

A New Type of Fbg Sensor with High Temperature Sensitivity

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Abstract: A method of using polymer to encapsulate the bare FBG is proposed and implemented. The principle of the increasing in sensitivity of FBG is introduced, a novel packaging material composed of 100 wt% unsaturated polyester, 2 wt% Methyl Ethyl Ketone Peroxide and 2 wt% cobalt naphthenate is realized. With the help of casting a model, FBG is encapsulated. After establishing the experimental platform, the temperature sensitivity of the packaged FBG is also analyzed. The comparison of the experimental results between the packaged FBG and the bare FBG shows that over the temperature of 24–44°C, the equivalent temperature sensitivity of the packaged FBG is 0.10387 nm/°C, which can be increased by about 14.268 times as much as that of bare FBG and close to the theoretical values 0.108 nm/°C. The FBG package material and technique is effective in the increasing of the temperature sensitivity, which is suitable for applications where wavelength references for FBG sensor system with high temperature sensitivity is required, especially in the measurement of human body temperature.

Keywords: FBG, polymer package, temperature sensitivity, temperature sensitizing

INTRODUCTION

The Fiber Bragg Grating (FBG) sensor, as one of the new optical passive devices, has attracted a considerable amount of interest in recent years. As the 1990s new FBG sensor, it is widely used in the field of sensing because of its advantages such as high sensitivity, small volume, corrosion resistance, anti electromagnetic radiation, optical path can be bent, easy realization of remote sensing (Jin *et al.*, 1997; Zhang *et al.*, 2011; Dong *et al.*, 2009; Liu and Chen, 2006). Especially in the measurement of strain and stress distribution in the area of aviation, spaceflight, etc., it has the incomparable advantage over the traditional sensor resistance strain film (Li *et al.*, 2006; Rao *et al.*, 2000; Koulaxouzidis *et al.*, 2000; Song *et al.*, 2000). FBG has stable sensing property and is the ideal temperature sensor. As temperature sensor, the temperature sensitivity is one of the key technical parameters that should be taken into consideration, but because the traditional optical fiber Bragg grating has low sensitivity to temperature, naked fiber grating with the wavelength being 1550 nm has a temperature sensitivity of about 0.0082-0.012 nm/°C, optical fiber Bragg grating itself is very delicate, very

brittle and the sensor's working environment is often complex. So we must use the material with large thermal expansion coefficient to encapsulate Bragg gratings effectively, in order to improve its mechanical strength and temperature sensitivity (Lo and Kuo, 2002; Xu *et al.*, 2009). This study put forward the option of polymer-encapsulating optical fiber Bragg grating sensor, which is not only make the bare FBG have certain mechanical strength, but also higher temperature sensitivity. With axial stress on grating, the change in the wavelength of the FBG is only related to temperature. This study also makes a discussion on the temperature sensitivity property of FBG sensor after it is packaged.

THEORIES OF FBG TEMPERATURE SENSING

The structure of FBG is shown in Fig. 1, the broadband light fired into the FBG, the wavelength meet the certain conditions can be reflected back and the rest of the light transmission out. The basic principles of the FBG sensing is using the effective refractive index of the FBG and the grating period sensitivity to the external parameters, then transform the parameters changes into the drift of the FBG wavelength, according to detection

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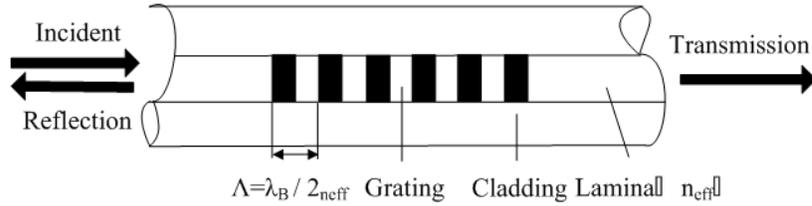


Fig. 1: FBG structure

of the center wavelength drift of the refractive grating, the external parameters changes can be measured.

Known by the coupling theory, the Bragg wavelength of FBG is described as:

$$\lambda_B = 2n_{eff} \Lambda \tag{1}$$

where λ_B represents the central wavelength of FBG, n_{eff} is the effective refractive index in of the fiber core and Λ denotes the periodicity of the index modulation. Just as Eq. (1) shows, the shift in the Bragg wavelength λ_B can be determined by the change of n_{eff} and Λ , which related to strain and temperature. Strain and temperature, affect n_{eff} through the elastic-optic and the thermo-optic, then led to the drift of λ_B .

Studied have proved that the force generated by the strain and the thermal generated by the temperature are independent of each other. Assuming the FBG is limited only by the temperature, from Eq. (1), the Bragg wavelength changes caused by the temperature is as Eq. (2) shows:

$$\Delta \lambda_B = 2 \Lambda \Delta n_{eff} + 2n_{eff} \Delta \Lambda \tag{2}$$

Set ΔT as the temperature changes, then the thermal expansion $\Delta \Lambda$ caused by the grating period can be expressed as:

$$\Delta \Lambda = \alpha \cdot \Lambda \cdot \Delta T \tag{3}$$

where, α is the thermal expansion coefficient of the FBG, the effective refractive index changes caused by the thermo-optic is show in Eq. (4):

$$\Delta n_{eff} = n_{eff} \cdot \xi \cdot \Delta T \tag{4}$$

where, ξ is the thermo-optic coefficient of the fiber material, combine (2), (3) and (4), we have:

$$\Delta \lambda_B / \lambda_B = (\alpha + \xi) \cdot \Delta T \tag{5}$$

Equation (5) shows that a linear relationship between the Bragg wavelength drift and the temperature changes is existed when there is no strain force. Therefore, we can get the temperature changes through the analysis of the FBG demodulation. Ordinary FBG is generally doped germanium silica fiber, whose α is $0.5 \times 10^{-6} / ^\circ\text{C}$ and ξ is $7.0 \times 10^{-6} / ^\circ\text{C}$, the temperature sensitivity coefficient of the FBG at the normal temperatures can be estimated by Eq. (5), which is about $7.5 \times 10^{-6} / ^\circ\text{C}$. Considering the use of the packaging materials to enhance the temperature sensitivity of FBG, the relationship between reflection wavelength and the temperature is given by Eq. (5), after the package substrate material and the FBG bonded:

$$\frac{\Delta \lambda_B}{\lambda_B} = [\zeta + (1 - P_e) \alpha_s] \Delta T \tag{6}$$

where α_s is the thermal expansion coefficient of the substrate, the effective elastic extinction coefficient of the FBG material is P_e . So, in order to improve the mechanical strength and the temperature sensitivity of the bare FBG, package it with the polymer of large thermal expansion coefficient is feasible.

EXPERIMENTAL RESULTS AND ANALYSIS

FBG encapsulation: To meet the requirements of the practical applications, in the process of packaging, the problem of the packaged sensor's repeatability, stability, linearity and mechanical strength must be take into account. The study proposes a simple polymer encapsulation method, which is easy operated, protect the FBG and also enhance the temperature sensitivity.

The packaged FBG sensor should be as small as possible to make the sensor easy carried and less affected of the frequency response characteristics. The FBG packaged in the study is prepared by phase mask method which is one type of the UV-written method, for the FBG, the peak reflectivity is close to 100%, the ratio of the side mode suppression is about 29 and 3 dB bandwidth is 0.8 nm. According to the basic principle of the sensor sensitizing package, the study select unsaturated polyester

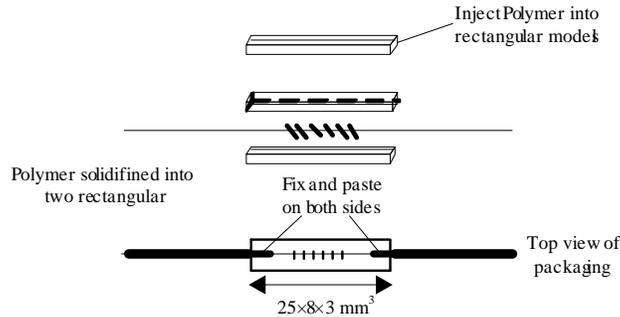


Fig. 2: Diagram of bare FBG encapsulation process



Fig. 3: Diagram of the packaged FBG

resin mixtures 2 wt% Methyl Ethyl Ketone Peroxide and 2 wt% cobalt naphthenate to package the bare FBG, for what, the coefficient of the thermal expansion is large, the temperature has a good stability and the FBG compatibility is high.

Because curing package materials will take a long time, the study proposes a method that place a FBG partly embedded in a polymer-filled tube. The diagram of the bare FBG encapsulation process is shown in Fig. 2.

According to Fig. 2, inject polymer which is mixed evenly into two long strip model with length, width and thickness of 25, 8 and 3 mm, respectively, after long time curing, two long strip polymer received. Grind a groove in the center of the polymer with fine sandpaper, polish smooth and then put the bare FBG in the groove. Finally, fix and paste on the both side of the FBG until the structure is cured and taken shape, the packaged FBG is shown in Fig. 3 and 4 shows the spectrum of polymer packaged FBG sensor. During the packaging process, the FBG is imposed a certain degree of prestressing to avoid the nonlinear and the distortion of the reflection wavelength shift date, which is caused by the chirp of the FBG. Fix FBG at both side of the substrate to make sure that the FBG located in the center of the substrate material

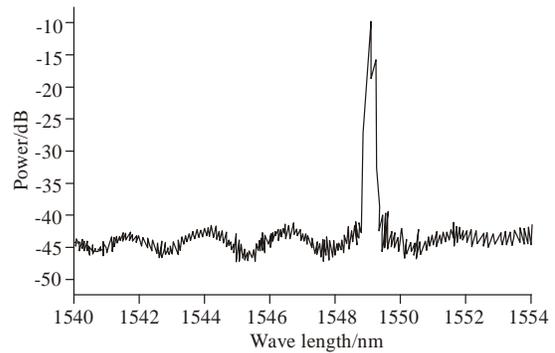


Fig. 4: Spectrum of polymer packaged FBG sensor

and parallel to the base material, As a result, not only the good linear relationship between the FBG wavelength and the temperature is ensured, but also the stability of the sensor structure.

Temperature sensitivity of the packaged FBG: To detect the sensitivity of packaged FBG, the experimental platform as shown in Fig. 5 is carried on.

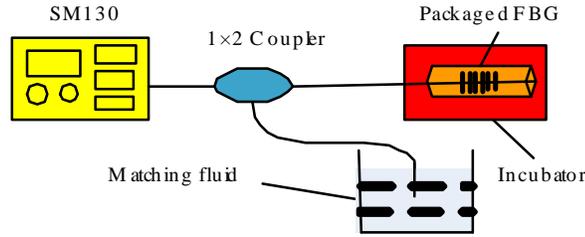


Fig. 5: Experimental platform used to detect the temperature sensitivity of packaged FBG

The bare FBG packaged in the study is with the center wavelength of 1549.04 nm. Because of the axial stress during encapsulation, the wavelength of the packaged FBG sensor is 1549.05 nm. Using FC/APC jumper header as the joint adopts, SM130 demodulation devices which is produced by the US MOI company is used as Bragg wavelength recognition system, for what, the wavelength resolution is less than 1 pm, the highest scan frequency can reaches 1 kHz. Packaged FBG sensor is placed in the incubator in order to effective regulate and maintain the temperature. The bandwidth light from the SM130 come through the coupler, part of which incident to the FBG and another part get into the matching liquid to reduce the reflection of the optical fiber surface, the light reflected from the grating come through coupler again and then reflect back to SM130 demodulation which is used to observe and analyze the changes of FBG wavelength. Put thermometer and FBG in the same plane to make sure the accuracy of the FBG temperature measurement, change the temperature in of the incubator and then record the corresponding temperature the thermometer shows and the wavelength we test, The results are shown in Fig. 6.

It can be seen from Fig. 6, there is an approximately linear relationship between the bare FBG wavelength and the temperature. The liner fitting cure is $y = 0.00728x + 1548.53572$ and the equivalent temperature of which is $0.00728 \text{ nm}/^\circ\text{C}$. For the packaged FBG sensor, the relationship between the bare FBG wavelength and the temperature is linear too, the liner fitting cure is $y = 0.10387x + 1445.23333$ and the equivalent temperature is $0.10387 \text{ nm}/^\circ\text{C}$. Take the thermal expansion coefficient of the unsaturated polyester resin into Eq. (6), the temperature sensitivity of the packaged FBG sensor is $0.108 \text{ nm}/^\circ\text{C}$, the experimental value is close to the theoretical values, which is about 14.268 times of the bare FBG sensor. The reason why temperature sensitivity of the packaged FBG much higher than the bare FBG is that the thermal expansion coefficient of the polymer material is larger than SiO_2 which is the main ingredient of the fiber and in the process of the temperature changes, an

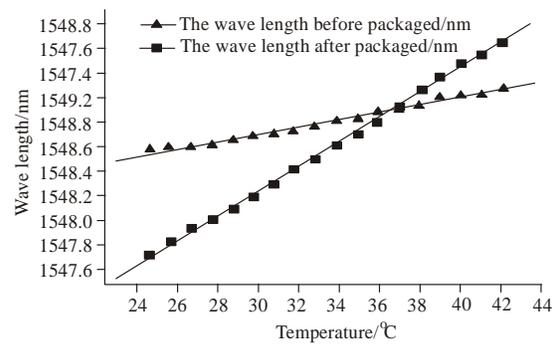


Fig. 6: Contract diagram of wavelength changes before and after encapsulation

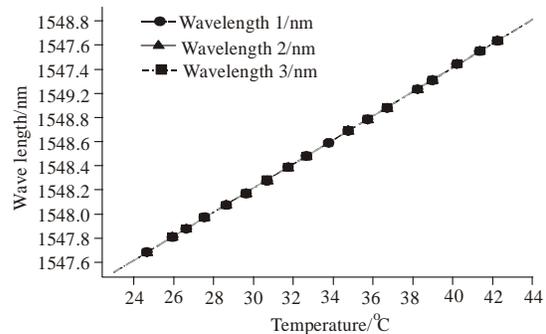


Fig. 7: Repeatability curve of the packaged FBG temperature sensor

axial tensile stress is formed between the polymer and the temperature, which is also increase the temperature sensitivity of the packaged FBG.

Repeat the experiment of the packaged FBG temperature sensor to get large amounts of data. Choose any three sets of the data to draw the curves as is shown in Fig. 7. From the platform we can see that the curve drawn with the three group of measured data has good repeatability, which proved the optical fiber grating encapsulated in this polymer has good stability.

CONCLUSION

The experiment proves that by doing encapsulation processing to FBG with the polymer materials of larger thermal expansion coefficients, fiber grating temperature sensitivity can be largely improved. Encapsulation has a good effect on FBG. In this article, we used the mixture of the unsaturated polyester resin, Methyl Ethyl Ketone Peroxide, cobalt naphthenate to construct polymer materials to encapsulate the optical fiber grating. In this way, not only the mechanical strength, but also the temperature sensitivity of the FBG is improved, but also lead to the improvement of the optical fiber grating temperature sensitive coefficient of about $0.10387 \text{ nm}/\mu\text{æ}$. This packaged method has advantages of simple operation, low cost, materials convenient to get, so that the FBG temperature sensor has higher practical value.

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