Research on stress characteristics of Fabry-Perot sensor with center microbubble structure

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Abstract: The optical fiber based on silicon materials has a smaller thermal expansion coefficient, therefore it can be used for the preparation of sensor devices which are insensitive to temperature but sensitive to refractive index, strain, stress, etc. For example, we can use optical fiber Fabry-Perot (F-P) sensor to achieve high sensitivity stress sensing. In this paper, we design an optical fiber F-P sensor with low cost and high sensitivity based on chemical etching method and analyze the stress sensing properties. Hydrofluoric acid is used to prepare the end face concave hole of the optical fiber first, and then the hollow structure of the fiber F-P sensor is obtained by melting and discharge. This preparation method contributes greatly to enhancing the stress sensing properties and temperature insensitivity of the optical fiber device. The experimental results show that interference spectrum peak change is proportional to the stress change of optical fiber F-P sensor, stress sensitivity can reach 5.2, and the cost is relatively low. Based on this, it has a certain application value in the stress sensing field.

Key words: optical fiber sensor; F-P interference; stress sensing

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Optical fiber Fabry-Perot (F-P) sensing technology is a novel technology[1]. It has advantages of small size, high sensitivity, low loss, high cost performance, good reusability, wide band, wide dynamic range, continuous detection, easy formation of a telemetry network with an optical fiber transmission system[2-3], etc, therefore optical fiber sensing technology has been used in various fields. At present, optical fiber F-P sensor is widely used in temperature, strain and stress sensors[4-5]. In recent years, with the rapid development of optical fiber F-P sensing technology, sensitivity of fiber F-P pressure sensing technology has caught extensive attention and measurement range has also expanded[6-7].

The F-P optical fiber sensor has different preparation methods. For example, WANG An-bo, et al. made optical fiber and capillary fuse together into F-P cavity by means of laser melting technology[8]. We can fuse multimode optical fiber and single mode optical fiber together by using welding machines. Because fiber core refractive indexes are different, we can make a preparation of the optical fiber F-P sensor with low reflectivity and low transmission loss based on Fresnel reflection[5]. Some journals have reported some F-P cavity preparation methods using special optical fiber[9-10]. Different preparation methods have different effects on sensitivity characteristics. For example, Ma J from Hong Kong Polytech University made a study of optical fiber F-P sensor stress sensitivity with the structure of nano graphene films and sensitivity of 3.8[11]. In Ref. [12], the sensitivity after routine F-P cavity stress testing is 2.8. For compressible F-P cavity sensor, the cavity can be freely compressed into ambient pressure and the sensitivity

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is greater than 1 000 nm/kPa[13].

For the above mentioned F-P structure, not only preparation is more difficult, but also its sensitivity is relatively low. Therefore, we propose a kind of optical fiber F-P sensor based on chemical etching method and analyze the stress sensing properties. Hydrofluoric acid is used to etch the optical fiber whose end face is concave hole, then corroded optical fiber and single mode optical fiber are fused together by welding machine. This preparation method is helpful to enhance the stress sensing properties and temperature insensitivity of the optical fiber devices. The experimental results show that the change of interference spectrum peak is proportional to the change of stress for optical fiber F-P sensor. The stress sensitivity can reach 5. 2, and it has lower cost and higher sensitivity.

1 Principle of optical fiber F-P sensor

In this paper, the structure of resonant cavity is manufactured by fusing corroded optical fiber and single mode optical fiber together using welding machine and this cavity contributes to solving light transmission problem. For the designed F-P interferometer, the end face of the corroded optical fiber can gather the light into F-P cavity. The structure of F-P cavity is shown in Fig. 1.

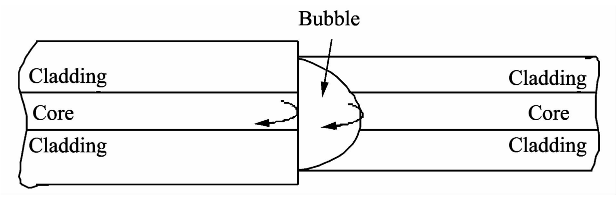


Fig. 1 Structure of F-P cavity

By means of F-P interferometer, the reflected beam or transmitted beam meet the relevant conditions. Thus we can get the intensity of the reflected light and transmitted light as

$$I_T=\frac{I_0}{1+\frac{4R}{(1-R)^2}\sin^2\left(\frac{\delta}{2}\right)}, \tag{1}$$

$$I_R=I_0-I_T=\frac{2R(1-\cos\delta)}{1+R^2-2R\cos\delta}I_0, \tag{2}$$

$$\delta=\frac{2\pi}{\lambda}\Delta L, \tag{3}$$

where I_0 is input light intensity, R is mirror reflectivity, δ is phase difference between rays of light in F-P cavity, ΔL is optical path difference between two beams, I_T is transmitted light intensity, and I_R is reflected light intensity[5-6].

From the above formula, we know that the transmitted light nd the reflected light are complementary in the process of light transmission. When reflectivity R is a certain value, the transmission interference light intensity changes with δ. When R approaches 1, the F-P cavity reflectivity is the maximum. When the reflectivity is larger, the change of interference intensity is more significant and the resolution is the highest.

2 Experiment and analysis

When we use chemical etching method for corrosion of optical fiber, optical fiber is placed in hydrofluoric acid solution. Since hydrofluoric acid is a kind of weak acid in water, it can not be completely separated into ions. The speed of hydrofluoric acid corroding silicon dioxide is proportional to the concentration of molecules and ions. The corrosion rate will increase linearly when the the concentration of molecules or ions increases, but it has no relation to molecules and ions. The reaction rate of ions and oxides is five times higher than that of molecules. However, when the hydrofluoric acid solution concentration is higher, hydrofluoric acid solution also includes high-order compound ions and ions reaction rate is faster than that of ions. Therefore, with hydrofluoric acid solution concentration increasing, optical fiber corrosion rate will increase faster. But corrosion rate will slow down after a period of corrosion, the main reason is that the molecules and ions are consumed, which leads to decrease of hydrofluoric acid solution concentration. The experiment system for corrosion is shown in Fig. 2. The experimental device takes optical fiber to metal plate with grooves using adhensive tape, and then put optical fiber into hydrofluoric acid solution placed into glass container for corrosion.

The corrosion process can be observed by microscope, and the data are recorded at four different moments (4, 18, 32 and 46 min). The side views of fiber are shown in Fig. 3.

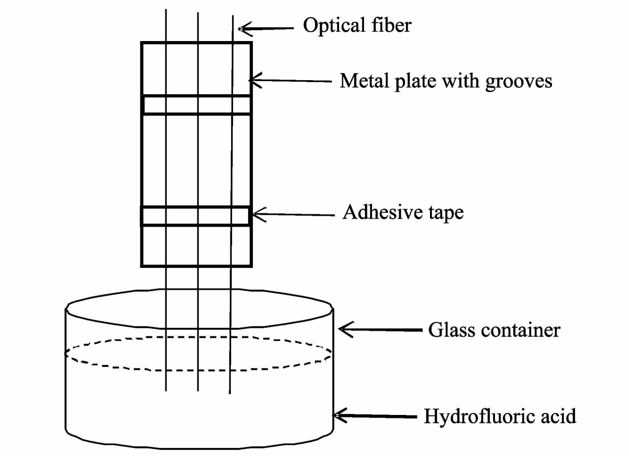


Fig. 2 Experiment system for corrosion

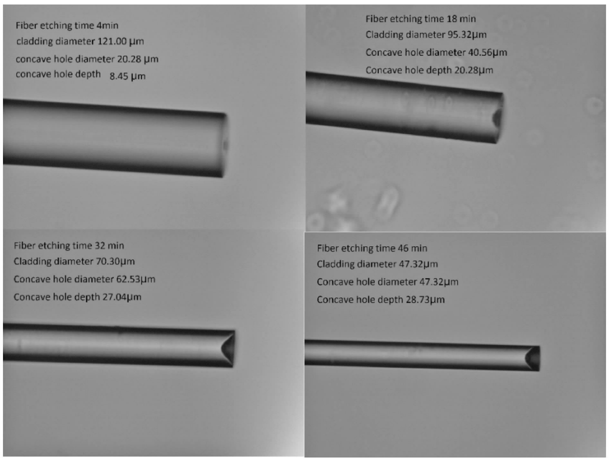


Fig. 3 Side views of fiber after corrosion

Fig. 4 shows the structure parameters of fiber at different moments. In Fig. 4, the squares represent the cladding diameter, the dots represent the diameter of concave hole and the triangles are the depth of concave hole.

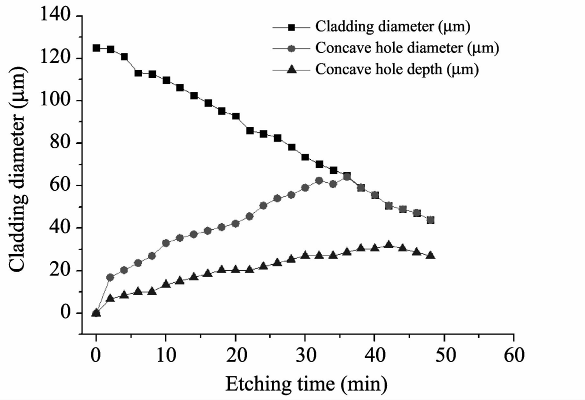
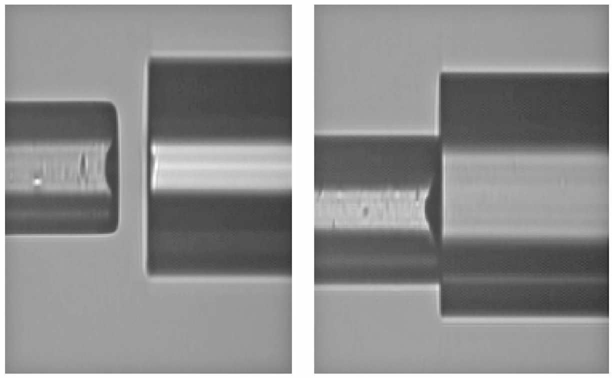


Fig. 4 Structure parameters at different etching time

The F-P cavity is manufactured by fusing corroded optical fiber and single mode optical fiber together using welding machine. The welding process is shown in Fig. 5.



(a) Cutting of optical fiber end face (b) Welding by discharge

Fig. 5 Manufactuning process of F-P cavity

In this experiment, the total length of measured optical fiber is 500 mm, with one side fixed and the other side connected to a move plate, and the moving plate definition of 10 μm. When light source wavelength is 1 570 nm and stress is increased from 0 to 1 060 με (with step of 50 με), the reflection spectrum movement is observed and compared.

When stress is 0 με, the reflection spectrum is show in Fig. 6. The spectral width is 90 nm.

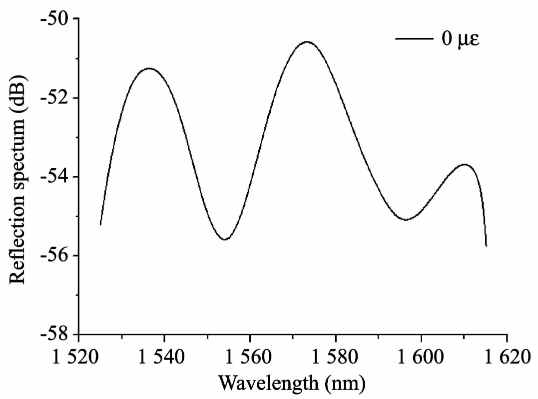


Fig. 6 Reflection spectrum of stress at 0 με

From the figure we can see that the reflection spectrum of F-P cavity interferometer is a relatively complete waveform, and the peaks and troughs are relatively obvious .

Fig. 7 shows the reflection spectra at different stress values. It can be seen that the larger the stress applied to the fiber F-P sensor, the more obvious the wave peak movement towards reflection spectra.

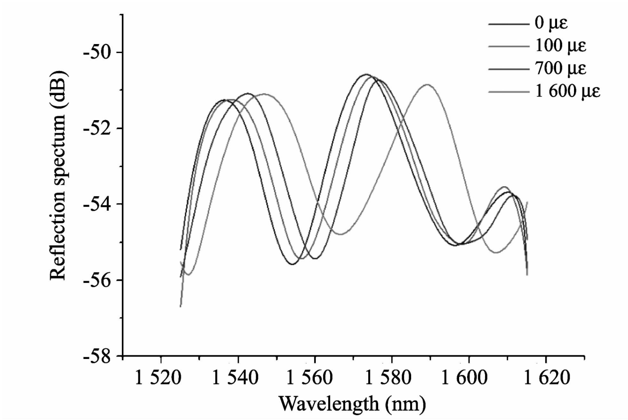


Fig. 7 Reflection spectra of stress at 0 , 100, 700 and 1 600 με

In Fig. 8, when stress values are different, the single peak movement can be observed and the change can be calculated.

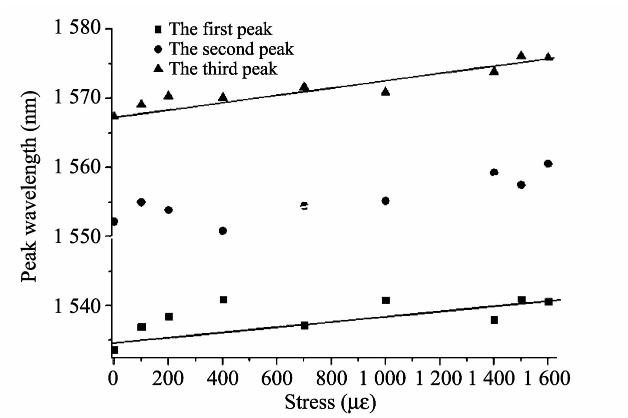


Fig. 8 Stress sensitivity characteristics

The F-P cavity structure designed in this paper is used to test the stress. From Figs. 6 and 7, it can be seen that the interference spectrum peaks and valleys are obvious. By calculating the stress characteristics of the peaks and valleys, the sensitivity can be got. The stress and wavelength changes of fiber F-P interferometer are in proportion. The stress sensitivity of the sensor is 5. 2.

3 Conclusion

In this paper, we proposes an optical fiber F-P sensor based on chemical etching. Because F-P cavity has very small thermal expansion, this preparation method is useful to enhance the stress sensing properties and temperature insensitivity of the optical fiber devices. The experimental results showed that the interference spectrum peak change is proportional to the stress change of optical fiber F-P sensor. The stress sensitivity can reach 5. 2, therefore it has lower cost and higher sensitivity.

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基于中心微泡结构的光纤 F-P 传感器应力特性研究

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摘　要： 硅基材料光纤具有比较小的热膨胀系数，可用来制备具有折射率、应变、应力等敏感特性而温度不敏感特性的传感器件，比如利用光纤 F-P 传感器可实现高灵敏度的应力传感。本文提出了一种基于化学腐蚀法的低成本、高灵敏光纤 F-P 传感器件，并分析了其应力传感特性。该方法先利用 HF 溶液制备凹孔端面光纤，然后采用熔融放电方法制备空心结构的光纤 FP 传感器，有助于增强光纤器件的应力传感特性和温度不敏感能力。实验结果表明，所设计的 F-P 传感器其应力变化与光纤 F-P 传感器干涉谱峰变化呈正比关系，其应力灵敏度可以达到 5.2，且成本较低廉，具有一定的应用价值。

关键词： 光纤传感器；F-P 干涉；应力传感

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