Design of photonic crystal fiber for Sagnac interferometric pressure sensing with high sensitivity

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Abstract: We propose a new design of polarization-maintaining photonic crystal fiber for Sagnac interferometric pressure sensing. Simulation demonstrates its pressure sensitivity is enhanced by over 20 times compared with existing sensors of the same type.

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

1. Introduction

Photonic crystal fibers (PCFs) in which air-hole channels are running along its length have been intensively studied in recent years because they exhibit a lot of unique optical properties over conventional optical fibers, such as endless single-mode operation, tailored dispersion curve, high birefringence, nonlinearity [1]. Due to the existence of air holes in the fiber cross section, PCFs are essentially more sensitive to physical parameters such as strain and pressure [2, 3]. Birefringence can be introduced to PCF by applying a non-circular core. This results in polarization-maintaining PCF (PM-PCF). The birefringence property of PM-PCF provides a new freedom for sensing application, i.e., polarimetric sensing. Several pressure sensors based on PM-PCF have been reported. However, since existing PM-PCFs are not specially designed for pressure sensing, they suffer from relatively low sensitivity [4, 5]. The authors ever proposed a side-hole PM-PCF to enhance pressure sensitivity [6]. But the side-hole PM-PCF is not practical to fabricate, because it contains both ultra-large air holes with diameter of 25 μm and small holes with diameter of 1 μm in the cross section.

In this work, we proposed a new PM-PCF with its pressure sensitivity enhanced by 20~30 times compared with existing pressure sensors of the same type. And the proposed PM-PCF is more practical to fabricate than the one reported in [6]. It has two hexagonal air-hole arrays located at the opposite direction of the core, which function like a pair of large side-holes. When subjected to hydrostatic pressure, the highly asymmetric air hole structure causes strongly anisotropic stress distribution, which leads to a high value of birefringence-pressure coefficient. What's more, the proposed PM-PCF is designed to have relatively low group birefringence, which also helps enhance pressure sensitivity, since *dB/dp* is inversely proportional to the group birefringence.

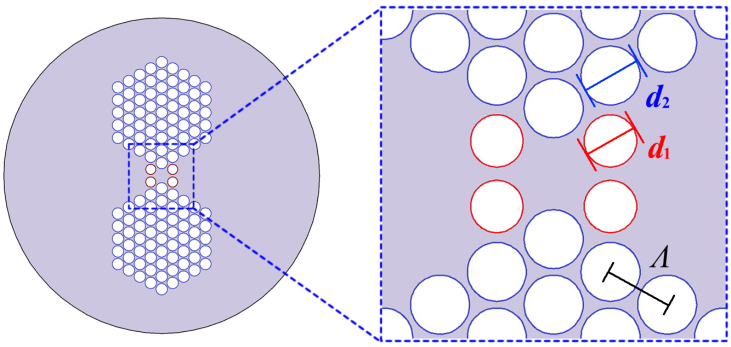

Fig. 1. Cross section of the proposed PM-PCF. The white area represents air hole channels; the gray area represents pure silica.

2. Principle and Simulation method

Figure 1 shows the cross section of the new PM-PCF we proposed for Sagnac interferometric pressure sensing. As can be seen from it, the fiber has two hexagonal arrays of larger air holes with diameter of d_2 located at the opposite sides of the core, and four smaller air holes with diameter of d_1 located at the other two sides of the core. The center to center distances (the pitch) of all the air holes are Λ. Because of the difference in d_1 and d_2, the fiber core is non-circular and thus causes form birefringence. When subjected to hydrostatic pressure, the asymmetric distribution of air holes in the orthogonal directions over the fiber cross section leads to isotropic stress distribution. This produces stress birefringence and modulate the fiber's overall birefringence, resulting in high polarimetric pressure sensitivity.

For a Sagnac interferometer, its pressure sensitivity is expressed as follow [5]:

$$d\lambda / dp = (\lambda / G)\cdot(dB/dp) \\ G = B - \lambda \cdot (dB / d\lambda) \quad , \tag{1}$$

where λ is free space wavelength, p is hydrostatic pressure applied to the fiber, B is phase modal birefringence, and G is group modal birefringence. The polarimetric pressure sensitivity is defined as

$$dB / dp = (B - B_0) / p \, , \tag{2}$$

where B_0 is the initial modal birefringence when the fiber is free of pressure, B is the modal birefringence in the presence of pressure, and p is the hydrostatic pressure loaded on the fiber. We use a full-vector finite element method (FEM) to calculate B_0, dB/dp, G, and finally the pressure sensitivity $d\lambda/dp$.

3. Results and Discussion

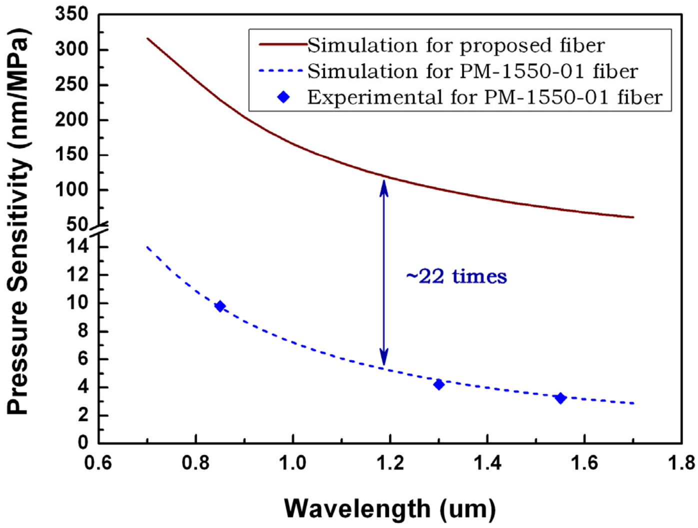

Fig. 2. Simulation results: wavelength dependence of pressure sensitivity for our proposed fiber and the PM-1550-01 fiber.

For comparison and to verify the correctness of our simulation method, the pressure sensitivity of a widely studied fiber PM-1550-01 by NKT Photonics is also calculated. And the theoretical results agree well with the experimental results reported in [5] for the three wavelength ranges (850nm, 1310nm, and 1550nm). This indicates that our simulation method is reliable and convincible. Theoretical results demonstrate that the pressure sensitivity of our proposed fiber is enhanced by more than 20 times than that of the PM-1550-01 fiber in the entire wavelength range from 700nm to 1700nm. For both our proposed fiber and the PM-1550-01 fiber, they exhibit higher pressure sensitivity at shorter wavelength range because group birefringence increases with increasing wavelength. The enhancement of the pressure sensitivity of our proposed fiber relies on the following two mechanisms: on one hand, the air hole distribution of our fiber is highly asymmetric, which results in larger value of *dB/dp*; on the other hand, by carefully designing the size and air filling ratio of the air holes, lower value of group birefringence G is achieved. Both these two factors contribute to the significant improvement (22 times) of the pressure sensitivity.

Acknowledgements

This work is supported in part by the Fundamental Research Funds for the Central Universities under grant no. 1613334, and in part by the Hong Kong Polytechnic University under grant no. 4-ZZE4.

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