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STUDY ON THE ELECTRIC CURRENT SENSOR OF FIBER BRAGG GRATING*

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Abstract A new electric current sensor based on a fiber Bragg grating tuned by a magnetostrictive material rod was obtained. The fiber Bragg grating was firmly clung on a magnetostrictive rod that was put into the central part of a solenoid. The rod was elastically lengthened along the direction of the magnetic field, so the Bragg wavelength of the fiber Bragg grating was changed when the uniform magnetic field in the solenoid increased. The relationship between the electric current in the solenoid and the change of wavelength is basically linear. The wavelength range of linear tuning is about 0.9nm, and its tuning sensitivity is about 0.001nm/mA.

Key words magnetostrictive material, fiber Bragg grating, solenoid, electric current sensor.

光纤布喇格光栅电流传感器研究*

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摘要 本文实现了一种基于磁致伸缩棒在均匀磁场中的伸缩效应的光纤布喇格光栅电流传感器.把光纤布喇格光栅牢固地沿纵向粘贴在一个置于多层漆包线绕成的螺线管中间的磁棒上,磁棒在螺线管中间部分的匀强磁场中随漆包线中电流的增加而沿纵向伸长,从而带动光栅在应变的作用下改变波长.实验测得电流跟波长变化基本上成线性关系,波长的改变范围约0.9nm,其灵敏度约为0.001nm/mA.

关键词 磁致伸缩材料,光纤布喇格光栅,螺线管,电流传感器.

Introduction

Recently fiber Bragg grating (FBG) sensor technology has become one of the most progressing sensing technology as FBG sensors can measure a wide range of parameters[1~4]. The main reason is that FBG sensors have a number of distinguished advantages over other implementations of fiber-optic sensors, such as absolute measurement, potential low-cost, flexibility and uique wavelength-multiplexing capacity. So FBG sensors are very important in civil, industrial and military fields.

Faraday effect is used for conventional current sensors while Kerr or Pockels effect is used for voltage sensors[5]. Optical fiber sensors exploiting Faraday effect have been intensively studied. However, the practical application of optical fiber sensors cannot solve the problems associated with inducing linear birefringence, temperature and vibration, which have limited the application of sensors. Several alternative methods have been set up in experiments to measure current and voltage. For example, a hybrid system is used that consists of a conventional current transformer and a piezoelectric element and an interferometric wavelength-shift detection method. FBGs are ideal for use in electrical power industry due to the immunity to electro-magnatic interference. A new electric cur-

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rent sensor based on FBG tuned by magnetostrictive material rod is demonstrated in this paper.

1 Principle

Bragg wavelength λ_B of the FBG is given by

$$\lambda_B = 2n_{eff}\Lambda, \quad (1)$$

where Λ is the fringe spacing of the FBG and n_{eff} is the effective refractive index. Both the refractive index and spacing are dependent on temperature and strain. Assuming the temperature is unvarying, the relation between strain and wavelength will be

$$\frac{\Delta\lambda_B}{\lambda_B}(1 - P_e)\varepsilon_{z}, \quad (2)$$

where P_e is the effective photoelastic coefficient. ε_{z} is the strain along the grating's axis direction. The effective photoelastic coefficient can be

$$P_e = \frac{n_{core}^2}{2}[p_{12} - \mu)(p_{11} - p_{12})], \quad (3)$$

where p_{11} and p_{12} are the photoelastic coefficients of strain tensor, μ is Poisson ratio and n_{core} is the refractive index of fiber core. For SiO_2 fiber, $n_{core}=1.46$, $p_{11}=0.12$, $p_{12}=0.27$, $\mu=0.16$, so $p_e \approx 0.22$.

According to Eq. (2), the Bragg wavelength can shift under an axial strain. The magnetostrictive material is a special kind of alloy of $TbDy(FeM)_2$, and a magnetostrictive rod of dimensions $\phi 5 \times 50$mm is used as magnetic field transducer. When a magnetic field is applied, the magnetic domains in the magnetostrictive material tend to align along the field direction. As a result of the magnetoelastic coupling, the material suffers an elastic lengthening in the direction of the magnetic field[6,7]. Assuming a FBG is held on a magnetostrictive rod which is placed into the central part of a multi-layer solenoid, the Bragg wavelength of the fiber grating will shift when the uniform magnetic field in the solenoid changes because the strain of the magnetostrictive rod will transfer to the FBG.

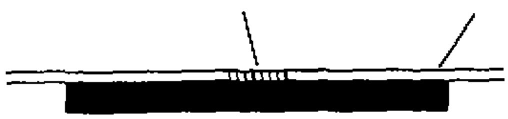

Fig. 1 FBG sensing head
图1 光纤布喇格光栅传感头

2 Experimental Results and Discussion

Figure 1 is the schematic diagram of FBG sensing head. The FBG of approximate 11mm in length is used. It is fabricated in Germanium-doped silica fiber by using a 248nm KrF excimer laser and a phase mask. The FBG with the peak reflectivity of 96% at 1549.02 nm and 0.22 nm bandwidth is used in the preliminary experiment. Figure 2 shows the setup for current measurement of the sensor. Light from a broadband light source (BBS) is launched into the sensing head, and the *transmission light is monitored* by a *commercial* optical spectrum analyzer (OSA, Advantest Q8383) with a resolution 0.1nm. According to the properties of the magnetostrictive material, the application of mechanical prestress will result in significant modification of its performance. The prestress will reduce the sensitivity to the magnetic field and give a more linear response. The solenoid has about 2000 circles and the length of this solenoid is 120mm. Put the sensing head in the central part of a multi-layer solenoid. And the magnetic field is uniform in the central part. The magnitude of uniform magnetic field is determined by the scope of the electric current in wax cloth windings. No mechanical prestress is applied in order to achieve maximum sensitivity to magnetic field. The relationship between the electric current and the Bragg wavelength was shown in Fig. 3, the

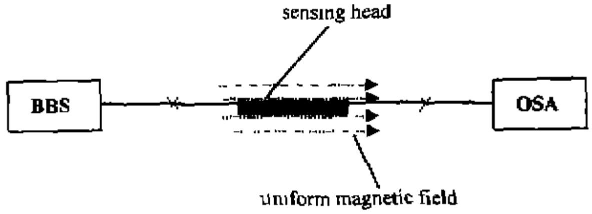

Fig. 2 Schematic diagram of experimental setup for the measurement of current effect
图2 测量电流效应的实验装置示意图

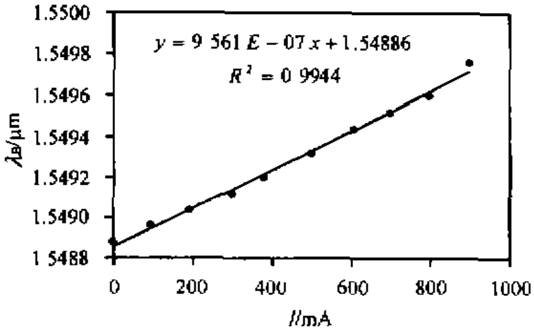

Fig. 3 The relationship between the Bragg wavelength λ_B of FBG and electric current I

图 3 光纤布喇格光栅的波长与外加电流的关系曲线

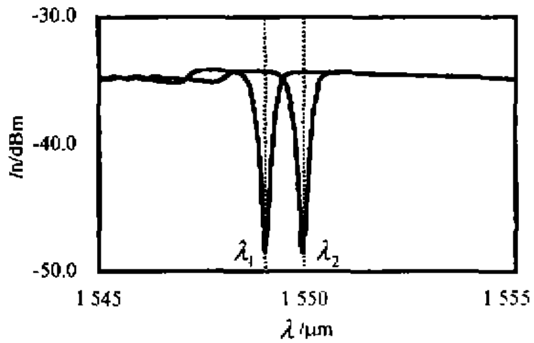

Fig. 4 The transmission spectra of FBG at different electric current

图 4 不同电流时的光纤布喇格光栅的透射谱线

dots are experimental results, and the line is the fitted line.

It is easy to see that the relationship between the current and the Bragg wavelength shift of FBG is basically linear ($R^2 = 0.9944$) in measuring range and the Bragg wavelength range of linear tuning of 0.9nm is achieved. The tuning sensitivity is about 0.001nm/mA. When the current exceeds the linear operating range of the magnetostrictive material, the nonlinear behavior will appear due to the saturation of the alloy, which will introduce the chirping of FBG. In experiments we observe that hysteresis will affect the measuring results if we go on increasing the current (for example, more than 1A), so the measuring range of this current sensor is not very wide. The FBG suffers no chirp in the tuning process as illustrated in Fig. 4. The original wavelength λ_1(1.54902μm) is tuned to the wavelength λ_2(1.54992μm). The y-axis indicates the relative spectral intensity.

In addition, temperature effect must be considered if the measuring time is long. The heat created by the solenoid will be accumulated and it will affect the Bragg wavelength. In experiments, we used an adiabatic pipe to protect the sensing head from heat. How to eliminate the hysteresis and how to temperature effect and how to extend the measuring range are important questions to be resolved.

3 Conclusion

A new electric current sensor based on FBG tuned by magnetostrictive material rod is proposed. The relationship between the electric current and the wavelegth shift is basically linear by the regression coefficient of $R^2 = 0.9944$. The tuning sensitivity is about 0.001nm/mA. This device has many characteristics, such as simple structure, high sensitivity, and good linearity. It is promising to be used in the industrial measurement and biological sensing. It also offers a potential application of optoelectronic technology for improving human health, safety and environmental protection.

REFERENCES

[1]Alan D Kersey, Michael A Davis, Heather J Patrick, *et al.* Fiber grating sensors. *J. Lightwave Technol.*, 1997, **15**: 1442

[2]Yun-Jiang Rao. Recent progress in in-fiber Bragg grating sensors: applications. *SPIE*, 1998, **3555**: 429

[3]M G Xu, H Geiger, J P Dakin. Fibre grating pressure sensor with enhanced sensitivity using a glass-bubble housing. *Electron Lett.*, 1996, **32**(3): 128

[4]P M Cavaleiro, F M Araujo, L A Ferreira. Simultaneous measurement of strain and temperature using Bragg grating written in Germanosilicate and Boron-codoped Germanosilicate Fibres. *IEEE Photon Technol. Lett.*, 1999, **11**(12): 1635

[5]Yang Zhi, Li Changsheng, Zhang Weidong, *et al.* A novel multi-function optical fiber sensing system for simultaneous measurement of current and voltage. *SPIE*, 1998, **3555**: 57

[6]J L Cruz, A Diez, M V Andres, *et al.* Fiber Bragg gratings tuned and chirped using magnetic fields. *Electron. Lett.*, 1997, **33**(3): 235

[7]Xia Chunlin, Ding Fan, Lu Yongxiang. The measurement of features of magnetostrictive material and its application. *Chinese J. Scientific Instrument* (夏春林, 丁凡, 路甬祥. 超磁致伸缩材料的特性参数测量及其应用研究. 仪器仪表学报), 1999, **20**(4): 368