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A new method for resolving the influence of circular birefringence in FBG weak pressure sensor

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ABSTRACT

Ideally, there is a linear relationship between the max of *PDL* and pressure in FBG weak pressure sensor. However, the linear relationship has been broken down because of the cross sensitivity about the circular birefringence and pressure. In this paper, the relative *PDL* was proposed to solve the cross sensitivity problem. For different circular birefringences, the experimental results show the same pressure sensitivity value of 2.29 dB/(N/nm). The theoretical analysis and experimental results prove that the proposed method can solve the cross-sensitivity problem in FBG weak pressure sensor. This research can provide useful information to practical application.

1. Introduction

Fiber Bragg gratings (FBG) are key components for high speed optical transmission systems as well as for sensors purposes. Currently, the FBG sensor based on the wavelength shift detection is widely used due to the good linear relationship between Bragg wavelength and physical parameters, such as temperature, stress and acceleration [1–3], FBG sensor based on optical polarization can also be used to sense the environment parameters. Recently, there is increased interest in sensing some parameters using the polarization properties of FBG because of high sensitivity, such as transverse strain [4,5] and magnetic field [6].

However cross-sensitivity problems exist in both of the above sensors. The center wavelength will change not only with the strain but also with the temperature [7] in wavelength detection scheme. Similarly, the polarization properties are influenced by the linear and circular birefringence [8,9] in polarization detection scheme. A number of techniques have been proposed to dell with cross sensitivity issues, such as dual-wavelength superimposed grating, two FBGs in different diameter fiber, hybrid FBG/long period grating, superstructure FBG and Fabry–Perot cavity method [10–12]. These methods provided some approaches to solve the cross-sensitivity problem, but most of them need specific gratings and special technique which are complexity or expensive.

In this paper, the cross sensitivity problem about the circular birefringence and pressure is reported. In order to solve this problem, the relative *PDL* is proposed. Simulation and experimental results proved that the relative *PDL* can effectively solve the cross sensitivity problem about the circular birefringence and pressure. The monitoring of the relative *PDL* maximum amplitude evolutions offers weak pressure measurements in the range 0–10 N with a 10-mm-long FBG.

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2. Theoretical models

2.1. Principle of measurement

The schematic structure of FBG pressure sensor is shown in Fig. 1.

The applied force causes an anisotropic change in the effective refractive index n_{eff}, which can be expressed as [13–15]:

$$\Delta n_x = -\frac{n_{eff}^3}{2E}\left[(p_{11} - 2\upsilon p_{12})\frac{2F}{\pi LD} - [(1-\upsilon)p_{12} - \upsilon p_{11}]\frac{6F}{\pi LD}\right] = K_x\frac{F}{LD}$$
$$\Delta n_y = -\frac{n_{eff}^3}{2E}\left[[(1-\upsilon)p_{12} - \upsilon p_{11}]\frac{2F}{\pi LD} - (p_{11} - 2\upsilon p_{12})\frac{6F}{\pi LD}\right] = K_y\frac{F}{LD} \quad (1)$$

where Δn_x and Δn_y are the effective indexes in the x- and y-directions, the n_{eff} is the refractive index in the unstressed fiber core, the p_{11} and p_{12} is the photoelastic tensor, E is Young's modulus, υ is the Poisson ratio, D is the diameter of fiber, respectively. For silica fiber, $n_{eff} = 1.455$, $E = 74.52$ Gpa, $\upsilon = 0.17$, $p_{11} = 0.121$, $p_{12} = 0.27$, $D = 125\ \mu m$, $K_x = 7.73 \times 10^{-12}$/Pa, $K_y = -1.54 \times 10^{-12}$/Pa.

Due to the relation $\Delta n = \Delta n_x - \Delta n_y$, the x and y modes undergo different couplings through the grating, the Jones vector associated to the FBG transmitted signal is given by Ref. [5]:

$$\begin{pmatrix} E_{t,x} \\ E_{t,y} \end{pmatrix} = \begin{pmatrix} t_x & 0 \\ 0 & t_y \end{pmatrix}\begin{pmatrix} E_{i,x} \\ E_{i,y} \end{pmatrix} = \begin{pmatrix} t_x E_{i,x} \\ t_y E_{i,y} \end{pmatrix} \quad (2)$$

where $(E_{i,x}, E_{i,y})^T$ is the Jones vector of the input signal and $t_{x(y)}$ denotes the transmission coefficient of $x(y)$ mode FBG [16].

$$t_{x(y)} = \frac{j\alpha_{x(y)}}{\sigma_{x(y)}\sinh(\alpha_{x(y)}L) + j\alpha_{x(y)}\cosh(\alpha_{x(y)}L)} \quad (3)$$

where $\sigma_{x(y)}$ and $\alpha_{x(y)}$ depend on the n_{eff} and on the grating parameters (the grating period Λ, index modulation δ_n). L is the grating length. The power coefficients are obtained by $T_{x(y)} = |t_{x(y)}|^2$.

Polarization Dependent Loss (*PDL*) is defined as the maximum change in the transmitted power by the grating as the input state of polarization is varied over all polarization states. It can cause large power fluctuations in optical systems.

In this paper, the input signal is the linear state at $\pi/4$ between the $x(y)$ mode, $E_{i,x} = E_{i,y}$. In the case of Bragg gratings, the *PDL* for the transmitted signal is given by Ref. [17]:

$$PDL(\lambda) = \left|10\log_{10}\frac{T_x(\lambda)}{T_y(\lambda)}\right| = \left|10\log_{10}\frac{E_{t,x}^2(\lambda)}{E_{t,y}^2(\lambda)}\right| \quad (4)$$

The study of Caucheteur et al. demonstrated that there is linear relationship between the max of *PDL* and pressure [5].

According to Eq. (4), typical spectra of $T_{x,dB}$, $T_{y,dB}$ and *PDL* are shown in Fig. 2a. Pressure leads to wavelength shift between $T_{x,dB}$ and $T_{y,dB}$. *PDL* is just the difference between $T_{x,dB}$ and $T_{y,dB}$ in terms of decibel.

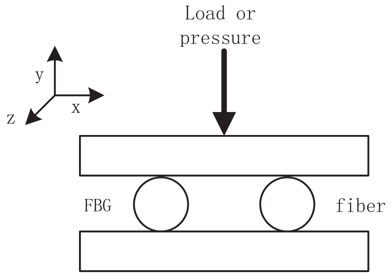

Fig. 1. Schematic structure of FBG pressure sensor.

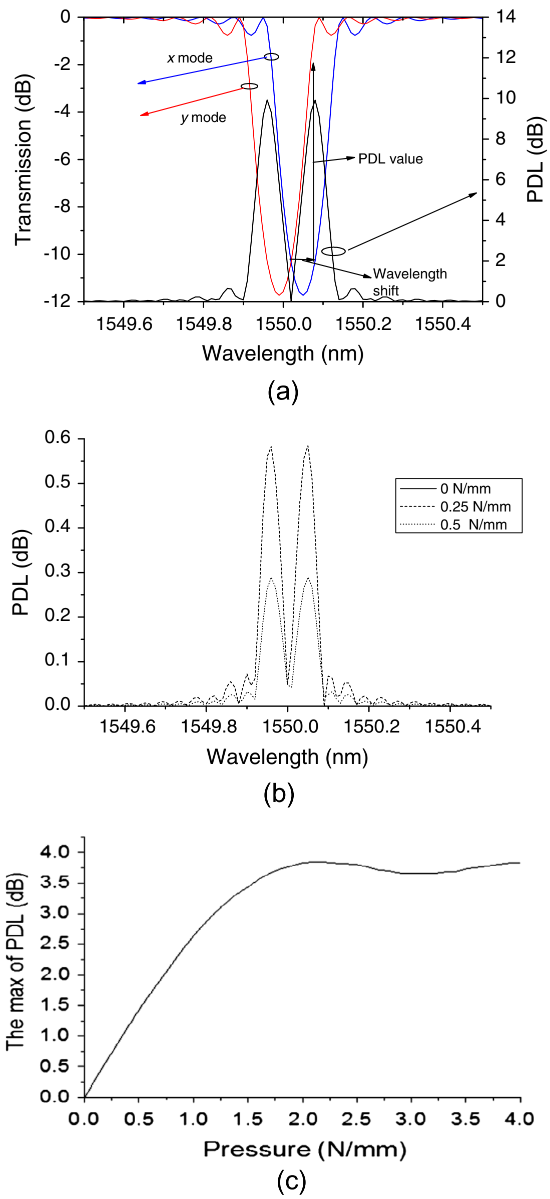

Fig. 2. (a) Transmission coefficients (for two modes) and *PDL* evolution with wavelength, (b) *PDL* versus wavelength at pressure without circular birefringence, and (c) the max of *PDL* as function of pressure.