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Simultaneous Measurement of Torsion and Temperature Based on Helical Structure in Multicore Fiber

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Abstract: An all-fiber torsion sensor based on a helical structure in a multicore fiber is demonstrated. The sensor exhibits the ability of discriminating torsion direction, torsion angle and temperature.

OCIS codes: (060.2370) Fiber optics sensor; (120.3180) Interferometry

1. Introduction

Fiber torsion sensors are very significant components in the applications of architecture heath monitoring, robot position tracking and so on. To date, fiber torsion sensors have been reported based on several different schemes. For example, torsion sensors were demonstrated by constructing interferometers based on birefringent photonic crystal fibers (PCFs) [1, 2]. However, since the fabrication of PCFs is costly, the applications of torsion sensors based on PCFs are limited. Two other common schemes are based on polarization-maintaining fiber Bragg gratings (FBGs) [3] and conventional long period gratings (LPGs) [4, 5]. Furthermore, L. Zhang *et al.* reported a torsion sensor with directional discrimination based on a chiral LPG [6]. However, the torsion sensors based on FBGs and LPGs present cross sensitivity to temperature. Another torsion sensor with directional discrimination based on a tapered fiber was demonstrated by N. Chen *et al*. [7]. However, the taper region makes the mechanical strength of the sensor relatively worse.

In this paper, a fiber torsion sensor with torsion directional discrimination based on a helical structure (HS) in a multicore fiber (MCF) is proposed and experimentally demonstrated. The sensor is formed by single-mode-multimode-multicore-multimode-single-mode fiber structure. It can be used to monitor temperature and torsion simultaneously by discriminating the different responses of two resonant dips of the transmission spectrum. Moreover, as all the segments of the sensor are solid fibers with the same cladding diameter, the proposed sensor has relatively good mechanical strength.

2. Sensor fabrication

Fig. 1(a) shows the microscope image of the cross section of the MCF used in this wok. As can be seen, it has one centric core and six identical outer cores. The refractive index of the outer cores is a little higher than that of the centric core. The cladding diameter, core pitch and core diameter are 125 μm, 42 μm and 8.4 μm, respectively. More detailed descriptions of the MCF can be found in [8, 9]. The HS with a total pre-torsion of 4π was fabricated by utilizing a CO_2 laser splicing system (Fujikura, LZM-100). Manual Controller of LZM-100 was utilized to implement the HS fabrication. Firstly, the V-grooves and the two translation stages of LZM-100 were aligned, and a segment of the MCF with coating stripped was fixed between the two stages with a distance of about 4 cm. Then the theta motor of one stage was rotated by 0.5π. After using the Splicing Function of LZM-100, the rotation of 0.5π was concentrated into a small region of the MCF. The processes of rotating and splicing were repeated 8 times. After the total pre-torsion was added into the MCF, the length of the HS in the MCF is about 800 μm. The side view microscope image of the HS is shown in Fig. 1(b).

In order to couple light into not only the centric core, but also the outer cores, the MCF with the HS was fusion spliced between two segments of multimode fibers (MMF).Then the sensor head was spliced between two single mode fibers. The length of the MCF was about 18 mm. The MMF has a cladding diameter of 125 μm and a core diameter of 105 μm. Both the two MMFs have the same length of about 1 mm. Figure 1(c) illustrates the transmission spectrum of the sensor.

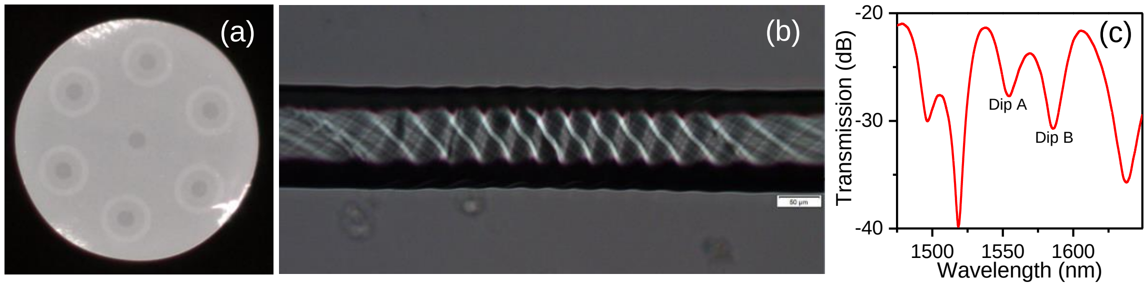

Fig. 1. (a) Microscope image of the MCF cross section. (b) Side view microscope image of the HS in the MCF. (c) The transmission spectrum of the proposed sensor

3. Sensing Characterization

To investigate the torsion response of the proposed sensor, the fiber was clamped between two rotators. One rotator was fixed, the other one can be rotated along clockwise (CW) or anticlockwise (ACW) direction. The distance between the two rotators was about 24.5 cm. The transmission spectral were collected for the torsion angle range from -360° to 360°. The corresponding twist rate range is from –25.641 rad/m to 25.641 rad/m. Fig. 2(a) shows the spectral shift of the sensor with varying twist rate. As can be seen from Fig. 2(a), when the twist rate increases along CW direction, both dip A and dip B shift to shorter wavelengths. Moreover, the intensities of both dip A and dip B decrease. Comparing with the CW direction, when the twist rate increases along ACW direction, even though both dip A and dip B still shift to longer wavelengths, but the intensities of the two dips have opposite variation trends. The torsion responses of dip A and dip B are illustrated in Fig. 2(b) and Fig 2(c), respectively. As can be seen from Fig. 2(b), the wavelength of dip A shifts linearly and monotonically with a sensitivity of –0.116 nm/(rad/m) for the twist rate range from –19.943 rad/m to 14.245 rad/m. The intensity of dip A also varies with twist rate linearly for the ranges from –19.943 rad/m to –2.849 rad/m, and 5.698 rad/m to 17.094 rad/m, respectively. As illustrated in Fig. 2(c), the wavelength dip B exhibits similar torsion response with dip A. It has a sensitivity of –0.119 nm/(rad/m) for the twist rate range from –17.094 rad/m to 25.641 rad/m. Within the ranges from –22.792 rad/m to 0 rad/m and 0 rad/m to 17.094 rad/m, good linearity to varying twist rate is observed for the intensity of dip B.

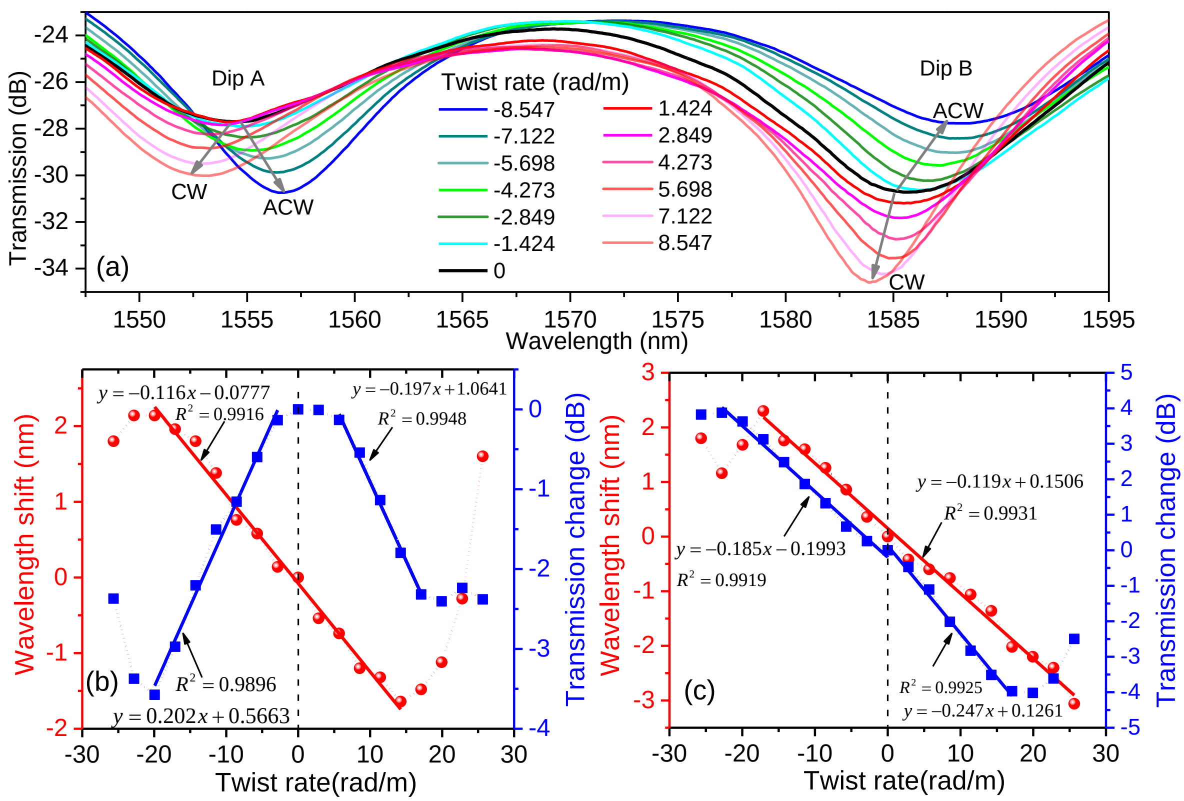

Fig. 2. (a) Spectral shift with varying twist rate. Torsion response of (b) dip A and (c) dip B.

In order to measure the temperature response, the proposed sensor was put in the straight groove of an oven with a temperature precision of 0.1 ℃. During the temperature sensing characterization, the temperature was increased from 25 ℃ to 90 ℃ with a step of 5℃. Figure 3(a) shows the spectral shifts of dip A and dip B with increasing temperature. The temperature responses of dip A and dip B are illustrated in Fig. 3(b). The linear fitting of the experimental data shows that the temperature sensitivities are 0.053 nm/℃ and 0.107nm/℃ for dip A and dip B, respectively.

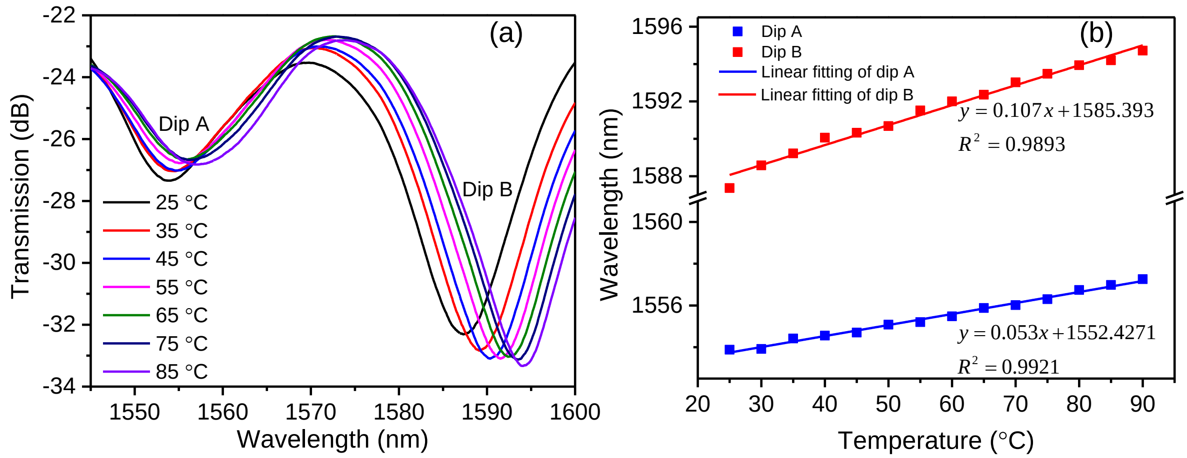

Fig. 3. (a) Spectral shift with increasing temperature. (b) Temperature response of dip A and dip B.

Since the wavelengths of dip A and dip B present different linear responses to twist rate change and temperature change, this parameters can be measured simultaneously by constructing a matrix consisting of the torsion and temperature sensitivities for the twist rate range from -17.094 rad/m to 14.245 rad/m. In addition, the torsion direction can be also discriminated.

4. Conclusions

In this paper, we reported the HS fabrication in a MCF and experimentally demonstrated a compact sensor based on the MCF with HS for simultaneous measurement of torsion direction, torsion angle and temperature. Additionally, the proposed sensor has a relatively better mechanical strength than the previously reported torsion sensors based on tapered fiber.

5. Acknowledgements

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