

Simultaneous measurement of temperature and strain based on fiber loop mirror combined with fiber Bragg grating

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Simultaneous measurement of temperature and strain without cross-sensitivity using a polarization maintaining fiber (PMF) in a fiber loop mirror (FLM) and a fiber Bragg grating (FBG) is presented. The sensing head is formed by inserting a FBG to the PMF-FLM. This sensor can not only be multi-parameter identification simultaneously, but also eliminate cross-sensitivity. Experimental results show that the proposed sensor has the temperature sensitivity of $-1.5096 \text{ nm}/^\circ\text{C}$ and strain sensitivity of $0.01042 \text{ nm}/\mu\epsilon$, respectively.

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1. Introduction

Sensors with simultaneously measuring temperature and strain have a widespread application prospect in the field of intelligent building monitoring, power transmission and ocean exploitation etc. The measurement of strain in the presence of significant temperature changes using optical fiber sensors presents a considerable challenge due to the inherent sensitivity of optical fibers to temperature. So simultaneous measurement of temperature and strain is necessary. In recent year, a number of methods for avoiding the problems of the cross-sensitivity of temperature and strain have been reported [1-3]. C. Zhang et al. realized the simultaneous measurement of temperature and strain by using a Z-shape fiber structure, which is fabricated by exposing a single mode fiber (SMF) to a CO₂ laser [1]. Their experiments demonstrated that the strain and temperature sensitivity could reach to $129.78 \text{ pm}/\mu\epsilon$ and $62.1 \text{ pm}/^\circ\text{C}$. The temperature sensitivity is low. Besides, the fabrication precision is difficult to control and the mechanical strength of this Z-shape fiber is weak when compared to SMF. At the same time, Y. Wu et al. proposed a hybrid-structured Fabry-Perot interferometer for simultaneous measurement of strain and temperature [2]. But the sensitivities of strain and temperature were only $28.95 \text{ pm}/\mu\epsilon$ and $12.71 \text{ pm}/^\circ\text{C}$. Besides, the large lateral offset splicing will also weaken the mechanical strength of the sensor head. To enhance the measurement sensitivity, C. Lin et al. designed a liquid modified photonic crystal fiber (PCF) integrated with an embedded directional coupler [3]. The high-sensitivity simultaneous measurement of temperature ($14.72 \text{ nm}/^\circ\text{C}$) and strain ($13.01 \text{ pm}/\mu\epsilon$) were obtained. However, the cost of liquid modified PCF is high. And the infiltration of liquid into

three adjacent air holes is difficult.

Fiber loop mirror (FLM) has aroused increasing research interests, because it is flexible, stable, and easy to manufacture. FLM behaves like a band-pass filter, and the characteristic is similar to an unbalanced Mach-Zehnder interferometer [4]. Various kind of sensors based on FLM have been demonstrated for numerous applications, such as the measurement of temperature [5-7], force [8, 9], and other physical or chemical parameters [10-12]. These presented sensors have shown the advantages of low prices, high sensitivity and compact structure.

In this paper, the combination of a PMF-FLM and a FBG was utilized to simultaneously measure temperature and strain. The PMF-FLM has different temperature and strain sensitivity responses from the FBG. Therefore, by measuring the responses of the resonance wavelength shifts of the PMF-FLM and the FBG to the variations of temperature and strain, it is possible to establish a 2-by-2 matrix. Finally, according to the dual-wavelength matrix method, the changes of the temperature and strain can be determined simultaneously.

2. Experiment

The experimental setup of the proposed sensor for temperature and strain measurement is shown in Fig. 1, which consists of an amplified spontaneous emission source (ASE), an OSA with spectral resolution of 0.02 nm , and a FLM. The FLM configuration consists of a 3-dB optical coupler with low insertion loss, an FBG with central wavelength of 1550 nm and a section of PMF with a length of 15.5 cm . The input light is split into two beams propagating clockwise and counterclockwise by the 3-dB

optical coupler. Then the two beams recombine at the coupler and appear interference due to the birefringence property of the inserted PMF.

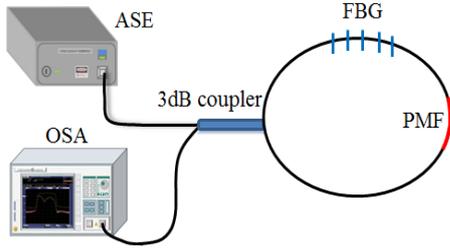


Fig. 1. Experimental setup of the sensor

The transmission spectrum of the PMF-FLM can be described as [13]:

$$T(\lambda) = \left[\sin(\theta_1 + \theta_2) \cos\left(\frac{\pi BL}{\lambda}\right) \right]^2 \quad (1)$$

where θ_1 and θ_2 are the angles between the light at both ends of the PMF and the fast or slow axis of the PMF, respectively, and B , L and λ are the birefringence, the length of PMF and the wavelength, respectively.

The wavelength spacing between the transmission dips can be written as:

$$\Delta\lambda \approx \frac{\lambda^2}{BL} \quad (2)$$

Fig. 2 shows the simulated interference spectrum of the HBFLM with different lengths of PMF. When an ambient temperature change or a strain is applied to the PMF and FBG, the birefringence, the fiber length and the grating pitch will change, and then the resonance wavelengths will shift. The shifts of the resonance wavelengths of the PMF and the FBG can be expressed as:

$$\begin{bmatrix} \Delta\lambda_{\text{FBG}} \\ \Delta\lambda_{\text{FLM}} \end{bmatrix} = \begin{bmatrix} K_{T(\text{FBG})} & K_{\varepsilon(\text{FBG})} \\ K_{T(\text{FLM})} & K_{\varepsilon(\text{FLM})} \end{bmatrix} \begin{bmatrix} \Delta T \\ \varepsilon \end{bmatrix} \quad (3)$$

where $\Delta\lambda_{\text{FBG}}$ and $\Delta\lambda_{\text{FLM}}$ are the FBG and PMF-FLM wavelength shifts, ΔT and ε are temperature change amount in $^{\circ}\text{C}$ and applied strain in $\mu\varepsilon$, respectively, and $K_{T(\text{FBG})}$, $K_{\varepsilon(\text{FBG})}$, $K_{T(\text{FLM})}$, $K_{\varepsilon(\text{FLM})}$ are the corresponding temperature and strain coefficients, which can be obtained from the experiment. The evaluations of the temperature and strain are obtained from the following matrix equation:

$$\begin{bmatrix} \Delta T \\ \varepsilon \end{bmatrix} = \frac{1}{K_{T(\text{FBG})}K_{\varepsilon(\text{FLM})} - K_{T(\text{FLM})}K_{\varepsilon(\text{FBG})}} \times \begin{bmatrix} K_{\varepsilon(\text{FLM})} & K_{\varepsilon(\text{FBG})} \\ K_{T(\text{FLM})} & K_{T(\text{FBG})} \end{bmatrix} \begin{bmatrix} \Delta\lambda_{\text{FBG}} \\ \Delta\lambda_{\text{FLM}} \end{bmatrix} \quad (4)$$

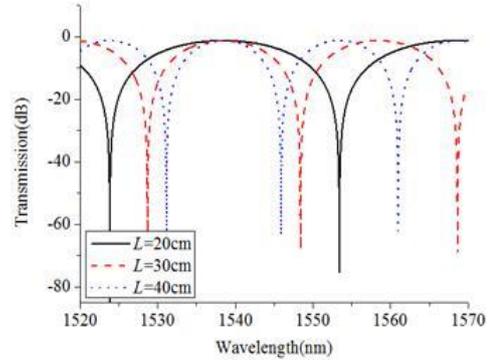


Fig. 2. Simulated interference spectrum of HBFLM

3. Results and discussion

Fig. 3 shows that the transmission spectrum responses to the temperature change with no strain. It can be observed that the spectrum of FBG is superimposed on the spectrum of the PMF-FLM. The difference between the experimented transmission spectrum and the simulated transmission spectrum (Fig. 2) of the PMF-FLM is mainly due to that the introducing of FBG decreases the light intensity and the actual length and birefringence of the PMF are slight different from the simulation setting. As the temperature increases, the resonance wavelength has a blue shift. Fig. 4 shows the wavelength shifts of the PMF-FLM and FBG response to temperature increasing. It can be seen that the PMF-FLM has a high sensitivity to the ambient temperature and the sensitivity of the PMF-FLM and the FBG to temperature is different.

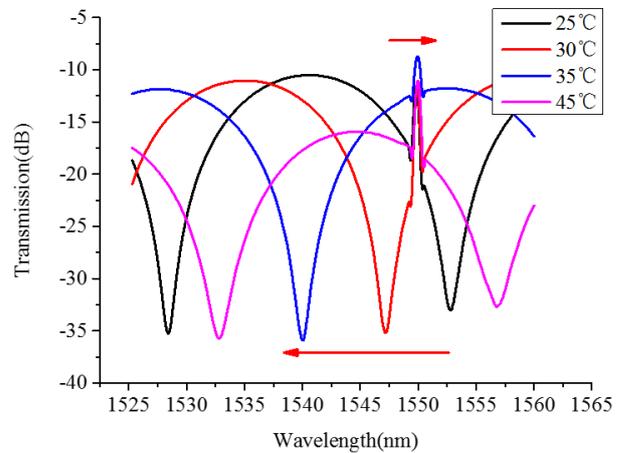


Fig. 3. Transmission spectrum response to temperature variation with no strain

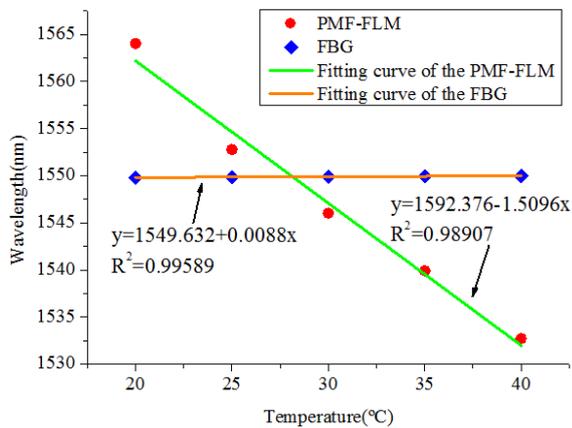


Fig. 4. Wavelength shifts as a function of temperature with no strain

The transmission spectrum responses of the FBG and PMF-FLM to the strain change is shown in Fig. 5, under the condition that the temperature is stable at 35 °C. The strain was applied by stretching the fiber through the control of a screw thread micrometer. With the increase of strain, the transmission spectrum of the PMF-FLM moves to shorter wavelength, and the movement of the spectrum is almost negligible. The sensitivity of the PMF-FLM and the FBG to strain is different too. The ambient temperature change and the applied strain can be detected by measuring the resonance wavelength shifts of the FBG and PMF-FLM. The errors of measurement are mainly determined by the resolution of the OSA, the PMF-FLM resonance and the bandwidth of the FBG

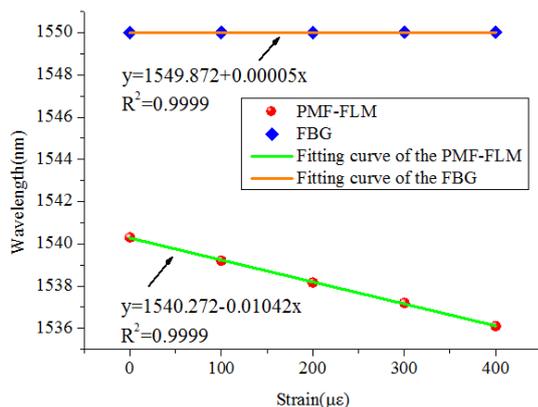


Fig. 5. Wavelength shifts as a function of strain when the temperature is stable at 35 °C

The experimental results show that the matrix coefficients of the temperature and strain can be obtained by measuring. The coefficients of the corresponding temperature are $K_{T(\text{FBG})} = 0.0088$ and $K_{T(\text{FLM})} = -1.5096$. The coefficients of the corresponding strain are $K_{\epsilon(\text{FBG})} = 0.00005$ and $K_{\epsilon(\text{FLM})} = -0.01042$. Therefore, the feasibility of the sensor for simultaneous measurement of

temperature and strain is demonstrated.

4. Conclusions

The combination of a PMF-FLM and an FBG can be a sensing head. It can be seen that the transmission spectrum of the PMF-FLM has a blue shifts with the increasing of the temperature and strain. The wavelength shifts of the transmission spectrum are obtained from the coefficient matrix for measuring the ambient temperature and applied strain simultaneously. Experimental results show that the proposed sensor has the sensitivities of $-1.5096 \text{ nm}/^\circ\text{C}$ and $0.01042 \text{ nm}/\mu\epsilon$, respectively. In addition, the temperature sensitivity of the overall sensor can also be improved by increasing the temperature sensitivity of the FBG, through attaching or covering the FBG to a material which has large coefficient of thermal expansion [14, 15]. Besides, bimetal is also an effective way to tune the strain sensitivity of the FBG and has been used for enhancing its temperature sensitivity [16, 17].

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