Wavelength demodulation method using a tilted FBG and a PSD for a fiber optic micro-displacement sensor

YONG ZHAO*, QI WANG, HE HUANG
Northeastern University, College of Information Science and Engineering, Shenyang 110819, China

Micro-displacement is measured by the fiber Bragg grating (FBG) sensor based on a cantilever structure. The micro-displacement is generated by the piezoelectric transformer (PZT), which is placed under the free end of the cantilever. The FBG is attached at the center of the lower surface of the cantilever. When the PZT is expanded with the applied voltage, deflection at the free end of the cantilever will occur, resulting in the strain variation on the lower surface of the cantilever. This strain will act on the FBG sensor, whose reflected wavelength will shift. A tilted fiber Bragg grating (TFBG) is used to change the FBG's shifted wavelength to varied radiation angle from the TFBG, and a position sensitive device (PSD) is used to record the light spot position variation, which is corresponding to the varied radiation angle. Sensor structure and measurement principle are introduced. The feasibility is explained theoretically and results show that displacement measurement resolution of 62nm can be obtained.

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1. Introduction

Fiber optic displacement sensor are wide researched and developed in many industrial fields. The earliest fiber optic sensor is based on the light intensity modulated method which includes an emitting fiber and a receiving fiber. As the time goes on, more and more new and advanced structures and technologies have been proposed to improve the performance of the reflected intensity-modulation based fiber optic displacement sensors[1,2,3]. Interferometry-based fiber optic displacement sensor has higher resolution than those intensity-based sensors, but the ambient temperature will affect the measurement results[4].

Fiber gratings have a comprehensive prospect in optical communication and sensing systems, due to their excellent optical properties[5,6]. However, Tilted fiber Bragg grating, an important member of fiber gratings, has been paid much attention for its special structure. In past twenty years, the theoretical and experimental study on TFBG has made some achievements, and it also has been used in the area of optical communication, sensing system and wavelength demodulation.

A micro-displace measurement method based on fiber Bragg grating sensor is developed in this paper, a tilted fiber grating and a position sensitive device are used as the signal detection elements. Theoretical methods, such as the coupled mode theory and volume current method, used to study the characteristics of tilted fiber gratings are described including their advantages and disadvantages, and applications. The new demodulation system is designed, after theoretical analysis on side detection of strong radiation-mode method based on TFBG, the demodulation system with such method has the ability of simplicity, stability and repeatability.

TFBG is a kind of special fiber Bragg gratings. Compared with those traditional FBGs, its gratings are not perpendicular to the axial direction of fiber core, but with a certain tilted angle, as shown in Fig.1 for those common FBGs, the gratings are perpendicular to the axial direction of fiber core, some of the input light that meet the Bragg formula will be coupled into the counterpropagation core mode which is limited within the fiber core as the input light. So, an FBG can be regarded as a narrowband optical filter, as shown in Fig.1(a). As for the tilted FBG, the forward propagation basic mode will be coupled with a serious of cladding modes due to the tilted angle, resulting in the cladding modes. What's more, it has a radiation mode, as shown in Fig.1(b).

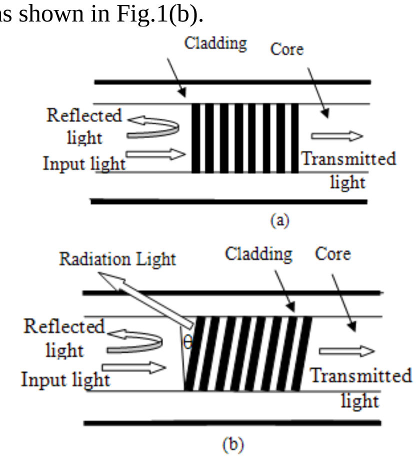

Fig. 1 (a) The schematic diagram of FBG (b) The schematic diagram of TFBG

2. Principles and structures

The micro-displacement sensing system and the wavelength demodulation schematic are shown in Fig.2.

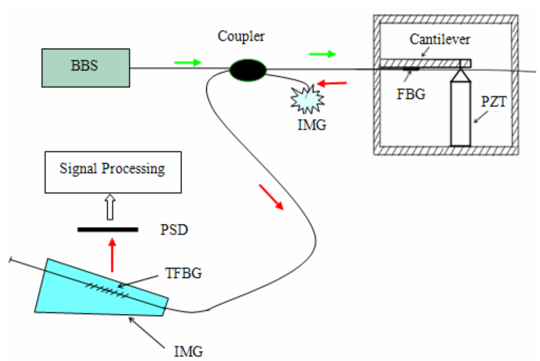

Fig.2. Micro-displacement sensor system based on TFBG.

2.1 Sensor head

The sensor head includes of piezoelectric ceramic transducer (PZT), cantilever, and a fiber Bragg grating. One end of the PZT is bonded on the base, and the other end is connected with the free end of the cantilever. The PZT will generate a micro-displacement due to the applied voltage, and is acted as a driving element, which implements the tuning of FBG due to the strain generated from the distortion of the cantilever.

2.2 Wavelength demodulation system based on TFBG

Based on the above analysis, different with those common FBGs, TFBGs could cause the intercoupling between the forward basic mode and the cladding mode, resulting in the radiation mode. The TFBG can be immersed into the refraction index matched liquid or properly coated, which will meet the coupling theory and some light will be coupled outside the fiber core. Fig. 3 is the coordinate system of TFBG geometrics.

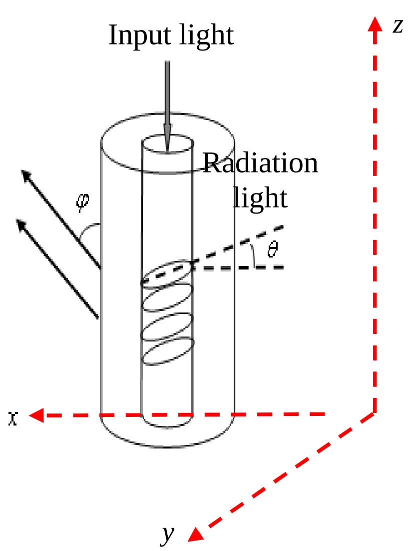

Fig. 3 The coordinate system of TFBG geometrics.

Based on the theoretical analysis, the relationship between the wavelength of the radiation mode and the titled angle of the TFBG.

When the light is incident in the direction of +*z*, there is

$$\cos(\varphi) = \frac{n_{neff,co} - \dfrac{\lambda}{\Lambda_g}\cos(\theta)}{n_{cl}} \tag{1}$$

When the light is incident in the direction of -*z*, there is

$$\cos(\varphi) = \frac{\dfrac{\lambda}{\Lambda_g}\cos(\theta) - n_{neff,co}}{n_{cl}} \tag{2}$$

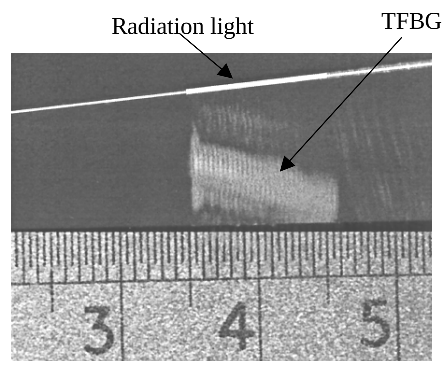

Fig. 4. Photograph showing 633 nm He-Ne light being out coupled from a TFBG

Fig. 4 is the radiation case with the He-Ne incident light, whose wavelength is 633nm. From the figure, the radiation light can be easily seen from the side face of the TFBG fiber.

It has been theoretically approved that as to the light with a certain wavelength, the radiation light from the side of the TFBG appeared to be the Gaussian distribution. Fig. 5 is an example when the light wavelength is 1520nm, the radiation light distribution from the side of the TFBG, which is recorded by a PIN diode and a two-dimension micro-displacement driver.

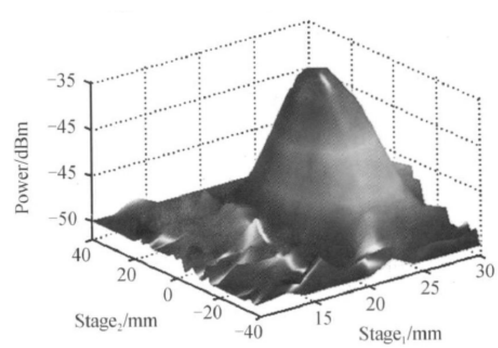

Fig. 5 Optical power distribution in the space far-field.

Based on the above face, a wavelength demodulation system for the micro-displacement measurement is proposed as shown in Figure 2. The reflected light from the common sensing FBG is radiated by the TFBG, and the radiation light from the TFBG is injected on the sensitive surface of the position sensitive device (PSD). When the measured displacement is changed, the reflected wavelength of the sensing FBG will change, resulting in the variation of the radiation angle of the TFBG. By measuring the position of the radiation light spot, the reflected wavelength of the sending FBG can be obtained. Compared with other wavelength demodulation method, this method based on TFBG has the advantages of small volume, simple principle, and fast speed. It is a great progress for the wavelength demodulation.

3. Experiments and results

The light source of the system is an ASE light source, which has the output wavelength range of 1530nm~1560nm, output light power of 25mW, and output light power stability less than +/-0.005dB. The parameters of the used FBG are as follows: center wavelength is 1550nm, 3dB bandwidth is 0.2nm, reflectivity is 0.9, the length of the grating is 10mm, and the side mode rejection ratio larger than 15dB. Figure 6 shows the reflected spectrum of the FBG.

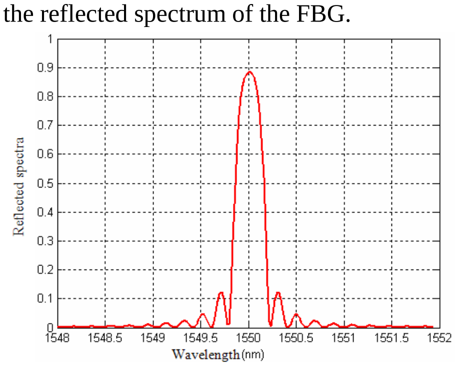

Fig. 6 The reflection spectrum of sensing FBG

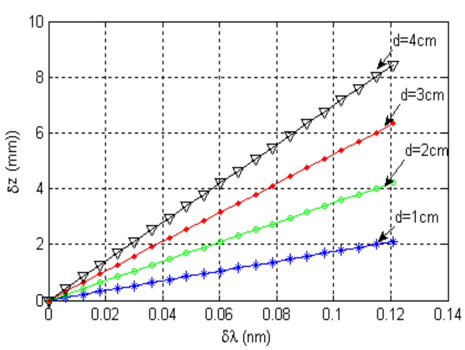

Fig.7 Spot position vs micro-displacement

As shown in Fig. 2, when there is an applied micro-displacement, the reflected wavelength of the sensing FBG will be shifted, and the spot position rejected on the sensitive surface of PSD will be changed. Figure 7 shows the spot position versus the measured micro-displacement.

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*Corresponding author: zhaoyong@ise.neu.edu.cn