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High sensitivity curvature sensor with a dual core photonic crystal fiber interferometer

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ABSTRACT

This paper presents a high sensitive curvature sensor based on a dual core photonic crystal fiber (DCPCF). Its curvature sensitivity reaches 7.3235 nm/m^{-1}, within the measurement range of 0.3078-0.9235 m^{-1}.

OCIS codes: (060.0060) Fiber optics and optical communications; (060.2370) Fiber optics sensors

1. INTRODUCTION

Optical fiber sensors for curvature sensing are of much significance due to their wide applications in robotic arms, and structural health monitoring [1,2]. In recent years, curvature sensors based on fiber modal interferometers (MI) have been popularly explored in sensing field because of their high sensitivities, small and compact structure and ease of fabrication. Many MI structures have been demonstrated, for example, Zhang et al. demonstrated an MI sensor by using lateral-offset splicing joint and an up-taper formed through excessive fusion splicing method [3]. Tian et al. presented an optical fiber curvature sensor based on a twisted multimode fiber sandwiched between two single-mode fibers (SMFs) [4]. Gong et al. introduced optical fiber curvature sensor with two peanut-shape structures MI, which shows high curvature sensitivity [5].

On the other hand, dual core photonic crystal fiber (DCPCF) is a special fiber with two core modes, which can fulfill directional coupling. Many research works have been focused on the sensing application of the DCPCF. For example, Kim et al. used it for measuring curvature, strain and temperature in 2009 [6]. Sun et al. applied micro-structured-core photonic-crystal fiber for refractive index (RI) sensing in 2013 [7]. Asymmetrically infiltrated twin-core photonic crystal fiber for simultaneous measurement of temperature and strain was presented in 2016 by Liu et al. [8]. However, the DCPCF used in these works is very long to make use of the interference between two core modes. This makes the sensor head too large and fragile. Moreover, there is a large transmission loss in these former works.

In this paper, a DCPCF based curvature sensor is demonstrated, and this type of sensor owns the unique features of small size, simple and compact structure, and even has the potential for simultaneous measurement of curvature and temperature. Experimentally, the transmission dip wavelength changes quasi-linearly with the increase of the curvature. Its curvature sensitivity is 7.3235nm/m^{-1}. Furthermore, the temperature sensitivity is -9.7 pm/℃, within the range of 22-60 ℃.

2. THEORETICAL MODEL AND EXPERIMENTAL RESULTS

The schematic diagram of the sensor head is shown in Fig. 1. It consists of SMF-DCPCF-SMF structure, with a core-offset in one of the splicing point between the SMF and DCPCF. In theory, the dominated interference arises from the coupling between the core modes and the cladding modes. In addition, there also exists interference between the two core modes, which could have a modulation effect on the final transmission spectrum. With a phase difference between the core modes and the cladding modes, the interference can be expressed as [9]

$$I_{out} = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\left(\frac{2\pi\left(n_{core,eff} - n_{clad,eff}\right)L}{\lambda}\right) \tag{1}$$

where I_1, I_2 are the intensities of the core and cladding modes, respectively. $n_{core,eff}$, $n_{clad,eff}$ are the effective RI of core mode and cladding mode, respectively. L is the interference length and λ is the wavelength.

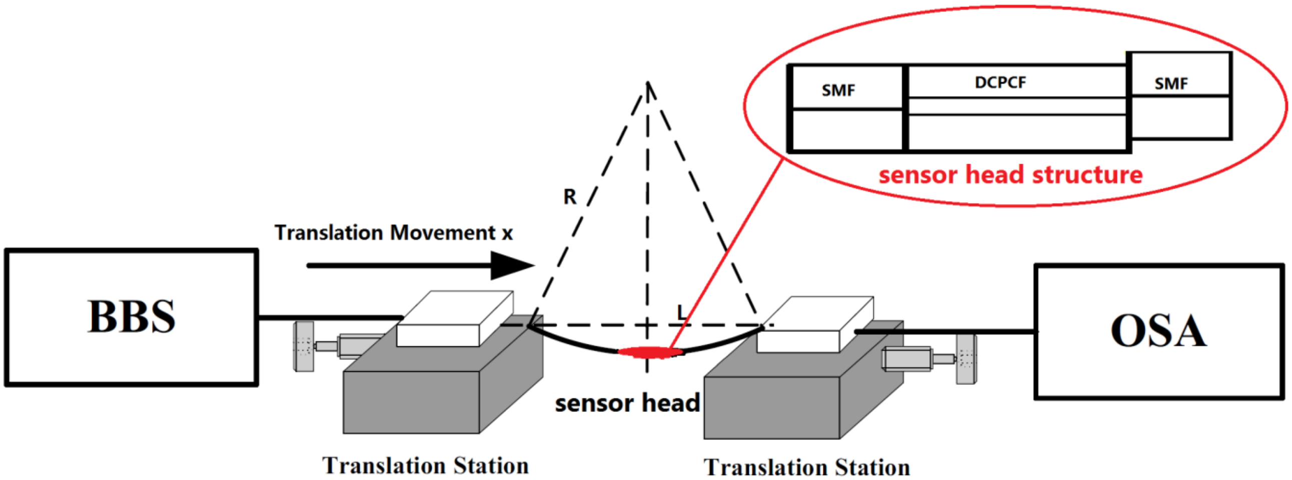

Fig.1. Schematic diagram of the experimental setup and sensor head structure.

An optical spectrum analyzer (OSA) with a resolution of 0.05 nm is used to monitor the transmission spectra of the MI. The two ends of the MI are clamped on two translation stages, and the distance between the two translation stages is 370 mm, denoted as L_0. One of the translation stages is fixed and the other translation stage is moved inward 0.2 mm each time, denoted as x. Therefore, the fiber will become bending and the curvature can be approximately expressed by [10]

$$C = \frac{1}{R} \cong \sqrt{24x / L_0^3} \tag{2}$$

For curvature sensitivity, according to [11,12], the wavelength response to curvature can be written as

$$\lambda_m = \frac{\Delta n_{eff_0} L}{2m+1} + \frac{kLd}{2m+1} \times \frac{1}{R} \tag{3}$$

where m is an integer, k is the strain RI coefficient, which is a constant; d is the distance between the core and the cladding modes, $1/R$ is the bending curvature, Δn_{eff0} is the effective RI difference between the core and cladding modes. As can be seen from Equ. (3), the change of the wavelength dip is related to the variations of the effective RI.

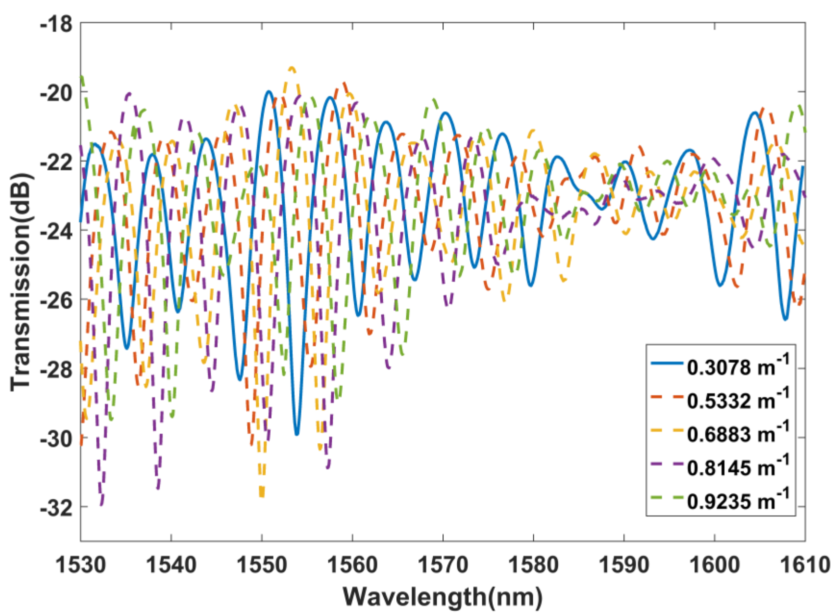

Fig.2. Transmission spectral response to curvature.

The sensing structure can be seen in Fig. 1. The splicing is operated on fusion splicer of Fujikura Fusion and Splicing Machine (FSM-100p). The length of DCPCF used in experiment is 20 mm. The largest extinction ratio reaches beyond 10 dB, as shown in Fig. 2. The transmission spectrum of the sensor is measured by an OSA with a wavelength resolution of 0.05 nm. The applied curvature is controlled within the range of 0.3078-0.9235 m^{-1}.

Fig. 2 shows the measured transmission spectrum shift under different curvatures. It can be observed that the extinction ratio varies with the increase of the curvature. This is because when the interferometer is bended, the higher order cladding modes will be highly changed. Besides, the dip wavelength also has a red shift with the increase of curvature.

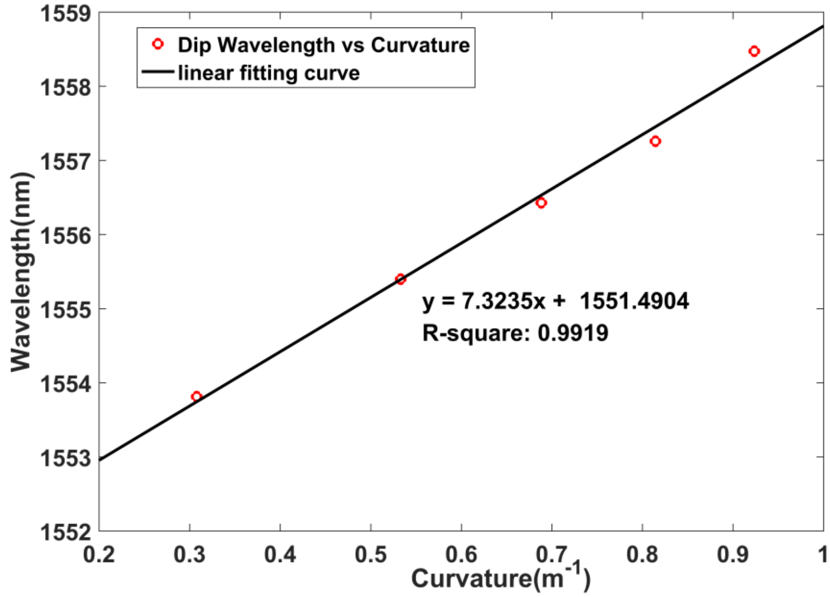

Fig.3. Relationship between the measured wavelength and curvature.

As shown in Fig. 3, dip wavelength from 1550 nm to 1560 nm are taken for detailed analysis. The dip wavelength shifts quasi-linearly as the curvature varies. The curvature sensitivity reaches 7.3235nm/m^{-1} with the correlation coefficient square of 0.9919. Therefore, the sensor presents high curvature sensitivity and good linearity.

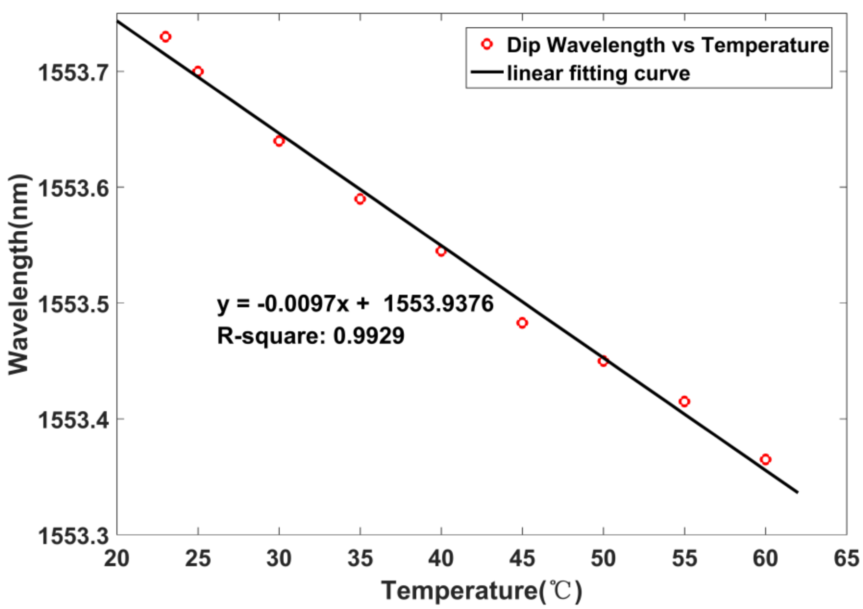

Fig.4. Relationship between the measured wavelength and temperature.

Furthermore, we also experimentally explore the temperature response of this sensor. As shown in Fig 4, with the increase of temperature, the dip wavelength moves to the short wavelength. The temperature sensitivity and correlation coefficient square are -9.7 pm/℃ and 0.9929, respectively.

3. CONCLUSION

In conclusion, a DCPCF modal interferometer based curvature sensor has been demonstrated. The curvature sensitivity of the sensor reaches 7.3235 nm/m^{-1}. Besides, the temperature response of this sensor has also been investigated experimentally. The temperature sensitivity is -9.7 pm/℃, within the measurement range of 22-60 ℃. This sensor also presents high potential for simultaneous measurement of curvature and temperature.

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