Stress and Hydraulic Pressure Sensor Based on a Dual-Core Photonic Crystal Fiber

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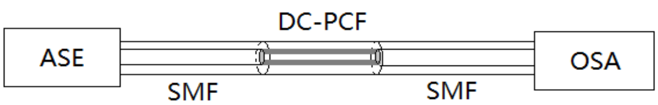
Abstract: A dual-core photonic crystal fiber (DC-PCF) sensor based on fiber Mach-Zehnder interferometer is proposed and demonstrated for stress sensing with a sensitivity of 1.4 pm/με and hydraulic pressure sensing with a sensitivity of -41 pm/MPa.

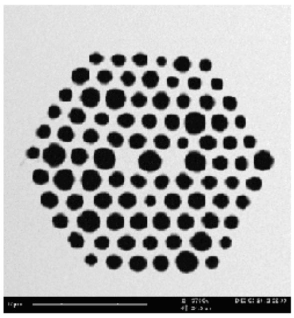
OCIS codes: (060.2370) Fiber optics sensors; (060.2310) Fiber optics; (060.4005) Microstructured fibers

1. Introduction

Owning to numerous advantages such as temperature insensitivity for stress sensing, high sensitivity for pressure sensing, immunity to electromagnetic interference and so on, photonic crystal fibers (PCFs) [1-4] have been studied extensively in fiber sensors[5,6]. Recently, interferometer sensors based on dual-core fiber (DCF) attract a wide range of research interests, which have shown some advantages such as small size, flexibility application, stability and other fine features[7,8]. In this letter, we demonstrate a novel fiber sensor based on a dual-core photonic crystal fiber (DC-PCF) which forms a fiber Mach-Zehnder interferometer (MZI) after splicing to single mode fibers (SMFs). The sensor based on a 20-mm DC-PCF has a sensitivity of 1.4pm/με for stress sensing with a range form 0 to1500με and a sensitivity of -41pm/MPa for hydraulic pressure sensing with a range form 0 to 20MPa.



(a)



(b)

Fig.1 (a) Experimental setup of stress/pressure sensing system; (b) Cross-section of the DC-PCF

2. Experiment and analysis

The experimental setup of stress/pressure sensing system was shown in Fig.1 (a). A fiber MZI was formed by splicing a DC-PCF with two SMFs where the two fiber cores of DC-PCF act as the two arms of MZI. We used a C+L Band amplified spontaneous emission (ASE) light source with an output spectrum from 1520 nm to 1610 nm and an optical spectrum analyzer (OSA) with the resolution of 0.02nm and the sensitivity of -80 dBm. The DC-PCF used in our experiments was fabricated by ourselves in the HongKong Polytechnic university and Fig. 1(b) shows the cross-section of the DC-PCF. The DC-PCF is formed by a triangular lattice of circular air holes with two missing holes as two fiber cores which are separated by one air hole. Two fiber cores have different size resulting in different mode index. The diameter of DC-PCF is 125μm, and the distance of two fiber cores is about 18μm. Owing to the mode index difference between the two fiber cores of DC-PCF, a MZI pattern could be achieved by measuring the transmission spectrum. We can ignore the mode coupling between the two fiber cores due to the relatively large air hole between the two fiber cores. The transmission of the MZI based on DC-PCF can be given by

$$I_{OUT} = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos(\varphi) \tag{1}$$

where I_1, I_2 and φ is light intensity of the two fiber cores and phase difference respectively. The phase difference φ can be written as

$$\varphi = \frac{2\pi L \Delta n}{\lambda} \tag{2}$$

where L is arm length of the MZI. λ is the signal wavelength in vacuum. Δn is the mode index difference between the two fiber cores of DC-PCF. According to Eq. (1) and Eq. (2), the peak wavelength of the transmission spectrum is achieved when the phase difference satisfies the following equation

$$\frac{2\pi L \Delta n}{\lambda} = 2m\pi \tag{3}$$

where m is an integer.

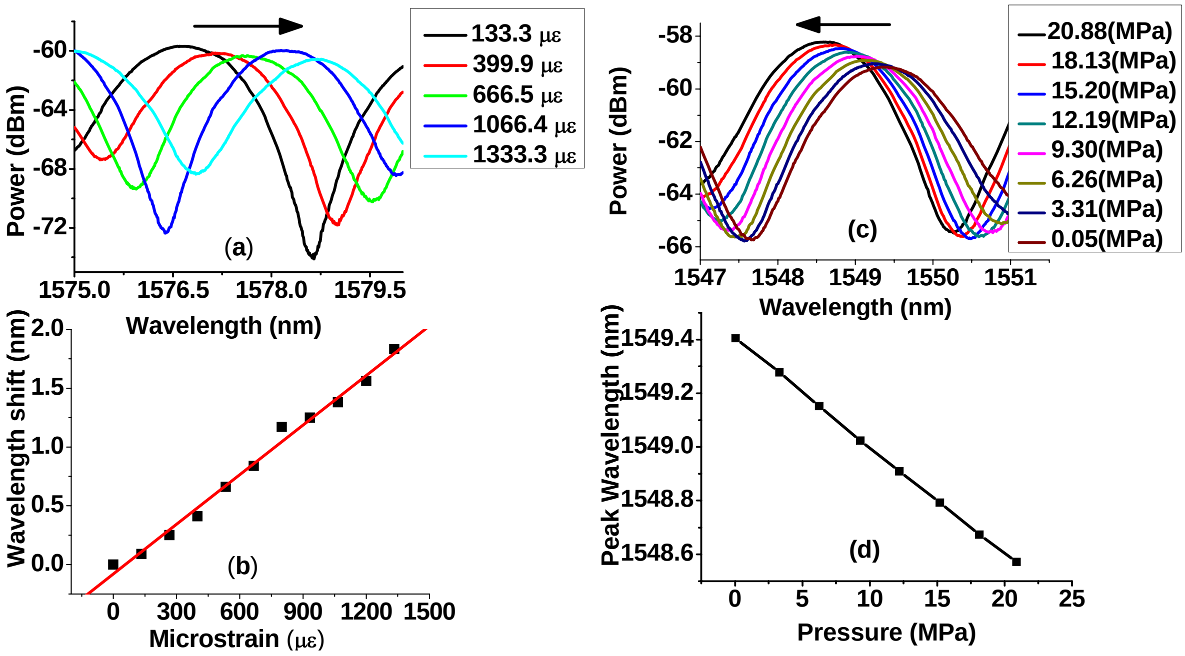


Fig.2(a)Output spectrum responses of the stress sensor for the different stress;(b)Wavelength shift of the interference spectra vs. different stress;(c)Transmission spectra of the pressure sensor under different pressure;(d) Peak wavelength of the pressure sensor around 1549 nm versus pressure.

In our experiment, a 20-mm DC-PCF was used as the sensing element for the axial stress sensor. Fig. 2(a) shows the output spectrum responses of the stress sensor with the different axial stress. Obviously, the output interference spectrum shifts to the long wavelength when the axial stress increases monotonically. In order to get the sensitivity of the stress sensor, we draw the curve for the wavelength shift of the interference spectra versus different axial stress, which was shown in Fig. 2(b). The peak wavelength shift has a good linear relationship with the stress, and the sensitivity of the stress sensor is 1.4pm/με with a measurement range form 0 to1500με. Transmission spectra of the 20-mm DC-PCF based hydraulic pressure sensor for the pressure of 0.05, 3.31, 6.26, 9.3, 12.19, 15.20, 18.13, and 20.88 MPa was shown in Fig. 2(c). We can observe a blueshift of the transmission spectrum of the 20-mm DC-PCF based hydraulic pressure sensor when the pressure applied to the DC-PCF increases. A linear relationship between the peak wavelength and the pressure can be observed. When we focus on the peak wavelength around the 1549 nm as shown in Fig. 2(d), we can get a sensitivity of -41 pm/MPa with a measurement range form 0 to 20MPa for the DC-PCF based pressure sensor.

3. Conclusion

In conclusion, we present a DC-PCF stress/pressure sensor based on a fiber MZI. The sensor based on a 20-mm DC-PCF has a stress sensitivity of 1.4pm/με and a pressure sensitivity of -41pm/MPa. The wavelength shift of the sensor has a good linear relationship with stress or pressure, which indicates the DC-PCF's application for measurements of the stress and pressure.

Acknowledgments

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References

[1] T. A. Birks, J. C. Knight, and P. St. J. Russel, "Endlessly single-mode photonic crystal fiber," Opt. Lett.22(13), 961–963 (1997).

[2] J. C. Knight, J. Broeng, T. A. Birks, and P. S. J. Russell, "Photonic band gap guidance in optical fibers," Science.282, 1476–1478 (1998).

[3] J. C. Knight and P. S. J. Russell, "Photonic crystal fibers: New way to guide light," Science 296, 276–277 (2002).

[4] J. C. Knight, "Photonic crystal fibers," Nature 424, 847–851 (2003).

[5] H. Dobb, K. Kalli and D. J. Webb, "Temperature-insensitive long period grating sensors in photonic crystal fibre," Eletron. Lett. 40, 657-658 (2004).

[6] X. Dong and H. Y. Tam, "Temperature-insensitive strain sensor with polarization-maintaining photonic crystal fiber based on Sagnac interferometer," Appl. Phys. Lett. 90, 151113-151115 (2007).

[7] Yongmin Jung, Sejin Lee, Byeong Ha Lee, and Kyunghwan Oh, "Ultracompact in-line broadband Mach-Zehnder interferometer using a composite leaky hollow-optical-fiber waveguide," Opt Lett. 33, 2934-2936(2008).

[8] Feng Su-Chun, Xu Ou, Lu Shao-Hua and Jian Shui-Sheng, "Switchable multi-wavelength erbium-doped fiber lasers based on a Mach-Zehnder interferometer using a twin-core fiber," Chin Phys Lett. 26, 064208(2009).