Sensing and Bio-Sensing Research 2 (2014) 38–42

Contents lists available at ScienceDirect

Sensing and Bio-Sensing Research

journal homepage: www.elsevier.com/locate/sbsr

An in-line fiber-optic modal interferometer for simultaneous measurement of twist and ambient temperature

Yongqin Yu [a,b,*], Quandong Huang [c], Xuejin Li [a,b], Xue Chen [c], Chenlin Du [c]

[a] College of Physics Science and Technology, Shenzhen Key Laboratory of Sensor Technology, Shenzhen University, China
[b] ShenZhen Engineering Laboratory for Optical Fiber Sensors and Networks, China
[c] College of Electronic Science and Technology, Shenzhen University, China

ARTICLE INFO

Keywords:
Photonic crystal fibers
Fiber optics sensors
Twist sensor
Temperature sensor

ABSTRACT

A novel and simple sensor based on fiber-optic modal interferometer fabricated by a segment of low elliptical hollow-core photonic bandgap fiber for simultaneous temperature and twist measurements is demonstrated. Meanwhile the sensor can also measure the twist angle and determine the twist direction simultaneously. The mode distribution of EHC-PBGF is demonstrated both in theory and experiments. There is an obvious difference of two transmission dips on the temperature and twist. The twist sensitivities of Dip 1 and Dip 2 are obtained to be −31.95 and −585.8 pm/(rad/m), respectively. The temperature sensitivities are 12.99 pm/°C for Dip 1 and 5.09 pm/°C for Dip 2, respectively. Two parameters of twist and temperature can be distinguished and measured simultaneously by using a sensing matrix. Meanwhile the structure is found to be weakly sensitive to the axial strain. It has the advantage of avoiding the crosstalk of strain in the applications.

1. Introduction

Twist is an important sensing physical parameter that needs to be monitored in multi-area applications, such as detecting the health condition of engineering structure and mechanical equipment. And optical fiber sensors have the advantages of possessing a small size, easy to embed into the structures and anti-electromagnetic interference, et al. [1]. So far, there have been many works to study fiber sensor characteristic of twist/torsion, for example, twist sensors by using the birefringence of photonic crystal fiber [2–4] and long period fiber gratings (LPFGs) [5–7]. In 2011, a fiber ring laser incorporating a pair of rotary long-period grating was used for torsion sensing with a torsion sensitivity of 0.084 nm/(rad/m) in the torsion range ±100 rad/m [8]. In the same year, Chen WG reported a highly sensitive torsion sensor based on Sagnac interferometer using side-leakage photonic crystal fiber [9]. The achieved maximum torsion sensitivity is about 0.9354 nm/degree. Twist sensors, such as special fibers composed by carbon nanotube [10], fiber-optic polarimetric twist sensor [4], or special fluid filled in photonic crystal fiber [11], have been evolving to diversified applications. To our best acknowledge, twist fiber sensors with a low temperature cross-sensitivity have been reported above, while simultaneous sensing of twist and temperature based on fiber has not been reported, which may be have a potential twist applications for the real-time monitoring of the components working in harsh and complex conditions.

Since hollow core photonic bandgap fiber (HC-PBGF) was proved of light guiding in low index air core in 1999 [12], its unique merits [13–15] have been attracting scholars' attention to investigate for sensor applications, such as the employ of original hollow-core trait structure as Fabry-Pérot-type strain sensor [16–18], fabricating LPFG sensor by collapsing part of surrounding air-core [19], in-fiber polarimeters and Sagnac interferometer are reported [20,21], offset-splicing a single-mode fiber (SMF) with HC-PBGF as a inclinometer for detecting direction was also reported as a novel application [22].

In this paper, an in-line fiber-optic modal interferometer based on low elliptical hollow-core photonic bandgap fiber (EHC-PBGF) has been studied for simultaneous measurement of twist and temperature. This in-line fiber-optic modal interferometer is simply composed by directly splicing a section of EHC-PBGF with single-mode fibers (SMFs). The mode distribution of EHC-PBGF is demonstrated both in theory and experiments. The sensitivities of temperature and twist are investigated. Utilizing the obvious difference of two transmission dips on temperature and twist, two parameters can be simultaneously distinguished and

* Corresponding author at: College of Physics Science and Technology, Shenzhen Key Laboratory of Sensor Technology, Shenzhen University, China.
E-mail address: yuyq@szu.edu.cn (Y. Yu).

http://dx.doi.org/10.1016/j.sbsr.2014.10.013
2214-1804/

measured by using one single modal interferometer. Meanwhile the twist direction can also be distinguished. Moreover, we find that the structure is weakly sensitive to the axial strain. It has the advantage of avoiding the crosstalk of strain and this structure is simple and easy to be fabricated as well.

2. Experimental setup

Scheme of experimental setup for simultaneous measurement of twist and temperature is shown in Fig. 1(a). A broadband light source, generated by a superluminescent light-emitting diode (SLED) (LIGHT COMM Inc. China) and an optical spectrum analyzer (OSA, YOKOGAWA AQ6370B) are connected to the sensing component to monitor the transmission spectra as applied physics parameters vary. The sensing component is composed of a section of EHC-PBGF spliced with SMFs. EHC-PBGF is fabricated and supported by Yangtze Optical Fiber and Cable Corporation in China. Scanning electron micrograph (SEM) image of its cross section is shown in Fig. 1(b) and its local enlarged image is shown in Fig. 1(c). The dark areas are the air holes and the bright areas are solid silica. The maximum dark area in the center is air core which is a low elliptical geometry with a long axis of 7.5 μm and a short axis of 6.9 μm, which indicates that it is a low-birefringence fiber, while six solid silica rods distributing around the air core are high birefringence due to their asymmetric structures, as shown in Fig. 1(c) by six red circle lines. The cladding is with a diameter of 125 μm. And the pitch of air holes surrounding the air core is about 4 μm. Fig. 1(d) shows the photograph of the segment of EHC-PBGF with a length of 651.8 μm that captured by optical microscope (Olympus BX51, Olympus Inc.). It can be seen that there is no obvious collapse in the air holes. Both ends of EHC-PBGF were spliced with SMFs by using a FETEL S178A fusion splicer; and all the splicing process was done manually by controlling the appropriate arc intensity and arc duration to protect collapse of air-core and realize a high splicing strength. We firstly spliced one end of EHC-PBGF with a SMF and cut off the other end under the optical microscope by remaining a needed length and then spliced the remaining EHC-PBGF with a SMF.

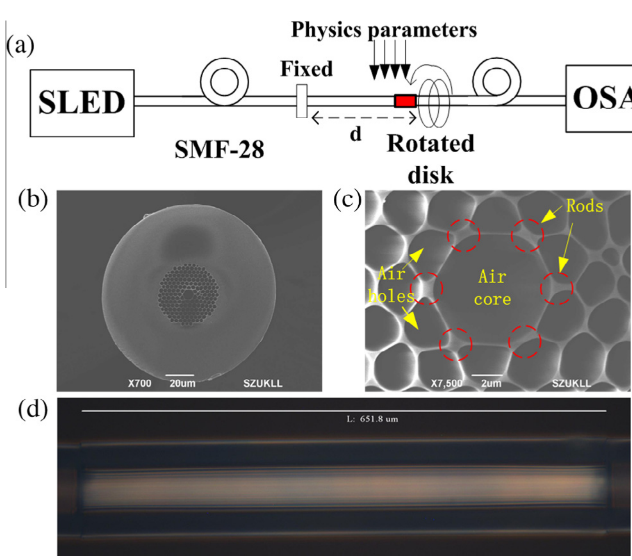

Fig. 1. (a) Scheme of experimental setup. SLED: superluminescent light-emitting diode, OSA: an optical spectrum analyzer; (b) Cross section SEM image of EHC-PBGF. (c) Local enlarged SEM image of the core region. Six solid silica rods distributing around the air core labeled in red dotted circle lines. (d) Photograph of EHC-PBGF with a length of 651.8 μm spliced with SMFs. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The propagation loss of EHC-PBGF is measured by the cutback method. The transmission spectra of EHC-PBGF with lengths of 0.6 and 1.2 m are obtained firstly using the same splicing conditions, as shown in Fig. 2. Then the propagation loss versus wavelength is obtained by subtraction and normalization as shown in Fig. 2 in blue color. There is a cut-off region of photonic bandgap located from 1360 to 1416 nm. The propagation loss at 1550 nm is obtained to be about 4.3 dB/m and the splicing loss between EHC-PBGF and SMF-28 is about 7.0 dB at 1550 nm. The high average insert loss we considered results by two reasons. Firstly, the homogeneous distribution of air holes in the cladding is not good, which leads to the weak photonic bandgap effect of EHC-PBGF and secondly the core is mismatched between EHC-PBGF and SMFs. The insertion loss is much higher in the short wavelength region because of the poorer bandgap effect. So in the sensing experiments, we only record the transmission spectra of EHC-PBGF in the long wavelength region.

The photographs in Fig. 3(a) and (b) show near field mode distribution of EHC-PBGF at 1550 nm captured by infrared microscope (Leica DM6000M, Leica Inc.) with a tunable laser. It indicates the existing LP_{01} and LP_{11} in the air core and cladding supermode in the solid silica rods. A full-vector finite element method with the commercial software COMSOL Multiphysics was applied to simulate the modal characteristic of EHC-PBGF. The photographs shown in Fig. 4(a) and (b) show the two core modes of LP_{01} and LP_{11} at the wavelength of 1550 nm and the supermodes distributed in the solid silica rods are clearly co-existing. Comparing Figs. 3 and 4, we can see the experimental results and simulated results are well consistent.

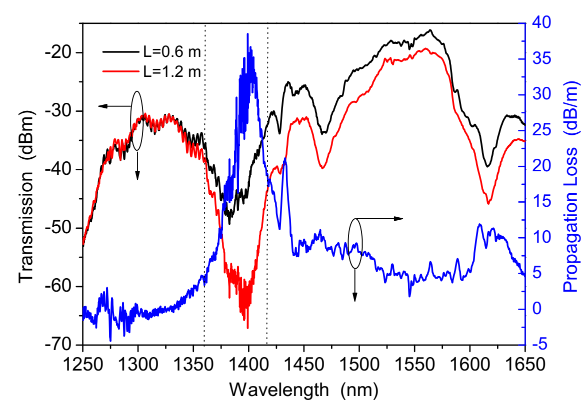

Fig. 2. Transmission spectra of EC-PBGF with lengths of 0.6 m (black line) and 1.2 m (red line), respectively. The propagation loss versus wavelength (blue line). A cut-off region lies between two dash lines. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

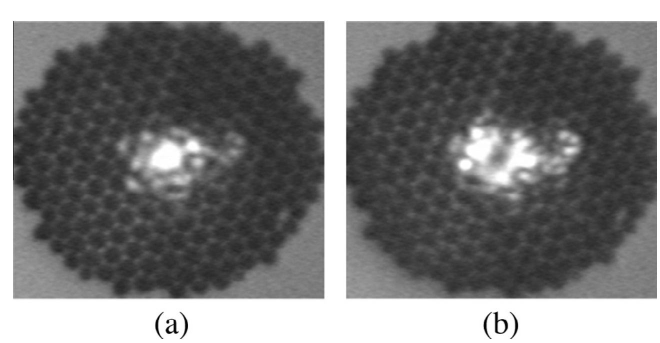

Fig. 3. The near field mode distribution captured by infrared microscope at the wavelength of 1550 nm. (a) LP_{01}, (b) LP_{11}; some supermodes in six bar-type silica rods of the cladding are also observed.