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Temperature Sensor By Using Selectively Filled Photonic Crystal Fiber Sagnac Interferometer

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Abstract

This paper reviews the application of a selectively filled photonic crystal fiber to construct sagnac interferometer (OFSI) based temperature sensor. The transmission of the OFSI is in sinusoidal form and dependent on temperature. A higher sensitivity is obtained by selective filling as compare to non selective filling, the sensitivity depends on infiltration length ratio.

Keywords: Interferometer, Sensor, Photonic Crystal Fiber, Birefringence

Introduction

In photonic crystal fibers the cladding consist of periodic structure of air holes running along the whole length of fiber. The presence of this air holes provides various potentials of the fiber and enhance special properties such as large mode areas large dispersion and special temperature response[1].

Optical fiber sagnac interferometer (OFSIs)[2] constructed by PM-PCF have been developed into various optical sensor with high performance and ease of fabrication[3]. Besides the design of air hole arrays there is a trend to tailor PCF properties by post processing of infiltration. A variety of liquids such as polymers[4], liquid crystal[5-7] and even metals [8] have been employed to fulfill applications of optical sensing

Working Principle

The fundamental working principle of the proposed temperature sensor is based on the splitting a ray into two parallel rays dependency of the selectively filled PM-PCF on temperature. Since liquids such as water or ethanol have much higher thermal expansion coefficients than solid silica, the fiber material, the effective refractive indices for slow and fast axes of the selectively filled PM-PCF change significantly with temperature. Hence, leading to a birefringence change of the selectively filled PM-PCF. This temperature induced birefringence change is detected by the OFSI and present in the form of spectrum shift.

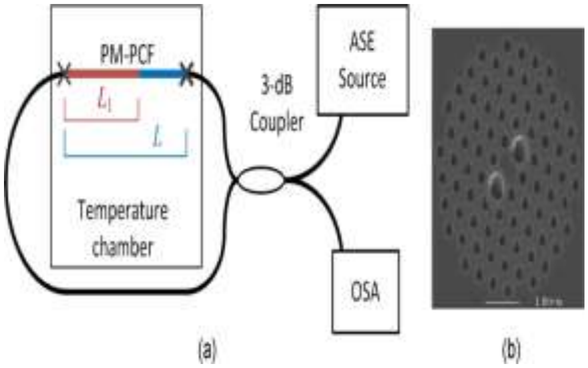

Figure 1. (a) Schematic diagram of the OFSI-based temperature sensor. L1 is the infiltration length, and L is the total length of PM-PCF inside the fiber loop. (b) SEM image of the cross section of the PM PCF Used[9]

Mechanism

The schematic illustration of the OFSI-based temperature sensor is shown in figure 1(a) and figure 1(b) shows the cross section of the PM-PCF used. There are two big air holes along one axis of the cross section and a number of small holes in other parts of the cladding. The noncentrosymmetric arrangement of air holes leads to the birefringence (Birefringence is the optical property of a material having refractive index that depends on the polarization and direction of propagation of light)[11] of the PM-PCF. The OFSI is an optical fiber loop composed of a piece of selectively filled PM-PCF with both ends connected to a 3-dB coupler. The input of the OFSI is connected to a light source, and the output is connected to an optical spectrum analyzer (OSA). The PM-PCF is placed in a temperature chamber to experience the temperature change. Suppose the total PM-PCF length inside the fiber loop is L, the selectively filled length is L_1, and the whole length of PM-PCF is inside the temperature chamber. The sensing mechanism of OFSI is given as follows[10]. First light is launched from the light source into the optical fiber loop. Then, the light is split into two waves when passing through the 3 db coupler. One sub beam propagates clockwise in the fiber loop. While the other sub beam propagates counterclockwise. The two sub beams experience different optical path lengths because of birefringence of the selectively filled PM-PCF, however, carrying on the same original frequency. Sharing a phase difference, the two sub beams interfere with each other when they recombine at the coupler. The phase difference is given by

$$\varphi = 2\pi BL/\lambda \qquad (1)$$

where B is the birefringence of the selectively filled PM-PCF, L is the total length of the PM-PCF, and λ is the wavelength of light. The transmission spectrum of the fiber loop is therefore approximately a sinusoidal function of wavelength, which can be described by the following equation:

$$T = (1 - cos\varphi)/2 \qquad (2)$$

If the condition ¼ *2m* is fulfilled, the transmission spectrum will reach its maxima. *m* is an integer and represents the fringe order. Therefore, the wavelength of the m^{th} order is given by

$$\lambda m = BL/m \quad (3)$$

The free spectral range, i.e., the wavelength spacing S, can be given as,

$$S = \frac{\lambda^2}{BL} \quad (4)$$

When the temperature changes, the thermal effect of the unfilled part of the PM-PCF can be neglected due to the extremely small temperature response. The birefringence change *B* at the infiltrated part of the PM-PCF with length L_1 contributes to the phase shift of the OFSI the most, which can be expressed as follows:

$$\Delta\varphi = 2\pi\Delta BL_1/\lambda \quad (5)$$

Therefore, the wavelength shift caused by temperature change for a certain wavelength is given by

$$\Delta\lambda = \lambda \frac{\Delta BL1}{BL} \quad (6)$$

For the selective filling pattern, the one giving a larger relative birefringence change $\frac{\Delta B}{B}$under the same liquid index change will provide a larger wavelength shift, thus a higher sensitivity.

Mechanism for Infiltration: The infiltration of liquid into voids of the PM-PCF is realized by capillary action. The capillary force for a certain air hole is given by

$$Fc = 2\pi a\sigma cos\theta \quad (7)$$

where *a* is the radius of the air hole, σ is the liquid–air surface tension, and θ is the contact angle between the liquid and the silica wall. Considering gravity, the achievable height of the liquid column
Supported by the capillary action is

$$h = \frac{2\sigma cos}{\rho\ g\ a} \quad (8)$$

where ρ is the density of liquid, and *g* is the local gravitational field strength.

Conclusion

An optimized infiltration pattern gives the most improvement in sensitivity. By comparison of sensitivities of sample with different infiltration length ratio, it is concluded that sensitivity of the sensor is proportional to PM-PCF infiltration length ratio.

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