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The Design of Bending Long Period of Photonic Crystal Fiber Grating Sensors

Xianlun Yu, Weidong Gao, Yong Qu, Shunjun Shu

Key Laboratory of Signal and Information Processing, The Chongqing Three Gorges University, Chongqing, China
Email: yuxian896@sohu.com

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Abstract

The bending photonic crystal fiber grating sensor is an important role in underwater monitoring and fire alarm systems. It is studied that the resonant wavelength expression of bending long period photonic crystal fiber gratings is deduced, it is designed that a bending long period photonic crystal fiber grating sensor system, it is calculated in theory that between the bending long period photonic crystal fiber gratings sensor resonance wavelength and the grating period and the bending strain. The result is shown by calculating and analysing in theory, the grating curvature is increased by the increase of the bending strain of the grating, and the resonance wavelength of the grating sensor is drifted, the drift amount is increased, one $\mu\varepsilon$ in this grating, the drifted amount of the resonant wavelength is 0.014 nm.

Keywords

Fiber Optics, Photonic Crystal Fiber, Photonic Crystal Fiber Grating Bending Sensor

1. Introduction

Photonic crystal fiber (PCF) is the communication medium of the center core defected and a cladding layer aligned parallel micro-sized cylindrical hole , PCF is strongly dependent on the design details, it is a unique light transmission characteristics that can be used to improve performance communication systems and new optoelectronic devices [1]-[3]. It is mainly the refractive index or geometry periodic perturbation along the longitudinal direction in PCF gratings, it is features both the PCF and fiber grating, and the PCF gratings have a wide potential value in the aerospace engineering and the automatic control and the monitoring wells and the health monitoring of roads and bridges. In PCF Bragg grating the grating period is of about one micron, which can be used for the temperature and pressure sensors .In the PCF long period fiber grating (LPG) the grating period is about 100 microns, which a low temperature sensitivity cannot be compensated for temperature [4]-[7].

Bending PCF grating is an important development direction, PCF LPG can be used to bended sensors. The bent of gratings will be produced in the external pressure which in bending PCF LPG sensor , the propagating light pulse energy losses will be generated and resonant wavelength will be drift in the grating , the detection changes of the external parameters can be facilitated by detecting energy loss and wavelength shift [8]-[10].

According to the principle of the bending PCF LPG sensor, the bending PCF LPG sensor system is designed,

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the relationship is calculated between the effective refractive index and the PCF LPG bending in the bending sensor, and the relationship is calculated between the amount of bending and the PCF LPG transverse and longitudinal strain, and the relationship is calculated between the bending PCF LPG sensor resonance wavelength shift and bend.

2. The Long-Period Photonic Crystal Fiber Grating Theoretical Model

Assuming PCF core made of pure silicon, the cladding layer disturbance composed of the periodic arrangement air holes, and the refractive index perturbations are only existed along the fiber length in the PCF LPG fiber core, the modes coupling in the PCF LPG will be primarily occurred between the waveguide mode and the cladding modes with the same propagations.

It is assumed in the long-period photonic crystal fiber gratings, that which (1) the fundamental guided mode is only existed in the core region of the weak fiber grating, (2) the longitudinal mode coupling coefficients of core can be negligible, (3) the coupling between the cladding modes is small and can be ignored, (4) the axial modes coupling can be ignored.

Under the assumptions, based on coupled mode theory and the mode coupling resonance conditions, the PCF LPG resonance wavelength is expressed as

$$\lambda(\varepsilon, \mathrm{z}, \mathrm{t}) = \Delta n \Lambda \tag{1}$$

where Δn is the refractive index fluctuation amount.

For bending PCF LPG, in (1) where the grating wavelength shift caused only by bending strain without the other factors, the zero Taylor series are expended in (1) to strain as independent variables, the grating strain belongs to the elastic deformation, the small that between the deformation and the grating length, retained the first term of a Taylor expansion, and according to the elasto-optic theory.

$$\Delta\lambda = (1 - \mathrm{p}_e)\varepsilon \Delta n \Lambda \tag{2}$$

The expression (2) is the relation between the PCF LPG resonance wavelength shift amount and the PCF grating strain ε and the PCF grating structure and the distribution of the PCF grating transverse refractive index, $p_e = n_{eff}^2 (p_{12} - \gamma(p_{11} - p_{12}))/2$, n_{eff} the effective refractive index of the optical fiber, p_{11}, p_{12} the fiber elastic-optic coefficient, γ the Poisson's ratio of the fiber, Δn refers to a change in the refractive index of the grating period. The refractive index distribution in PCF LPG can be calculated by the following Formula (3).

$$n(\mathrm{z}) = n_0 + \Delta n(\mathrm{z}) = n_0 + \Delta n[1 + \cos(2\pi \, \mathrm{z}/\Lambda)] \tag{3}$$

n_0 refers to the refractive index of pure silica core, general, $\Delta n << n_0$.

3. The Design of the Bending Long Period Photonic Crystal Fiber Grating Sensors

The photonic crystal fiber core is a solid core, which surrounded by the air holes arranged in hexagonal cycle ,in a long period of photonic crystal fiber grating the refractive index perturbation in the axial direction of the grating.

In the role of external parameters, the PCF LPG is deformed and curved, the schematic diagram is shown in **Figure 1**.

In **Figure 1**, L indicates the length of the PCF LPG, h represents the lateral bending amount of change in PCF LPG, *r* is the radius of curvature by the bending of PCF LPG. According to **Figure 2**, when the PCF LPG is bent, the curvature can be expressed as

$$1/r = -(8h)/(4h^2 + L^2) \tag{4}$$

Of (4) is differentiated, it is obtained that the relationship in the change amount of PCF LPG grating curved and the longitudinal and transverse strains in grating.

$$\Delta r = (L^2 - 4h^2)\varepsilon_y / 8\mathrm{h} \tag{5}$$

$$\Delta r = -L^2 \varepsilon_z / 4h \tag{6}$$

Which the longitudinal and transverse strains expressions (5) and (6) into (2), the function is got that the shift of the resonance peak wavelength and the PCF LPG sensor of curvature.

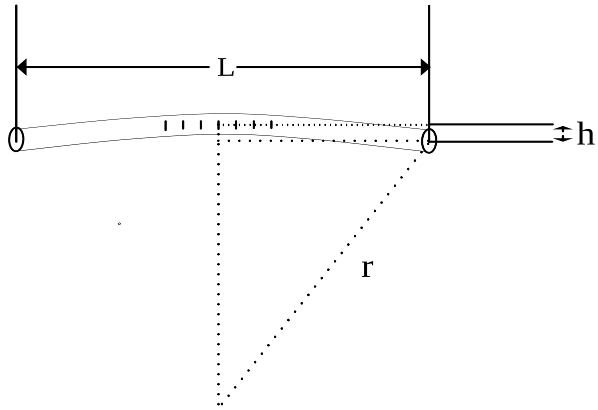

Figure 1. Diagram bending long period photonic grating.

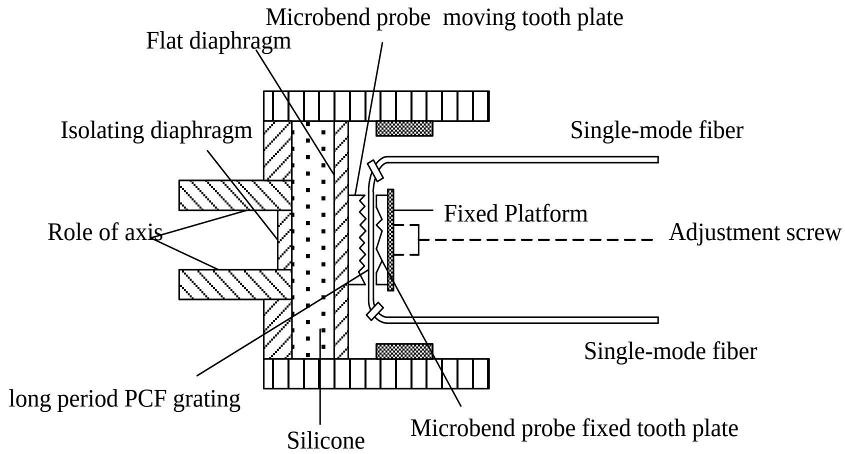

Figure 2. The bending long period photonic crystal fiber crystal fiber grating sensors structure.

According PCF structure and PCF LPG arguments presented in **Figure 1**, we design a PCF LPG bending sensor system, the system structure shown in **Figure 2**.

4. Numerical Analysis of Curved Long Period Photonic Crystal Fiber Grating Sensors

In **Figure 2**, the design of the bending PCF LPG sensor system. The following assumptions for the PCF LPG sensor system that designed: (1) the refractive index change of the PCF long period grating along the longitudinal PCF and periodicity radially symmetric distribution, (2) at the PCF transverse structure, the refractive index is uniformly distributed along all directions (3) the couple between the core mode Lp01 and the cladding mode LP11, (4) PCF circular bending along period grating and the structure shown in **Figure 1**. Based on the above assumptions, the equivalent refractive index distribution can be defined by the following formula in bent PCF.

$$n_{eff} = n_x \exp(x / r) \tag{7}$$

In (7) where n_x the refractive index of the photonic crystal fiber grating transverse distribution, r long-period PCF grating bending radius. Put (3) into (7) and

$$n_{eff} = n_x \exp(-8h\,x / (4h^2 + L^2)) \tag{8}$$

Put (8) into (1), the expression of the center resonance wavelength shift is in the long-period PCF gratings bending strain

$$\Delta\lambda = \{1 - [n_x \exp(-8h\,\mathrm{x}/(4h^2 + L^2))]^2 (p_{12} - \gamma(p_{11} - p_{12}))/2\}\varepsilon\Delta n\Lambda \quad (9)$$

L is the length of the grating and set 50 mm, adjusted the shaft of **Figure 2** so that the role PCF LPG and bending.

The PCF is composed of pure silica core, the core refractive index values of 1.465, the PCF LPG bent value is changed from 3 mm to 6 mm, taken as zero at the center of the core PCF, the calculated relationship between the transverse distribution of the effective refractive index and x in PCF LPG is shown as in **Figure 3** and **Figure 4**.

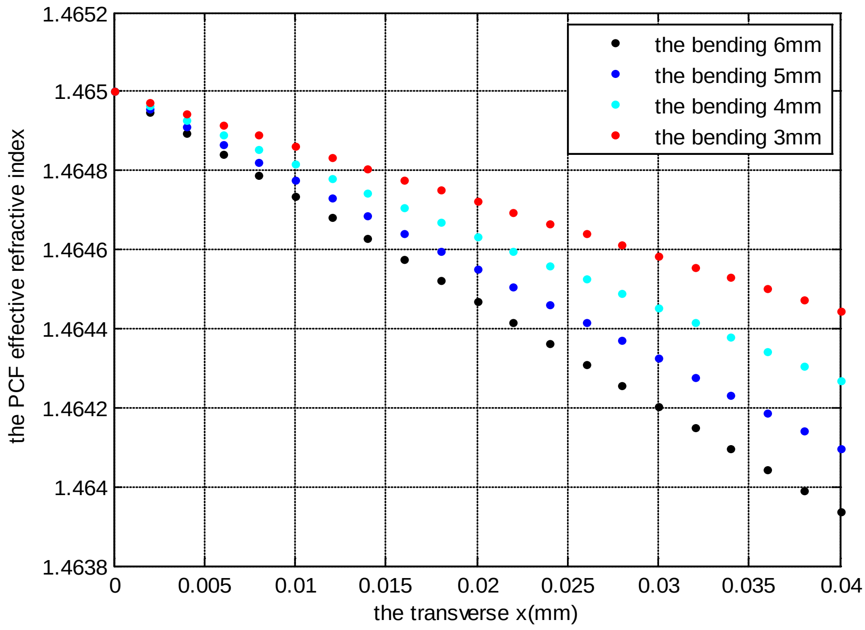

Figure 3. The relation between the transverse distribution refractive index and the transverse position of effective period photonic crystal fiber gratings.

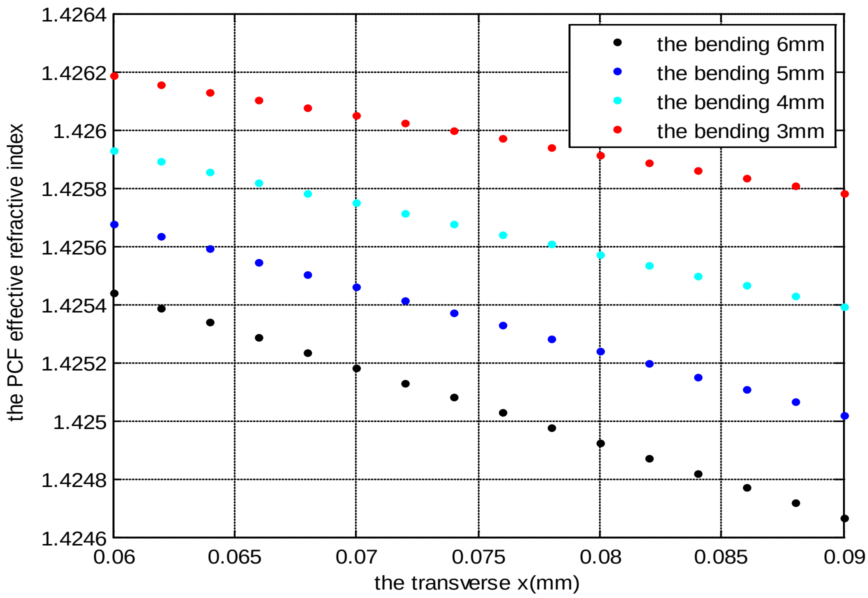

Figure 4. The relation between the transverse distribution of effective refractive index and the transverse position x in the core of long in the clad of long period photonic crystal fiber gratings.

Figure 3 shows the relationship between the effective refractive index of the core and the transverse attitude x in PCF LPG, the core is solid, made of pure silicon, the effective refractive index is also decreased with increasing x, in the same place, the effective refractive index decreases with the increase of the amount of bending, the farther away from the center, the decrease amount becomes large.

Figure 4 shows the relationship between the effective refractive index of the cladding and the lateral attitude x in PCF LPG, and the cladding period composition of the air hole and the silicon, which the effective refractive index will be lower than the core, when bending occurs, the same level of bending, the farther the center, the larger the effective refractive index, at the same position, with the effective refractive index is also decreased as the level of bending.

In **Figure 2**, because the role of the shaft, the PCF LPG would be bent, the transverse and longitudinal bending strain will be produced in gratings, because strain the curvature of the grating is generated, the relationship between the amount of the curvature and the strain is shown in **Figure 5** and **Figure 6**.

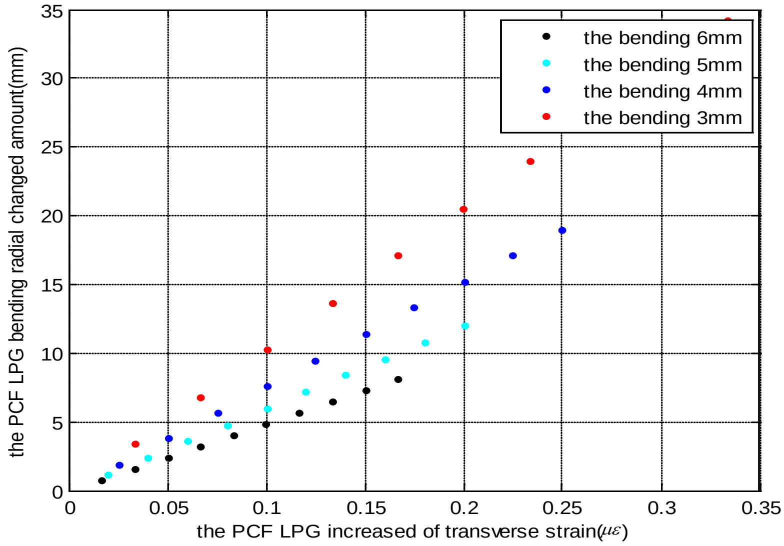

Figure 5. The relation between the transverse strain grating bending radius change in the bending photonic crystal fiber gratings.

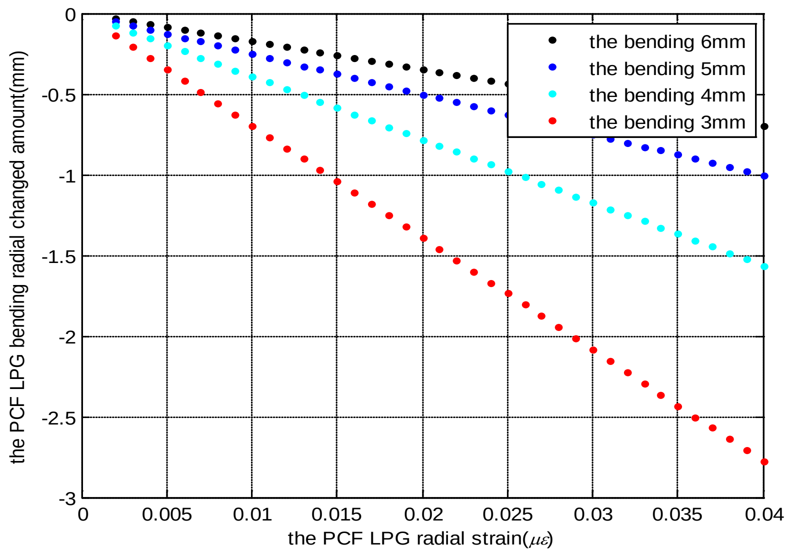

Figure 6. The relation between the longitudinal strain and the grating bending radius change in the bending long period long period photonic crystal fiber gratings.

In **Figure 5**, the same case in the degree of bending, the transverse strain in PCF LPG is increased, the bending radius of the grating will be increased. In the case of the same strain. As the curvature of the grating is increased, the increment amount of the bending radius of the grating would be increased.

In **Figure 6**, the relationship between the changed amount of the bending radius and the longitudinal strain is shown, which the longitudinal strain is occured in PCF LPG. When the grating bending is identical, the longitudinal strain is increased, the bending radius will be increased, and in the same longitudinal strain, the greater the level of bending, the increasing amount of bending radius in the grating will be reduced, where the amount of grating curvature becomes larger. In **Figure 6**, increasing the magnitude of radius of bending is a negative value, it indicates that with the increase of the transverse strain, and the bend direction is opposite to what we get.

The following values in Equation (11), the elasto-optical coefficient in the PCF $p_{11} = 0.12$, $p_{12} = 0.27$, PCF's Poisson coefficient $\nu = 0.17$ The refractive index of the core of the PCF 1.465, the effective refractive index of the cladding 1.437, relationships between the amount of drift of the resonance wavelength in PCF LPG and the grating period and the grating strain are shown in **Figure 7** and **Figure 8**.

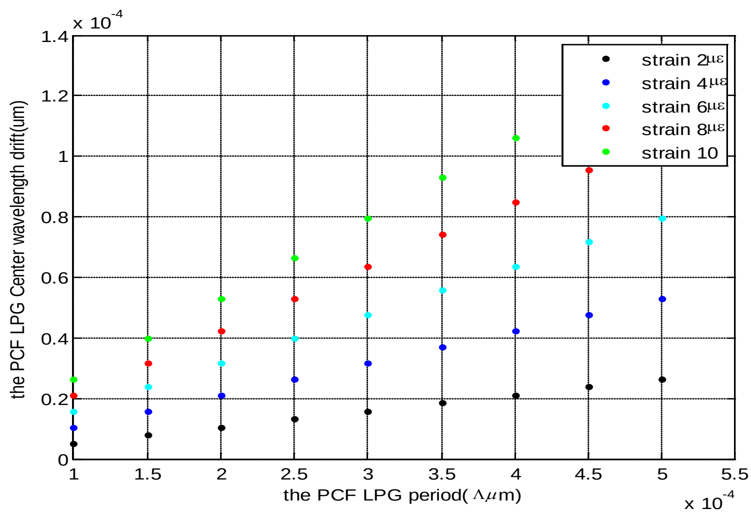

Figure 7. The relation between the shift of the resonance and the grating period in the bending photonic crystal fiber gratings.

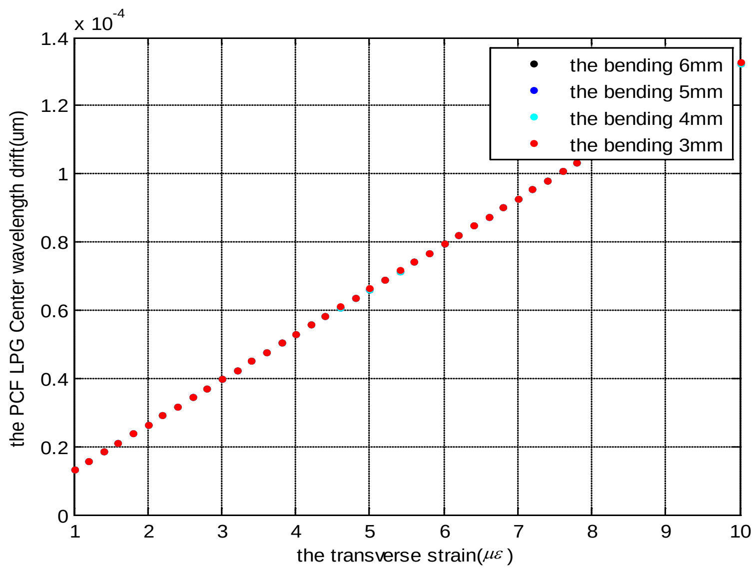

Figure 8. The relation between the shift of the resonance wavelength wavelength and the grating strain in the bending long period long period photonic crystal fiber gratings.

In **Figure 7**, if the PCF LPG period is constant, the resonant wavelength drift amount is increased as the grating strain is increased, the strain increases every two micro strain, the central wavelength shift amount increases by approximately 0.01 nm. while holding the same value of the grating strain, the shift of the resonance wavelength increases with the PCF LPG grating period increases, the grating period of every 50 micron, the center wavelength shift amount increases by approximately 0.005 nm.

The relationship is shown in **Figure 8** that between the resonance wavelength shift and the grating strain in PCF LPG when the grating would be bent, in Figure 10,in the same strain , the grating resonance wavelength drift is very small where the level bending of PCF LPG grating , on the same case of bending, the contribution of the resonance wavelength shift is larger that the amount of grating strain is increased, every one micro-strain of the grating is generated, the resonance wavelength shift of the grating is changed 0.014 nm.

5. Conclusion

Photonic crystal fiber grating is a new passive material with many unique light transmission characteristics, it may have special applications in optical fiber communication and optical fiber sensing, where the bending long-period photonic crystal fiber grating will exist in roads, bridges and buildings potential applications. The resonance wavelength expression of PCF LPG is derived herein, the resonance wavelength shift of the grating will be associated with the grating deformation and the specific PCF LPG made materials, the PCF LPG grating refractive index profile and the transverse and longitudinal strain will result in PCF long period grating bending, thus the resonance wavelength drift of PCF LPG are ultimately lead, the degree of bending of LPG. PCF can be detected by the resonant wavelength drift.

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