Research of a novel packaging structure and technology by red copper slice for fiber Bragg gratings

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ABSTRACT

The sensing principle of FBG packaged was developed, and packaging technology for fiber Bragg gratings (FBGs) and the embedding technique were studied. A scheme of packaging technology using the red copper slice for FBGs was presented, and experimental results indicate that the strain sensitivity coefficient of FBG packaged is nearly the same as that of the bare FBG, and that the FBG packaged can measure the 1με change, and that the temperature sensitivity coefficient of FBG packaged is 2.97 times as much as that of the bare FBG, and that the packaging structure using red copper slice improves the temperature resolution of demodulation equipment for FBG sensors, and that the FBG packaged sensors can measure the 0.03℃ change.

Keywords: Fiber Bragg grating (FBG), Packaging technology, Sensing characteristic, Strain sensing, Temperature sensing

1. INTRODUCTION

The fiber grating sensors have the merits of general fiber sensor and the particular advantage, fiber grating wavelength coding, and they are widely applied in the field of aerospace, civil engineering, petrochemical industry, and ocean platform [1-2]. However, the fiber is slim and fragile, and its shearing resistance ability is bad, so the bare fiber grating sensing components can not directly applied to the implementation environment, and then the fiber grating packaging structure and technique is one of the critical technology in the practical engineering application. Before applied, the fiber gratings must be packaged so that the packaging structure protect the fragile fiber gratings, and improve the sensing characteristics of fiber grating. Various kinds of packaging technologies for FBGs were studied over the recent years [3-5].

The red copper used to the packaging structure is one of the best thermal conductors in all metals, so the heat energy coming from outer environment is quickly transferred to fiber Bragg gratings (FBGs). In this paper, the sensing principle of FBG packaged was developed, and then the packaging technology for FBGs and the embedding technique based on the red copper were studied, and the sensing properties of FBG before and after packaged were theoretically and experimentally researched.

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International Symposium on Photoelectronic Detection and Imaging 2009: Material and Device Technology for Sensors, edited by Xu-yuan Chen, Yue-lin Wang, Zhi-ping Zhou, Qing-kang Wang, Proc. of SPIE Vol. 7381, 73811Q · © 2009 SPIE
CCC code: 0277-786X/09/$18 · doi: 10.1117/12.835306

2. BASIC PRINCIPLE

FBGs are a kind of excellent filter element, the Bragg wavelength of FBG is given by the following equation according to Bragg's law based on the coupled mode theory [6].

$$\lambda_B = 2n_{eff} \cdot \Lambda \qquad (1)$$

where n_{eff} is the effective index of refraction, Λ is the grating period, and the period of the refractive index modulation.

As is known to all of us, the Bragg wavelength will vary according to the temperature and/or the strain because of the temperature and strain dependence of the parameters Λ and n_{eff}. The change value of Bragg wavelength with temperature and/or strain is given by

$$\Delta\lambda_B = 2n_{eff} \cdot \Delta\Lambda + 2\Delta n_{eff} \cdot \Lambda \qquad (2)$$

with $\Delta\Lambda$ the grating period variation due to the thermal expansion effect and/or the deformation of strain, Δn_{eff} the index change because of the thermo-optic effect and/or the elasto-optical effect.

If the cross-sensitivity of FBG between temperature and strain is neglected, the Bragg wavelength of bare FBG will change with temperature and strain according to the following equation

$$\Delta\lambda_B = \left(\alpha + \xi\right) \cdot \lambda_B \cdot \Delta \mathrm{T} + \left(1 + p_{eff}\right) \cdot \lambda_B \cdot \Delta\varepsilon \qquad (3)$$

where the $\Delta\lambda_B$ is the change value of λ_B with temperature and strain, the α is thermal expansion coefficient of optical fiber, the ξ is thermo-optic coefficient of optical fiber, the p_{eff} is effective elasto-optical coefficient of optical fiber, and the p_{eff} can be expressed

$$p_{eff} = \frac{n^2}{2}\left[p_{12} - \upsilon\left(p_{11} + p_{12}\right)\right] \qquad (4)$$

where the p_{11} and p_{12} are elasto-optical coefficient of fiber, the υ is Poisson ratio, the n is effective index of optical fiber. As far as the pure silica fiber is concerned, the p_e of value is 0.22 [7], and the α of value is $0.55 \times 10^{-6} / {}^oC$ [7], and the ξ of value is $6.67 \times 10^{-6} / {}^oC$ [7]. If the bare FBG is only heated, the change value of Bragg wavelength with the outer temperature can be expressed by the following equation

$$\Delta\lambda_B = \left(\alpha + \xi\right) \cdot \lambda_B \cdot \Delta \mathrm{T} \qquad (5)$$

when the bare FBG is only stretched or compressed by axial strain, the change value of Bragg wavelength with axial strain is given by

$$\Delta\lambda_B = \left(1 + p_e\right) \cdot \lambda_B \cdot \Delta\varepsilon \qquad (6)$$

However, after the FBGs are packaged by some material, the thermo-optic coefficient of optical fiber doesn't alter while the thermal expansion coefficient of optical fiber will alter because the thermal expansion of optical fiber isn't equal to that of packaging material. Therefore, the relation of Bragg wavelength change of FBG packaged with the variation of temperature can be expressed [7]

$$\Delta\lambda_B = \left[\left(\alpha + \xi\right) + \left(1 - p_{eff}\right)\left(\alpha_{sub} - \alpha\right)\right] \cdot \lambda_B \cdot \Delta \mathrm{T} \qquad (7)$$

with α_{sub} the thermal expansion coefficient of packaging material.

According to the equations (5) and (7), the change value of Bragg wavelength of FBG packaged because of the variation of temperature is 2.85 times than that of bare FBG. That is to say, the temperature sensitivity coefficient of FBG packaged is 2.85 times as much as that of bare FBG, and it is improved due to the red copper having larger thermal expansion coefficient. For the strain sensitivity coefficient, it is not almost affected by packaging material.

3. PACKAGING TECHNOLOGY AND EXPERIMENT RESULTS

3.1 Packaging technology

The packaging structure of FBG was illustrated in fig.1. The bare FBG was loosely place at the slim slot in the red copper slice, and the shape and dimension of red copper slice in the practical application depended on the surrounding condition. During the optical fiber being fixing, the heat conduction cream was slowly injected into the slot, avoiding to generate air bubble in heat conduction cream because the air bubble affected the performance of FBG packaged. And the FBG packaged doesn't influenced by outer strain owing to the buffer and absorption action of heat conduction cream.

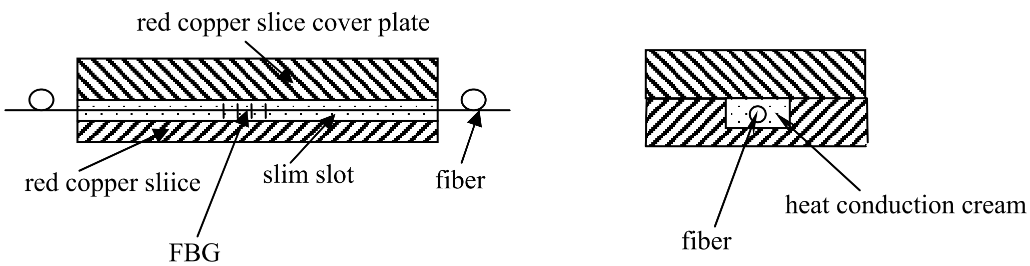
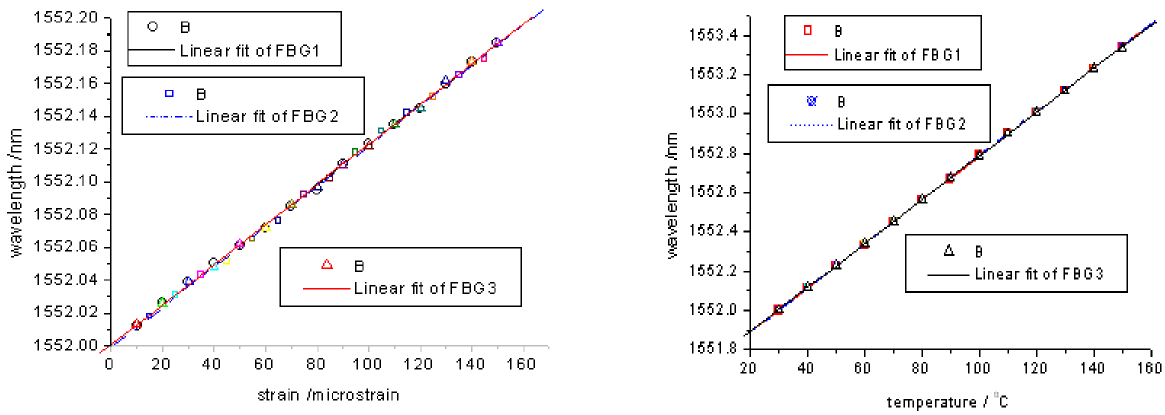


Fig.1 schematic diagram of profile for packaging FBG

The red copper is one of the best heat conductors in all metals, so the outer heat energy of red copper packaging structure is quickly transferred to the FBGs by the red copper slice. Because the red copper have larger coefficient of thermal expansion comparing with that of the bare FBG, the thermal expansion of red copper results in the larger temperature sensitivity coefficient of packaged FBG sensors compared with that of the bare FBG sensors. Therefore, the packaging technology taking advantage of the red copper slice speeds up transfer of temperature, which results in increase of the thermal coefficient of sensitivity. Nevertheless, the strain coefficient of sensitivity of FBG packaged is almost equal to that of bare FBG because elasto-optic coefficient isn't affected by packaging material. This kind of packaging structure by the red copper slice keeps the compact form, and is east to be applied to the high corrosion environment because of the corrosion resistance of red copper slice.

3.2 Test for performance of bare FBG

The battery of FBG was manufactured by means of phase mask， and the wavelength is 1552nm. The strain characteristics and temperature properties of bare FBG are illustrated in fig.2. Fig.2(a) shows that strain sensitivity coefficient is 1.22pm/με and 1.23 pm/με and 1.23 pm/με respectively, and we can see from fig.2(b) that temperature sensitivity coefficient is 11.15pm/^{o}C and 11.23 pm/^{o}C and 11.19 pm/^{o}C respectively. The results basically coincide with the theoretical value according to the equation (6) and (5).

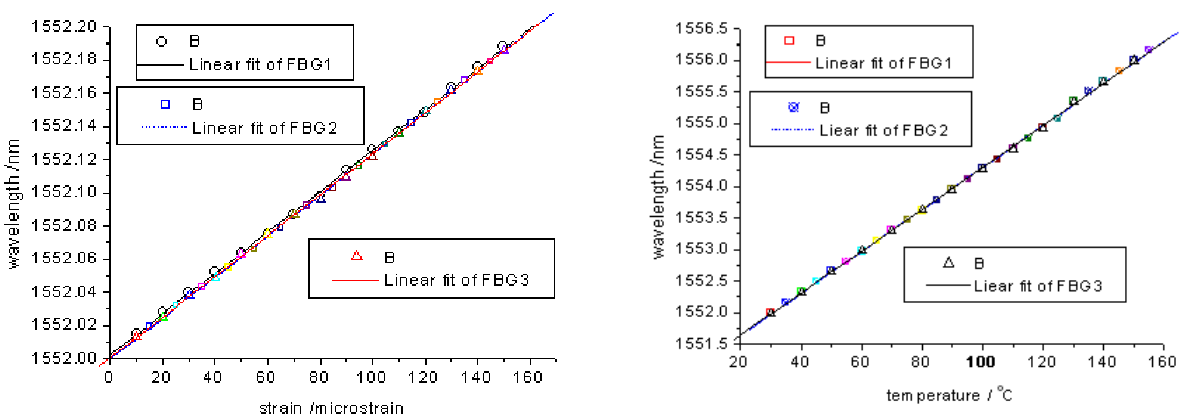


(a) (b)

Fig. 2 the strain characteristics and temperature properties of bare FBG

3.3 Test for performance of FBG packaged

After being packaged, the FBGs packaged are respectively studied in strain properties. And every FBG is respectively placed in the box for controlling temperature, then the characteristics of FBG packaged are researched in the same temperature range with the bare FBG. The results show in fig.3.



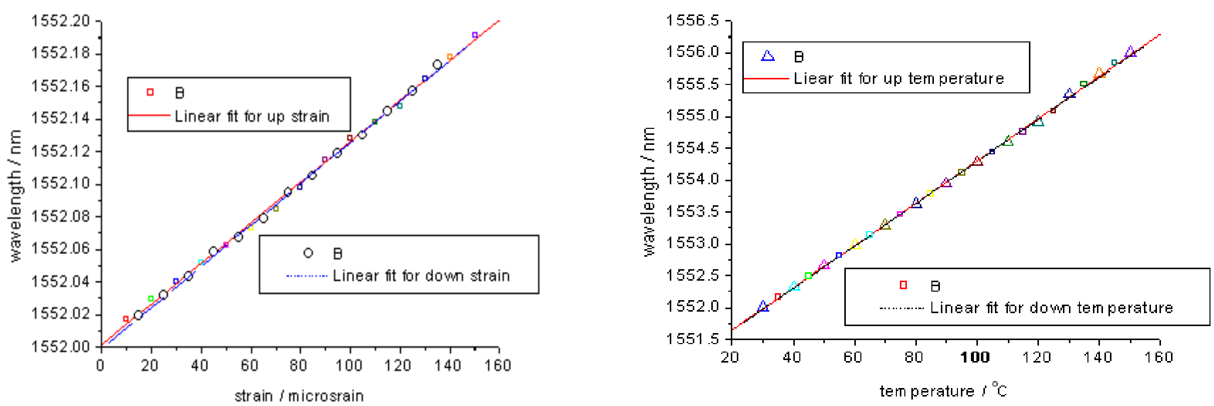
(a) (b)

Fig. 3 strain characteristics and temperature properties of FBG packaged

According to the fig.3, the strain sensitivity coefficient is 1.23pm/με and 1.24pm/με and 1.23pm/με respectively, and the thermal sensitivity coefficient is 33.25pm/^{o}C and 33.30pm/^{o}C and 33.28pm/^{o}C respectively. Thus, the average value of strain sensitivity coefficient is 1.23pm/με, and the average value of thermal sensitivity coefficient is 33.28pm/^{o}C. Compared with the strain sensitivity coefficient of bare FBG, that of FBG packaged is basically equal to that of bare FBG. Instead, the thermal sensitivity coefficient of FBG packaged is 2.97 times than that of bare FBG. These experimental results accords with the theoretical value. Because of the 0.01nm of resolution of FBG demodulation, the FBG packaged sensors can measure the 1με change and 0.03℃ change.

3.4 Repeatability of FBG packaged

In addition, two FBGs were optionally chosen in these FBG packaged what had studied above. One of them was researched in strain repeatability, and another was studied in temperature repeatability. The experiment results of repeatability of FBG packaged is illustrated fig.4. From fig.4, we can clearly see that the FBGs using the red copper slice to package are good repeatability in strain and temperature.



(a) repeatability of strain (b) repeatability of temperature

Fig. 4 repeatability of FBG packaged in strain and temperature

4. CONCLUSIONS

A scheme of packaging technology using the red copper slice for FBGs was presented, and then the strain and temperature sensing characteristics of FBG encapsulated sensors were theoretically and experimentally researched, and the strain and temperature sensing characteristics of the bare FBGs were studied as well.

The experimental results indicated that the strain sensitivity coefficient of FBG packaged sensors is nearly the same as that of the bare FBG sensor, and that the FBG packaged sensors can measure the 1με change and has good repeatability, and that the temperature sensitivity coefficient of FBGs packaged is 2.97 times larger than that of the bare FBG, and that the packaging structure using red copper slice improves the temperature resolution of demodulation equipment for FBG sensors, and that the FBG packaged sensors can measure the 0.03℃ change and has good repeatability. This kind of packaging structure by the red copper slice keeps the compact form, and adapts to build the FBG distributed sensor network, and is east to be applied to the high corrosion environment because of the corrosion resistance of red copper slice, and can be easily used in engineering.

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