Stable Torsion Sensor with Tunable Sensitivity and Rotation Direction Discrimination Based on a tapered Trench-Assisted Multi Core Fiber

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Abstract: A tapered Trench-Assisted Multi Core Fiber (TA-MCF) is firstly proposed and experimentally demonstrated for torsion sensing. The rotation direction can be discriminated and the torsion sensitivity is tunable up to 1.1 nm/°.
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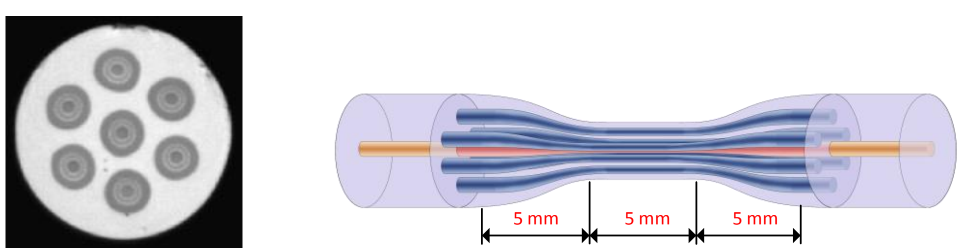
1. Introduction

Measurement of twist employing optical fibers is drawing significant attention from industry and the research communities. Different types of fiber optic torsion sensors have been demonstrated, including using long fiber Bragg gratings [1], photonic crystal fibers and Mach-Zehnder/Sagnac interferometers [2-4]. However, subsequent research work only focuses mostly on the improvement of sensitivity instead of its tunability. Tunable torsion sensors with high sensitivity are desirable in many industrial applications, for example in structural monitoring of wind turbines [5,6]. In addition, most of the twist sensors are generally based on either custom-made specialty optical fibers or complicated fabrication process, which is inevitably costly and time-consuming. Therefore, torsion sensor with tunable sensitivity as well as simple structure fabricated with commercially available fiber will be competitive and promising.

In this paper, we firstly proposed and experimentally demonstrated a novel and simple structure of torsion sensor based on a single-tapered TA-MCF, which is commercially available for spatial division multiplexing transmission and sensing system. The adjustment of pre-twist angle permits the tunability of sensitivity within the range of 0 to 1.1 nm/°. Meanwhile, twist direction and angle can be measured simultaneously and the performance of sensor proves to be stable.

2. Sensor fabrication and principle of operation

The fiber utilized to fabricate the torsion sensor is a commercial seven core fiber with index trench around each core whose cross section is shown in Fig. 1(a). The MCF consists of six identical outer cores and one center core. The cladding diameter, core diameter and core pitch are 150 μm, 8 μm and 41 μm, respectively. Dimension of the taper structure on TA-MCF was optimized to obtain desired optical spectrum on OSA. The MCF was tapered down to 30 μm in diameter by using CO_2 laser glass-processing machine (Fujikura, LZM-100) and then spliced to standard single mode fibers (SMFs) on both ends. During splicing, the center core of MCF was aligned to the core of SMF, which simplifies the fabrication process. The configuration of torsion sensor with optimized dimension of the taper structure is shown in Fig. 1(b). In principle, such configuration allows light propagating in the center core to couple equally to the surrounding six cores at the tapered region and periodic spectrum can be observed from the other end, as clearly shown in Fig. 2(a). The torsion induced by twisting the tapered region increases with the twist rate, which consequently changes the coupling coefficient. As a result, the spectrum shows corresponding shift.



(a) (b)

Fig. 1 (a) Microscopic image of the cross section of TA-MCF, and (b) the configuration of the proposed torsion sensor

The experimental setup of twist measurement consists of a fixed stage and a rotator, as shown in Fig. 2(b), where the fiber should be aligned precisely to the center of rotation. Even slight displacement between the two holders could incur significant influence on the sensing result, for example the accuracy, especially when the twisting length is short. In experiment, the precise alignment was realized by placing the two holders on one single-axis linear stage and the offset error is within a few micrometers. The twisting length between two fiber holders was set to 30 mm in order to cover the taper region. An OSA (Yokogawa AQ6370) and Broadband Light Source (BLS) with range of 1450 nm to 1650 nm were used to observe the transmission spectrum.

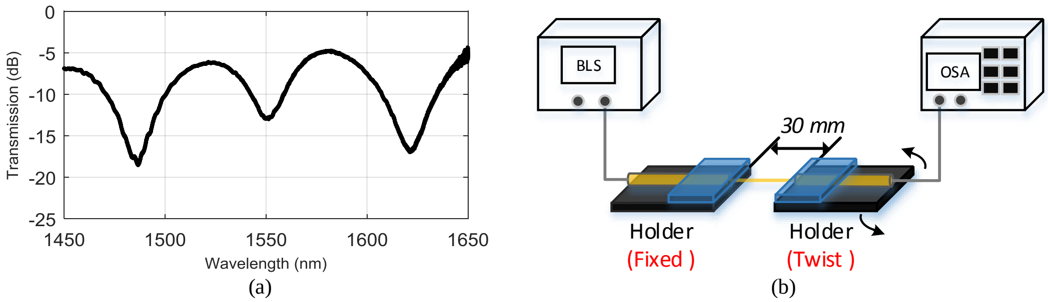


Fig. 2 (a) Measured transmission spectrum of the torsion sensor with a fringe spacing of ~60 nm, and (b) experimental setup of the twist measurement

3. Experiment results and discussion

In the experiment, the left-side fiber holder is fixed and the right-side holder was rotated precisely with rotation angle step of 1° in Clockwise (C.W) or Counter Clockwise (C.C.W) direction. In the measurement, twist angle varied from 0° to 1000° with step of 10° and the corresponding spectral responses at different twist angles were recorded by OSA with wavelength resolution of 0.05 nm and span from 1450 nm to 1650 nm. To demonstrate the tunability of the rotation sensor's sensitivity, eight measurement ranges with different center twist angles were conducted and three of them are illustrated in Fig. 3. It can be seen that, under the identical wavelength span of 150 nm and twist angle variation of 90°, twist regions with different center angle (255°, 355°, and 755°) show different amount of wavelength shift, as illustrated by the pink arrow line. However, the response in each region is approximately linear. The wavelength shifts of one valley with respect to the twist angle are linearly fitted and the sensitivities obtained in these three measurement ranges are: 0.11 nm/° (255°), 0.68 nm/° (355°) and 1.00 nm/° (755°), respectively. Therefore, the tunable sensitivity can be realized by applying a corresponding pre-twist angle to the sensor. Fig. 4 summarized the sensitivities of the eight ranges with different center twist angles. As discussed above, the sensitivity dramatically increases with fiber twisting and reaches as high as 1.1 nm/°.

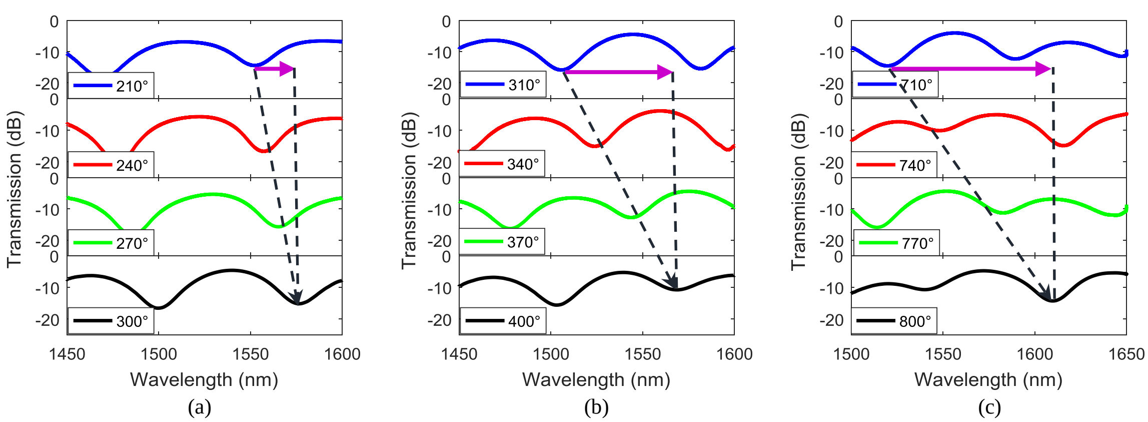
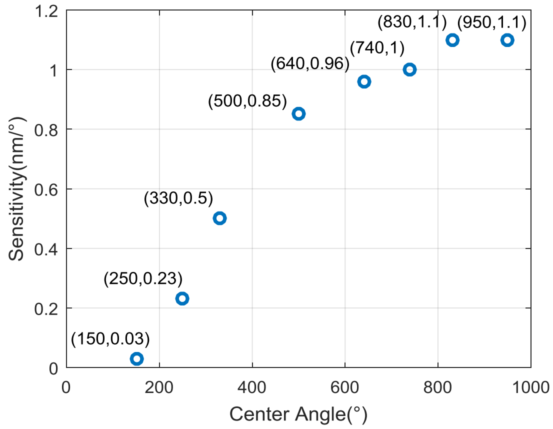


Fig. 3 Wavelength shift in transmission spectra when the sensor was rotated at a step of 30° in three ranges centered at: (a) 255°, (b) 355°, and (c) 755°



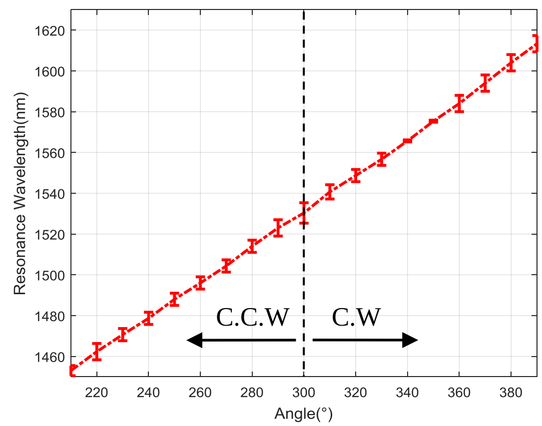


Fig. 4 Measured sensitivities at different twist ranges. Fig. 5 Wavelength shift as a function of the twist angle in the range centered at 300°

Since sensitivity during initial fiber twist is too small to observe the discrimination of rotation direction, we pre-twist the fiber with 300° initially and then changed the twist angle from 300° to 390° and 300° to 210°. Meanwhile, the measurement was repeated to demonstrate the repeatability of the sensing results. As indicated in Fig. 5, wavelength shift exhibits an opposite response to the rotation of clockwise (300° to 390°) and counter clockwise (300° to 210°) twist, corresponding to a red and blue shift on spectrum, respectively. In addition, error bar on every point in Fig.5, which stands for the error of measured twist angles within three measurements, shows reasonable repeatability of the sensing results. Therefore, this kind of sensor can measure the twist angle and direction simultaneously with stable performance.

4. Conclusion

In this paper, a novel rotation sensor based on a fiber-tapered fabricated with commercially available TA-MCF was proposed and demonstrated for torsion measurement. Eight measurement ranges centered at different angles were characterized and the sensitivity can be enhanced to as high as 1.1 nm/°. As a result, different wavelength shift in various measurement ranges was observed, which makes this kind of sensor flexible for twist sensing with tunable sensitivity. Torsion measurement under clockwise and counter clockwise direction was performed to show its discrimination of the rotation direction. We repeat the twist sensing experiment to verify its repeatability. Further improvement as well as the theoretical analysis are under investigation and will be presented at the conference. The authors acknowledge the financial supports of Grant HKPU 1-ZVHA and National Natural Science Foundation of China (NSFC) (Grant No. 61501027).

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