Optical Fiber Fabry-Perot Pressure Sensor with Silver-coated Surface

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Optical Fiber Fabry-Perot Pressure Sensor with Silver-coated Surface

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Abstract. To meet the need of the pressure measurement in high temperature oil wells, an extrinsic optical fiber Fabry-Perot(F-P) pressure sensor on the surface of silver coating realized by physical vapor deposition is developed. The F-P cavity sensor fabricated by CO_2 laser thermal bonding technique has characteristics of large dynamic gauge ranges, low temperature sensitive, high temperature resistance and high pressure resistance The pressure resolution of 0.006MPa, the temperature sensitivity is less than 0.005MPa/℃, the repeatability of 0.05%F.S over the full scale from 0 to 42 MPa has been achieved.

1. Introduction

Long-term and real-time monitoring of pressure parameters in oil and gas wells and timely access to underground information, which is of great significance to identify and determine underground production, increase oil and gas recovery rate and reduce oil recovery cost [1]. The reliability, anti-interference and short life of traditional electronic pressure sensors in high temperature and high pressure environment cannot meet the needs of underground measurement [2].

Extrinsic fiber optic Fabry-Perot(F-P) cavity pressure sensor has been widely used in many industrial environments due to its high precision and low temperature sensitivity. In order to reduce the test error, the fiber F-P cavity sensor often needs to be in direct contact with the tested liquid. At this point, hydrogen molecules and water molecules in the external environment will invade the sensor and react with defects in the sensor quartz material [3], which affects the performance of the sensor and even causes damage. The high temperature and high-pressure environment in the oil well exacerbates this erosion process.

In view of the related experience of optical fiber coating carbon film, in this paper, the silver film is coated on the outer surface of the sensor probe by means of physical vapor deposition, which avoid the direct contact between the sensor probe and the measured medium. Thus, the sensor can work in harsh environments without erosion, and the sensor properties can't be affected.

2. Fabracation of optical fiber pressure sensor

2.1. Working principle of the sensor

Optical F-P cavity interferometer [4]is an optical resonant cavity composed of two parallel optical planes. The distance between the two reflective surfaces (the length of the cavity) is *d*, *n* is the refractive index of the media in the cavity, and *i* is the refractive angle of light at the incident interface, as shown in Fig. 1.

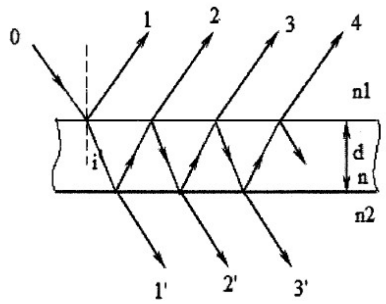

Figure 1. Principle of optical fiber F-P cavity

When a plane light wave is incident from one side at a certain angle, reflection and transmission are generated at the incident interface, and the incident light is continuously reflected and transmitted at the two interfaces. The amplitude and intensity are divided one at a time. The multiple beams of parallel reflected light that eventually form the incident optical surface and the multiple beams of parallel transmitted light on the lower reflective surface will experience interference effects between the beams of different emission times, and eventually form multi-beam interference, and reflection light intensity I_R can be expressed as [5]:

$$I_R = \frac{F\sin^2(\delta/2)}{1+F\sin^2(\delta/2)} I_0 \tag{1}$$

Where $\delta = \dfrac{4\pi d}{\lambda}$ is the phase difference between the two adjacent rays, and F is the fineness coefficient of the F-P interferometer, which is defined as [5]:

$$F = \frac{4R}{(1-R)^2} \tag{2}$$

Where R is the reflectivity of the two reflective end surfaces in the F-P interferometer, and the R≈ 4% between the quartz glass and the air interface [6]. The schematic diagram of the sensor structure is shown in Fig. 2, mainly consist of the incident fiber, the reflective fiber and the quartz capillary in total of three parts. When the F-P cavity length d = 125 μm, its spectral diagram is shown in Fig. 3.

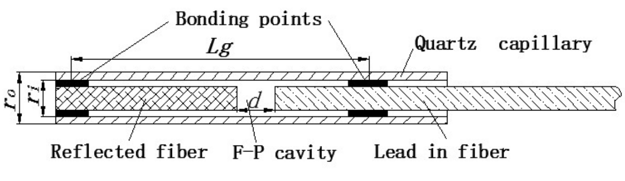

Figure 2. The structure diagram of optical fiber F-P cavity sensor.

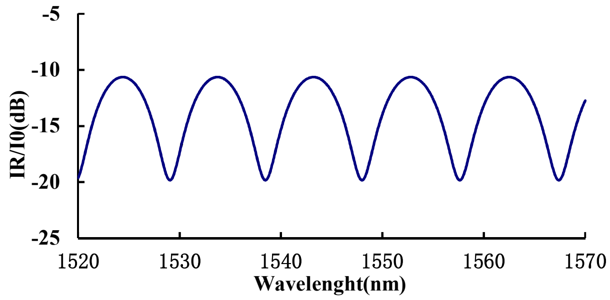

Figure 3. The light spectrum of the optical fiber F-P cavity

2.2. *Fabrication of the sensor*

The fiber and quartz capillary are bonded by CO_2 laser in high temperature. This is the first process of sensor probe production, and the sensor probe after the first process is shown in Fig. 4.

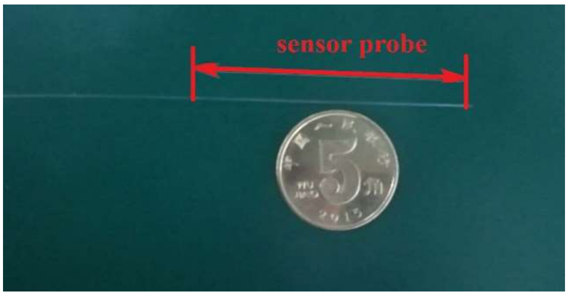

Figure 4. The sensor probe after the first process.

The sensor probe after the first process is coated with a silver film on its outer surface by means of physical vapor deposition. The process is shown in Fig. 5. At this point, the sensor probe is finished and the sensor probe finished as shown in Fig. 6.

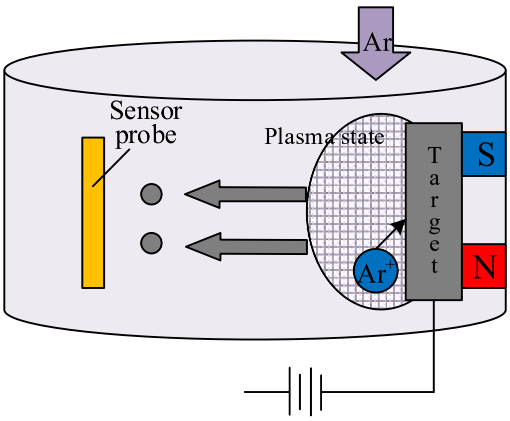

Figure 5. The schematic diagram of coating device

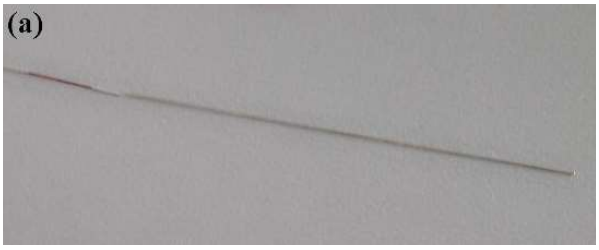

Figure 6. The sensor probe is finished (a) and under scanning electron microscope (b).

As shown in Fig.2, when the pressure *P* changes, the change Δd of cavity length can be expressed as[7]:

$$\Delta d = \frac{L_g r_o^2}{E\left(r_o^2 - r_i^2\right)}(1-2\mu)P \tag{3}$$

Where r_i, r_o is the inner and outer diameter of the quartz capillary, μ is the Poisson's ratio of quartz glass, *E* is the Young's modulus. We can adjust the pressure sensor measurement sensitivity and dynamic range within a certain range by adjusting the capillary diameter r_i, outer diameter r_o and gauge L_g of the three geometric parameters**.**

3. Laboratory test results

Because the silver coating is introduced into the material which is different from the sensor probe body, it will affect the sensor performance. In order to assess the performance of sensors, we tested its cross sensitivity of temperature and pressure, and repeatability.

3.1. Performance testing system

The test system of fiber optic F-P cavity pressure sensor which is designed in this paper is shown in Fig. 7, mainly including pressure gauges, thermostats, pressure pipes, pressure devices, demodulators and so on.

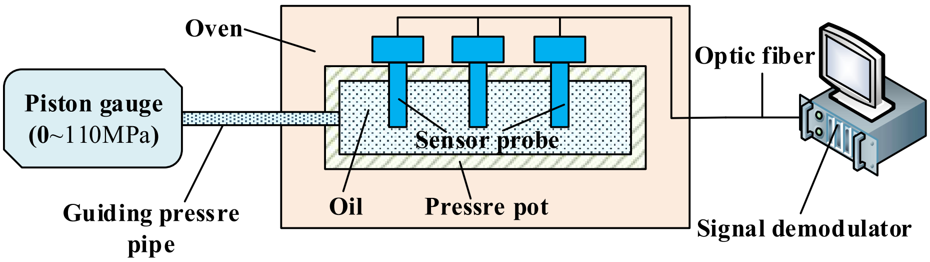

Figure 7. The Schematic diagram of the sensor testing system

3.2. Cross sensitivity of temperature and pressure

In the actual application of oil and gas well, the temperature and pressure changes occur simultaneously. Therefore, overcoming the cross sensitivity of pressure and temperature is the first consideration in the design of sensor probe structure and material selection.

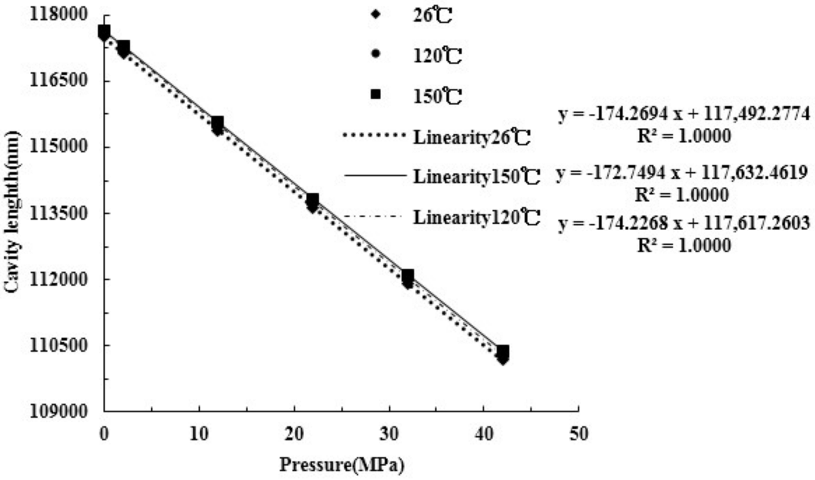

Figure 8. The cross sensitivity of temperature and pressure linearity of the sensor.

The fiber F-P cavity pressure sensor is put into the high temperature and high-pressure calibration device, and the pressure calibration at different temperatures is carried out to test the cross sensitivity of the temperature pressure. When the pressure changes from 0 MPa to 42 MPa, the length of the F-P cavity changes by about 7.5 μm. Fig. 8 gives the results of pressure calibration at 26 °C, 120 °C and 150 °C with the sensitivity of approximately 174nm/MPa, the resolution of 0.006 MPa, and the linear correlation R_2 = 1.000000. The maximum deviation of the pressure calibration curve at 26 °C, 120 °C and 150 °C is less than 2 %, the temperature sensitivity is less than 0.005MPa/℃, which shows that the sensor can effectively eliminate the cross sensitivity of temperature to pressure.

3.3. Test of the repeatability

Because the sensing surface is coated with substances different from optical fiber materials, when the external pressure changes, the quartz material and the coating will undergo corresponding retractable changes, but the degree of retractability of the two will be different, and additional errors may be introduced. It can also cause the reliability of the coating layer to be reduced, thus affecting the performance of the sensor. Therefore, it is necessary to perform repetitive assessment of the sensor after surface coating.

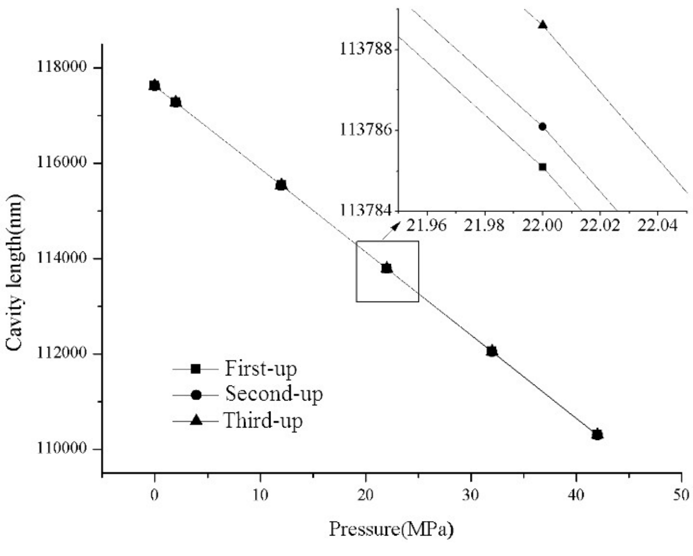

Figure 9. The repeatability of the sensor

Fig. 9 gives the repetitive measurement results of the sensor. The transverse coordinates are the results of the high-precision pressure calibrator measurement (GE3100 range 110MPa, accuracy 0.0008% F.S) and the longitudinal coordinates are the measurement results of the fiber fiber F-P pressure sensor. The pressure calibration of the maximum pressure of 42 MPa was performed three times in one month. The results show that the maximum deviation of F-P cavity length is 1nm and the repeatability is less than 0.05% F.S (Full scale) in three measurements, and the repeatability is very good.

4. Conclusion

An extrinsic optical fiber F-P cavity pressure sensor on the surface of silver coating realized by physical vapor deposition is developed. The F-P cavity sensor fabricated by CO_2laser thermal bonding technique has characteristics of large dynamic gauge ranges, low temperature sensitive, high temperature resistance and high pressure resistance The pressure resolution of 0.006MPa, the temperature sensitivity is less than 0.005MPa/℃, the repeatability of 0.05%F.S over the full scale from 0 to 42 MPa has been achieved.

Acknowledgments
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