Defocused Laser Pulses as RI Sensor

We have implemented eternal RI sensitivity test for both LPFG1 and LPFG2. It was found that a relatively large shift of RP existed around 1582nm while the other two RPs exhibited negligible shift. The test results for the RP near 1582nm are shown in Fig. 7.

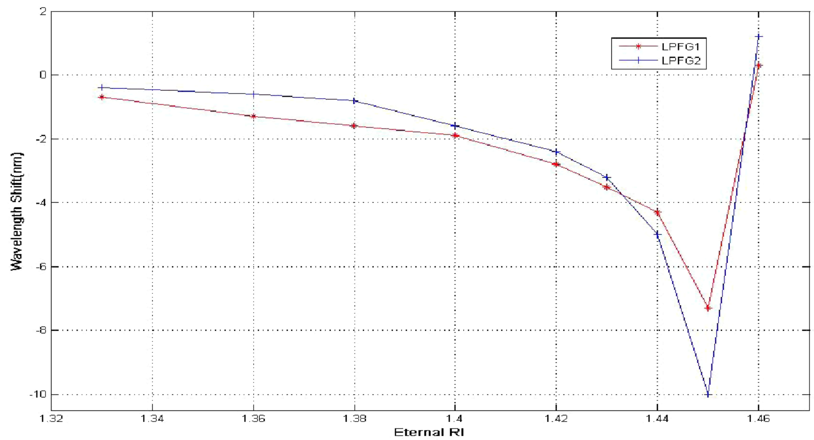

Fig. 7 Comparison between LPFG1 and LPFG2 when they are used as RI sensor

It can be seen from Fig. 7 that when the eternal RI is much smaller than the cladding RI, n_{clad} (~ 1.45), LPFG1 has a larger RI sensitivity however, when the eternal RI approaches n_{clad}, LPFG2 shows not only a larger wavelength shift but also a larger RI sensitivity. The reason is that the average RI change area of LPFG2 is closer to the cladding surface than that of LPFG1, similar to the difference exists between the edge written LPFG and conventional LPFG [2]. Besides, after the mode transition, when the eternal RI is larger than n_{clad}, LPFG1 and LPFG2 have a resonant loss of 7.5 and 12.13dB, respectively, which is larger than that reported in [8]. The results obtained indicate that LPFG2 can be effectively used as a high sensitive RI sensor.

3. CONCLUSION

An LPFG fabrication method by use of defocused CO_2 laser pulses is presented. The microscope image, PDL test and RP growth show that such kind of LPFG has a smaller asymmetric RI profile and possesses a relatively large RI sensitivity.

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