An optical fiber temperature/pressure sensor with dual-layer Fabry-Perot cavity structure for sensitivity enhancement

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Abstract. The multiple transfer method was used to fabricate two kinds of dual-layer composite structures for analysing the response of the dual-layer Fabry-Perot cavity structure. It’s proved that the sensitivity can be enhanced more than 20 times by optimizing the film layer parameters and combination methods of the dual layers.

1. Introduction
Optical fiber sensors have the advantages of low cost, high sensitivity, fast response time, good stability, and easy integration. Different sensor structures with various characteristics can be used to realize multi-parameter sensing, such as temperature, refractive index, etc. Currently, there are a number of studies that reported the investigations of multiple parameters monitoring. [1-2] What’s more, the monitoring sensors for temperature and pressure can be adjusted by FP cavity composite structures. [3-4] However, it is a fact that the production process is tedious and it is difficult to simultaneously achieve multiple parameters sensing of high sensitivity that utilized the existing FP cavity-based fiber sensors with composite structure in current studies. In this paper, a novel FP cavity with composite structure for fiber sensing is proposed, that is able to realize concurrently multiple parameters monitoring with high sensitivity.

2. Sensor principle and preparation

![Figure 1. The dual-layer sensor structure](image-url)
The dual FP cavity structure studied in this paper is shown in Fig 1. The sensor is mainly composed of a single mode tail fiber and two layers with different material. Fig 1 clearly shows that the formed FP cavity consists of three reflective surfaces. The improved three-beam interference model based on the sensor structure shows three reflected lights interfering with each other according to the principle of multi-beam interference. The corresponding three-beam interference intensity can be described as [5]:

\[ I = I_1 + I_2 + I_3 - 2\sqrt{I_1 I_2} \cos \left( \frac{\pi}{2} R_1 L_1 + \varphi_1 \right) + 2\sqrt{I_2 I_3} \cos \left( \frac{\pi}{2} R_2 L_2 + \varphi_2 \right) - 2\sqrt{I_1 I_3} \cos \left( \frac{\pi}{2} (R_1 L_1 + R_2 L_2) + \varphi_3 \right) \] (1)

Where \( I_1, I_2, I_3 \) in the formula (1) are the reflected light intensity at the three reflecting surfaces, \( \varphi_1, \varphi_2, \varphi_3 \) are the initial phases of the reflected light, and \( R_1, R_2 \) are the refraction of the dual-layer.

The fabrication process of the sensor is displayed in Fig 2, mainly include: 1) The standard single mode fiber was fixed on the platform, and the fiber was cut by a cutter to obtain a flat fiber end face; 2) PDMS adhesive, Ecoflex00-30 adhesive and epoxy resin AB adhesive were mixed and stored in the ratio of 10:1, 1:1, 1:1, respectively; 3) The port of standard SMF (SMF1) was fixed on the left bracket of the welder (Fujikura-60S). Then, the position of SMF1 and SMF2 was adjusted by the welder motor until the adhesive adhered to SMF2 was successfully transferred to the end surface of SMF1; 4) The sample SMF1 applied with a layer of glue material was left standing or heated to make the glue solidified. 5) The preparation steps were repeated to fabricate the optical fiber sensor of the FP cavity with a dual-layer structure of three materials.

3. Sensing characteristic test results and analysis
The improved sensors were connected with the ASE light source, the circulator and the OSA. The central frequency of the spectrometer was adjusted to be 1567.5 nm, and the wavelength range was from 1525 nm to 1610 nm. To avoid the influence of other factors, the dual-layer FP cavity was sealed in a constant temperature oven and a pressure chamber, and the temperature and pressure were measured simultaneously.

This paper carried out a comparative analysis, mainly discussed the FP cavity structure composed of three different film combinations, followed by \( S_1 \) -Ecoflex0030 silicone rubber /PDMS, \( S_2 \) -PDMS/Ecoflex0030 silicone rubber, as shown in Table 1.

| Combination | Material 1 | Material 2 | Thickness |
|-------------|------------|------------|-----------|
| \( S_1 \)   | Ecoflex0030| PDMS       | 31 \( \mu \)m |
|             |            | PDMS       | 10 \( \mu \)m |
| \( S_2 \)   | Ecoflex0030|            | 28 \( \mu \)m |

3.1. Temperature sensitivity analysis
The initial temperature was set to 40°C and the increment of temperature chamber was set to 10°C. The interference spectrum was updated until the temperature reached 100°C. Fig 4(a) displays that the temperature response of \( S_1 \) has multiple interference peaks from 1525nm to 1610nm. In Fig 5(a), the peak deviation reaches 32.96nm, which demonstrates relatively good fit with linear curve. The calculated temperature sensitivity was about 540pm/°C. The \( S_2 \) structure has the broader temperature response range. The fitting graph in Fig 5(b) displays that the peak shift of the third structure is about 61.46nm, and the temperature sensitivity reaches 1033pm/°C. In comparison, the \( S_2 \) structure has the broadest temperature response range and the highest temperature sensitivity coefficient in fabricated samples. The temperature sensitivity concerns the comprehensive effect of the dual-layer combinations and the nature of the materials.
3.2. Pressure sensitivity analysis

In this section, the experiment utilized an experimental device consisting of a spectrometer, a light source and an adjustable pressure pump, to test the response of the composite FP cavity sensor for pressure. The pressure test range was set from 100kPa to 400kPa. The $S_1$ composite sensor in Fig 7(a) clearly shows the redshift phenomenon to the incremental changes. As shown in Fig 7(b), the linear fitting graph shows that the peak deviation is about 10.48nm, and the calculated pressure sensitivity reaches 34.6pm/kPa. Fig 7(a) displays that the $S_2$ composite structure of dual-layer has lower pressure sensitivity comparing to its high sensitivity in temperature response. According to Fig 8(b), it can be seen that the structure has a good linear fit, and the peak change trend is relatively stable with slight fluctuations. The overall peak shift is 9.09nm, the pressure sensitivity is about 30.2pm/kPa. The results show that Ecoflex00-30/PDMS has a strong elastic effect and refractive index. It’s proved that the response of the gas pressure is closely related to the properties of different kinds of materials.
4. Conclusion
In this paper, due to the different properties of the film layer materials, the optical fiber temperature/pressure sensor based on the dual-layer of FP cavity shows different sensing characteristics in actual application. Compared with the common glass tube / PDMS structure optical fiber FP cavity sensors, different layers and combinations have produced more than 20 times of the temperature/pressure sensitivity enhancement effect. According to the sensitivity properties and actual application of the sensor, a novel composite structure can be optimized or adjusted the sensitivity and used for the detection of different occasions.

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