JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 8, No. 3, June 2006, p. 1247 - 1249

Torsion-sensitivity of mechanical long-period grating in photonic crystal fiber

X. YU*, P. SHUM, S. FU, L. DENG
Network Technology Research Centre, Nanyang Technological University, Research TechnoPlaza, 50 Nanyang Drive, Singapore 637553

We demonstrate for the first time the torsion-sensitivity of a single mode photonic crystal fiber by using a stress induced mechanical long-period grating. The *g*-value of this special fiber is measured to be 0.13. The evolution of mode coupling in the grating device is experimentally characterized by twisting the fiber in front of the long period grating. The resonance wavelength shift with the twisting is shown to be more sensitive than that of single mode fiber.

(Received March 16, 2006; accepted May 18, 2006)

Keywords: Long-period grating, Photonic crystal fiber, Torsion

1. Introduction

Long-period gratings (LPGs), which can couple light between the fundamental core mode and a set of well-defined co-propagating cladding modes, have been implemented in a wide variety of applications due to its promising advantages such as relative simple fabrication, low insertion loss, low back reflection, immunity to electromagnetic interference and compactness [1]. In particular, considerable attention has been given to the fiber-optic sensing systems over the past decade. Recently, research in this field has been greatly extended from conventional single mode fiber (SMF) to photonic crystal fiber (PCF) consisting of a pure undoped silica core surrounded by a periodic pattern of air holes running along the fiber length [2]. The motivation is that PCFs offer extraordinary control over the wave guiding properties [3], via their microstructured geometry in terms of air hole size and inter-hole spacing. So far, fabrication of LPG in PCF by the means of CO_2 laser [4] and electric-arc [5] with a point-to point technique has been reported. Their corresponding temperature and strain sensor characteristics have also been presented experimentally [6,7,8].

In this paper, we investigate, for the first time to our best knowledge, the torsion sensitivity of a stress induced Mechanical-LPG (MLPG) in a single mode PCF (SM-PCF). The relationship of the resonance wavelength shift with twisting angle is studied and compared with that of LPG inscribed in a SMF. The primary advantage of MLPG [9] is the tunability of several parameters: firstly, the grating period can be tuned by adjusting the angle (α) between the grooved plate and fiber longitudinal axis; secondly, the coupling coefficient κ, which determines the strength of mode coupling and is proportional to the index variation induced by photoelastic effects, is easily controlled by the pressure of the period grooved plate; and the transmission spectrum is reversible and removable with a good repeatability. Moreover, PCF-LPGs have a much smaller thermo-optic coefficient because of the unique structure of PCFs where there is no viscoelastic effect between the core and cladding (10.9 pm/^{o}C) compared with SMF-LPGs (119 pm/^{o}C), making them a favorite choice in sensor applications especially in harsh environment [8].

2. Experiments and analysis

In this work, we firstly measured the optical activity coefficient *g*-value for three types of fiber, SMF, SM-PCF and polarization maintaining PCF (PM-PCF). The light launched from a tunable laser source at 1550 nm followed by a polarizer goes into a section of twisted fiber. A polarimeter is used to obtain the S-parameters at different twisting angles. The input the state of polarization (SOP) is fixed at [1 0 0]. Thus the *g*-values are calculated from the S-parameter according to $S_1 = \cos(g\theta)$ [10], where θ is the twisting angle, and *g* is a suitable physical constant representing the proportionality between the twist rate and the induced circular birefringence. The birefringence *B* is also listed in Table 1. Compared with SMF which has an average birefringence value of 10^{-6}, the large index contrast and hexagonal-shaped core facilitate PCF around two orders greater.

Table 1. The birefringence (B) and g-value for three types of fiber.

Fiber-type	SMF	SM-PCF	PM-PCF
B (1550nm)	10^{-6}	10^{-4}	8.6×10^{-4}
g	0.16	0.13	2.0

The SM-PCF is chosen to write a MLPG and the experiment setup for demonstrating the shift of resonance wavelength by changing θ is shown in Fig. 1. It consists of a MLPG and a twist region which is composed of a fiber twister and a fiber holder with L=16 cm. The PCF in the twist region is straightened in order to avoid bending effects. The MLPG were formed by pressing the PCF with a periodically grooved plate (L_1=5 mm, L_2=50 mm, L_3=20 mm, Λ=500 μm, α=0º) with a fixed pressure of P=6.174 kN/m^2. The PCF from Crystal-Fibre A/S has a pitch of 8 μm and air-hole diameter of 3.68 μm. The outside diameter of fiber is the typical value of 125 μm. Higher linear-birefringence is achieved by increasing the transversal pressure. To test the resonance wavelength shift of the PCF-LPG, a broadband (1260~1460 nm) super luminescent diode (SLD) light source is used. The transmission spectrum was measured with an optical spectrum analyzer (OSA).

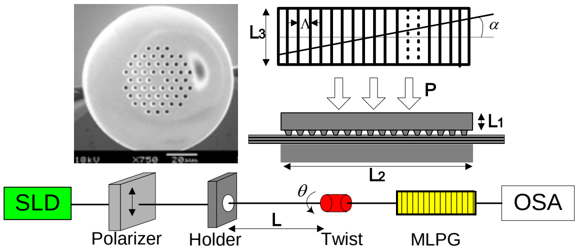

Fig. 1. The experimental setup for measuring the torsion sensitivity of the PCF. Insets show the cross-sectional image of the PCF and the grooved fixture.

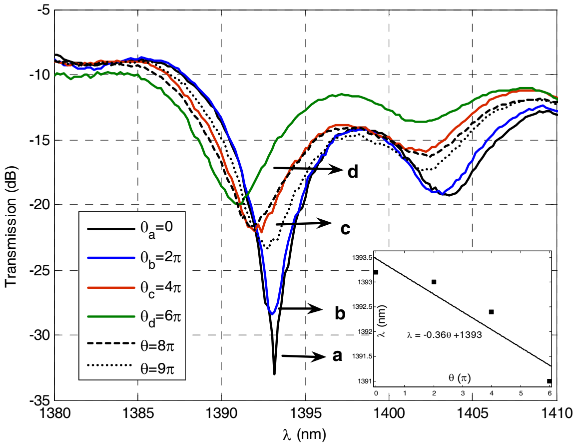

Fig. 2. The evolution of measured transmission spectrum of PCF-MLPGs by increasing the twisting angle θ. The inset shows the torsion sensitivity.

The polarizer is tuned to obtain an initial resonance at the longest wavelength, named λ_{max}. As the twisting angle θ increases, the polarization angle Φ of the input light varies linearly accordingly as Φ=gθ/2 [10]. Due to the variations of polarization angle and the field components along the two orthogonal axes, the resonance wavelength will oscillate between λ_{max} and λ_{min} and the turning point is at θ≈7.7 π. The theory agrees well with the evolution of the resonance wavelength shift shown in Fig. 2. The variation from curve-*a* to curve-*d* indicates the rotation of polarization angle from 0^o to about 70^o, whereas the transition from cure-*d* towards the dashed and dotted curves shows the reverse trend of variation, representing the polarization angle is beyond 90^o. The blue-shift of resonance wavelength is measured to be 0.73 nm/2π for both transmission dips near 1393 nm and 1403 nm.

In purpose of a better understanding about the torsion sensitivity of PCF-MLPGs, a comparison with SMF-MLPGs is demonstrated in Fig. 3. The resonance wavelength for the mode coupling near 1495 nm is blue-shifted, which follows the same trend of variation as PCF when the torsion rate increases (0<Φ<90^o). But the red-shift of resonance wavelength happens near 1387 nm. The resonance wavelength shift with the twisting angle is 0.33 nm/2π, which the sensitivity is reduced by half compared with PCF. Moreover, many ripples were observed in the spectrum, introducing inaccuracy factors to the system.

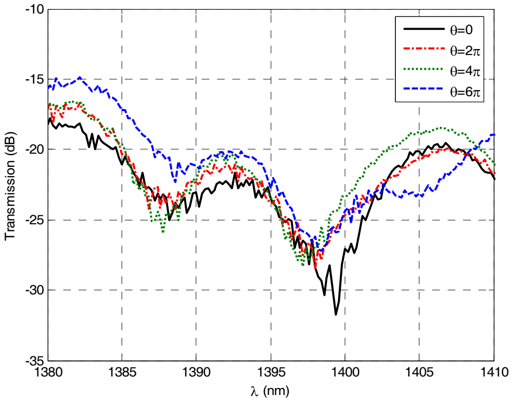

Fig. 3. The evolution of measured transmission spectrum of SMF-MLPGs.

3. Conclusion

The g-value of a SM-PCF is measured directly from the SOP to be 0.13. The torsion sensitivity of PCF-MLPG has been experimentally characterized and the shift of resonance wavelength with the twisting angle is 0.73 nm/2π, which is two times larger than a SMF-MLPG. The torsion sensitivity of this device can be enhanced when improving its linear birefringence by using a larger mechanical pressure.

References

[1] A. M. Vengsarkar, P. J. Lemaire, J. B. Judkins, V. Bhatia, T. Erdogan, J. E. Sipe, J. Lightwave Technol. **14**, 58 (1996).

[2] J. C. Knight, T. A. Birks, P. St. J. Russel, Opt. Lett. **21**, 1547 (1996).

[3] A. Bjarklev, J. Broeng, K. Dridi, S. E. Barkou, ECOC (1998), pp. 135-136.

[4] H. Kim, T-J. Ahn, D. Y. Kim, B. H. Lee, Y. Chung, U-C. Paek, W-T. Han, Appl. Opt. **41**, 3809 (2002).

[5] Malki. G. Humbert, Y. Ouerdane, A. Boukhenter, A. Boudrioua, Appl. Opt. **42**, 3776 (2003).

[6] G. Kakarantzas, A. Ortigosa-Mlanch, T. A. Birks, P. St. J. Russell, Opt. Lett. **27**, 1013 (2002).

[7] K. Morishita, Y. Miyake, J. Lightwave Technol. **22**, 625 (2004).

[8] Y. Zhu, P. Shum, H. Bay, M. Yan, X. Yu, J. Hu, J. Hao, C. Lu, Opt. Lett. **30**, 367 (2005).

[9] J. H. Lim, K. S. Lee, J. C. Kim, B. H. Lee, Opt. Lett. **29**, 331 (2004).

[10] A. Gerrard, J. M. Burch, Introduction to Matrix Methods in Optics, John Wiley & Sons Ltd., London, 1975.

---

*Corresponding author: p145144582@ntu.edu.sg