The Research of Transverse Weight Characteristics on Grooved Fiber Grating

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Abstract

Long period fiber grating(LPFG) is widely used in the transverse load measurement ,which can be used as the optical device. In this paper, the grooved grating can be fabricated by use of the optimized and improved CO2 laser to the single-mode fiber, and the experimental studied the transverse load characteristics of the grooved grating based on the cantilever beam. Using the software of the ANSYS to mesh generation and the modal simulation analysis for the cantilever beam, the displacement and stress distribution parameters of the cantilever beam are analyzed under different load conditions, and the best fitting point of the grooved fiber grating can be obtained by simulation analysis. The experimental results show that resonant wavelength of the grating increases linearly with the increase of transverse load and its sensitivity of the resonant wavelength can reaches to 0.187nm/g, and the loss peak of the transmission can increases with the increase of the load which the sensitivity can reaches to 0.0390dB/g. It can realize the function of the stain and load sensing in the application, which can realize the real-time monitoring for the engineering structure, so it has practical engineering application value

Keywords

Grooved Grating, Cantilever Beam, Transverse Load, Fiber.

1. Introduction

Fiber grating is a kind of performance sensitive device for processing optical signal in optical transmission, which is used in optical fiber communication and sensing information technology [1-3]. The technology of the fiber sensing continues to develop with the progress of society [4]. The grating is mainly composed of large bandwidth, small structure and loss low advantage so that it has become an indispensable transmission mode in the field of social communication in our country. And it has expanded the bandwidth capacity in the field of communication, and the study of transverse load characteristics is a more important feature of fiber gratings [5]. There is many fabrications of the LPFG, and the every written methods of the grating may be have different mechanism. Huang Q et al. had used the B/Ge co-doped LPFG for the transverse load sensing experiments with its sensitivity of 500 mm / (kg mm), whose sensitivity is 800 times higher than fiber brag grating (FBG) [6]. Xu X et al. studied the transverse load characteristics of LPFG by use of the UV light to fabricate in the non-high birefringence fibers [7]. It was found that the loss peak of the transmission spectrum gradually increased with the increase of load [8].

2. Experiment platform of Grooved Fiber Grating

The experimental setup for the fabrication of a grooved fiber grating is shown in Fig. 1. First of all, a part of the fiber is placed in the high-frequency CO2 laser focal plane, but it need keeps the fiber axial level, and the two ends of the fiber need be fixed by the fixture (both ends of the fiber fixed by stretch straight), the under of which has the bracket of the adjustable height. At last, the other part of the fiber needs to put a light objects that is about 10g, so that it can keep a transverse axial stress when the fiber grating is writing.

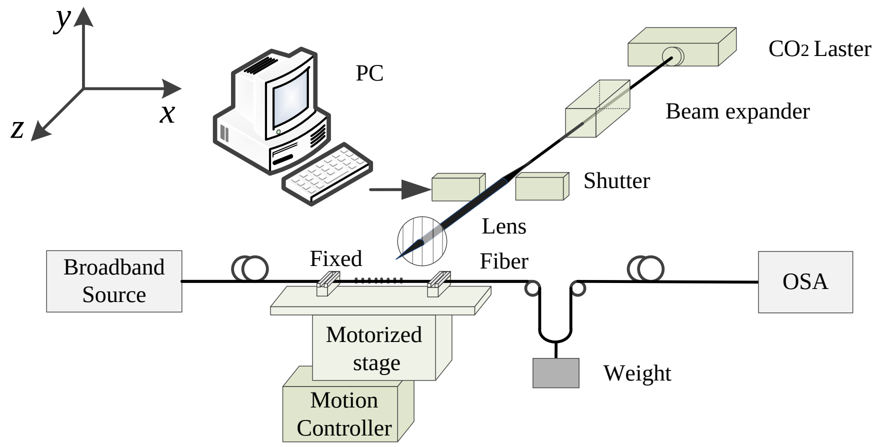


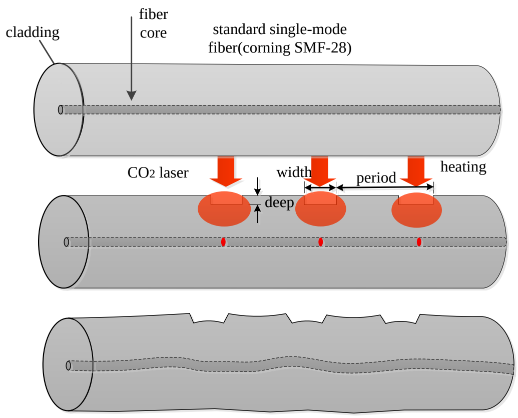
Fig. 1 Groove fiber grating experimental device diagram

This method can make writing efficiency improved. The computer controls the scanning galvanometer of the CO2 laser to scan the fiber. The beam of the output laser is first scanned in the X-axis direction on the fiber, and then the laser beam controlled by computer is scanned in the Y-axis direction of the grating period, and finally the laser repeats the above scanning operation until all the gratings number of cycles completed. So the fiber grating will be formed. In this paper, the depth of the grating groove is deeper than that of the past, and the groove structure and the micro-bending degree is deepened by the melt deformation, which will increase the refractive index of the optical fiber in period, and change the refractive index periodically to form the deep grooved fiber grating. The optical parameters used in this experiment are shown in Table 1.

Table 1. The main parameters of the fiber

Fiber	Core parameters	Cladding parameters	Mode radius	Numerical aperture
single mode fiber (G652)	Low doped germanium plus SiO2 (8.2um)	SiO2 added others(125um)	1550nm	0.14

The writing experiment of the fiber grating requires N times scanning process (N is the number of grating cycles), the above fabrication process of which needs scanning M times repeatedly (M is the number of cycles of the cycle scanning). Fig. 2 shows that a high temperature region is generated on the some areas of the optical fiber, making the surface SiO2 of the optical fiber occur gasification when the focused laser beam is scanned the fiber repeatedly. The SiO2 gasification of the fiber can cause the melting of the fiber region, forming the periodic grooved structure on the fiber. It can arouse the coupling of the multi-order cladding mode for the periodic grooved structure, making the transmission spectrum of the light changes. As shown in Fig. 2, the forming schematic diagram of the grooved fiber grating and photos are appeared as follows.



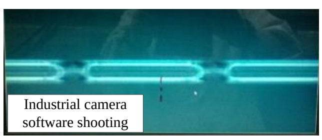


Fig. 2 (a) A schematic diagram of the grooved fiber forming (b) The microscope image

By the grating coupling model theory analysis， it can seen that the phase matching conditions can be written as:

$$\lambda_D^m = \left(n_{eff}^{co} - n_{eff}^{cl,m}\right)\Lambda \tag{1}$$

Where λ_D^m is the initial resonant wavelength of the optical fiber, Λ is the period, n_{eff}^{co} is the change of the fiber grating refractive index, and $n_{eff}^{cl,m}$ is the change in the refractive index of the primary cladding mode LP_{0m}. When a grooved fiber grating is written, the grating δn_{eff}^{co} and the $\delta n_{eff}^{cl,m}$ will increase, which makes the corresponding cladding mode coupling .the resonant wavelength λ_{res}^m can be written as:

$$\lambda_{res}^m = \lambda_D^m\left(1 + \frac{\delta n_{eff}^{co} - \delta n_{eff}^{cl,m}}{n_{eff}^{co} - n_{eff}^{cl,m}}\gamma^m\right) \tag{2}$$

In the above formula, when $\delta n_{eff}^{co} >> \delta n_{eff}^{cl,m}$, δn_{eff}^{co} can be ignored. The fiber waveguide dispersion factor γ^m is expressed as follows:

$$\gamma^m = \frac{\frac{d\lambda_D^m}{d\Lambda}}{n_{eff}^{co} - n_{eff}^{cl,m}} \tag{3}$$

3. Study on Transverse Load Characteristics of Groove Grating

3.1 Theoretical simulation analysis

Firstly, the cantilever beam is modeled by finite element analysis software (ANSYS). As shown in Fig. 3, the cantilever beam is set as 250mm×20mm×0.4mm and the starting load mass is 10mnm×30mm×4mm (about 20g). Secondly, according to the above theory, the stress concentration area of the cantilever beam is analyzed at the fixed end. When the load is placed at the end of the cantilever beam, the cantilever beam has a large degree of bending and energy. So it need be fixed for the one end of the cantilever beam to the specific fixed table and the other end of that need be applied a certain load, then the displacement and the stress distribution magnitude of the cantilever beam were analyzed under different load conditions. Finally, the data analysis is carried out on the modeling situation.

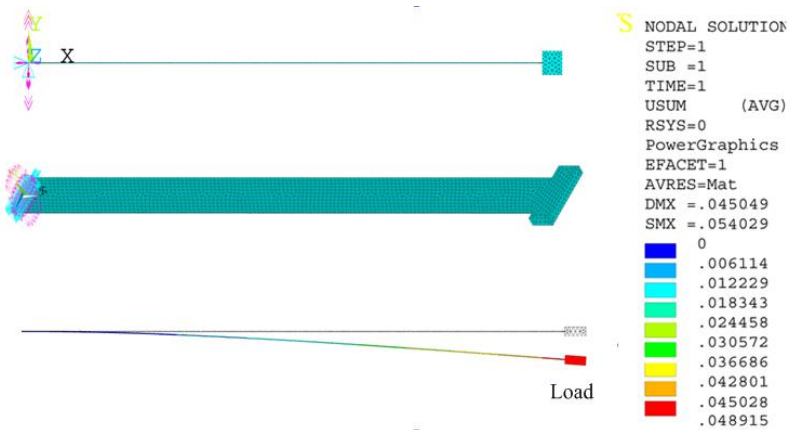


Fig.3 Simulation of Cantilever Beam Transverse Load Characteristics by ANSYS

Fig. 3 shows that the cantilever beam produces a certain displacement and bending when the cantilever beam is fixed at one end and the other end is subjected to a certain load. The color of the figure is the magnitude of the displacement and stress, where the red represents the maximum magnitude of the stress, and the Blue represents the minimum magnitude of stress.

The ANSYS analysis of the displacement and stress distributions of the cantilever beams is shown in Table 2 with different loads. According to the Table 2, it can be shown that the larger the displacement of the same position and the greater the stress with the load increasing.

Table 3.1 Simulation of experimental data of Cantilever beam bending

load(g)	0~20	20~40	40~60	60~80	80~100	100~120	120~160
Maximum displacement (um)	42.1	55.0	73.5	96.5	113.9	132.8	155.3
Maximum stress(MPa)	93.1	103.6	118	130.2	150.3	169.8	194
load(g)	0~20	20~40	40~60	60~80	80~100	100~120	120~160

3.2 Experimental apparatus and principle

The transverse load experimental platform of the grooved fiber grating is shown in Fig. 4, the input of which is the broadband light source and the output of which is the spectrum analyzer. The Spectrum Analyzer displays a spectral change curve and it stores the data in a computer. In the figure, the cantilever beam used the ordinary steel ruler, whose size is the 250mm × 20mm × 0.4mm, and the adhesive is selected epoxy resin optical glue. The grooved grating is placed in the middle of the cantilever beam, one end of which is fixed on the electric indexing plate by means of the fixture, and the other free end of which is placed a series of different loads. The bending of the cantilever beam is analyzed by the applied load, analyzing the deformation value of the grating. the transverse load is actually a strain force. In the experiment, it is necessary to paste the one end of the grooved grating sample at 100 mm of the steel bar. The grating should be placed in the paste place, and the grating should be given a certain axial stress. The other end of the grooved grating should paste in the steel ruler around 200mm. The experiment must ensure that the grating and the ruler are absolutely coincident. When the grating is given a certain load, it ensures that the steel bar is stable and uniform. the load usually needs to select the square magnetic block, and the magnetic block placed at the end of the cantilever beam, making the steel ruler greater bending degree.

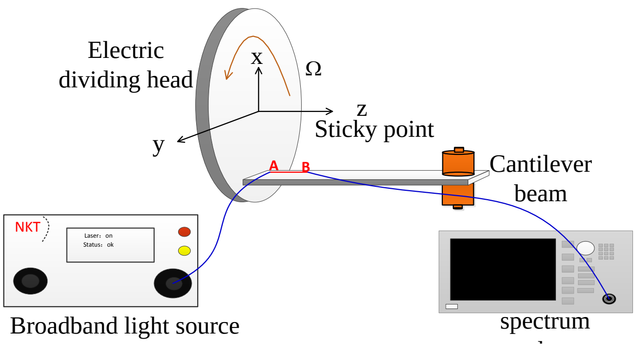


Fig. 4 Experimental device diagram of cantilever beam transverse load

3.3 Analysis of experimental results

In this experiment, the long-period fiber grating by use of the high-frequency CO_2 laser on the common single mode fiber to fabricate is selected. The period of the fiber Λ is 420nm, the period number N is 30, and the depth of the grooved fiber is the 5um. This experiment mainly changes the transmission spectrum characteristics of the fiber grating by changing the different axial loads. The total length of the cantilever beam is 250mm, the fixture width is 300mm, and the effective length of the grating node is 100 mm. The transmission spectrum is shown in Fig. 5. Under the same condition, the change of transmission spectrum was observed by changing the mass of the different load (0g, 20 g,40g, 60g, 80g, 100g, 120g, 140g, 160g, 180g). And ten sets of transverse load experiments were carried out. When the load gradually increased, the transverse three-dimensional dispersion curve of the grooved grating transmission spectrum is shown in the Fig. 5, the stereoscopic distribution of the squared image is shown in Fig. 5, the graph of the plane transmission spectrum of the groove type grating is shown in Fig. 5, and the resonant wavelength and the resonant peak curve shown in Fig. 6(a) through the fitting of the experimental data. where the sporadic point is the experimental data, the red curve and the blue curve are the fitting curve, and the curve of the resonance curve is shown in Fig. 6(b). After the resonant wavelength is fitted, the error between the data and the experimental data is 8%, and the resonant peak amplitude error is 6%. It can be seen that the resonant wavelength of the groove is gradually drifted to the short wave.

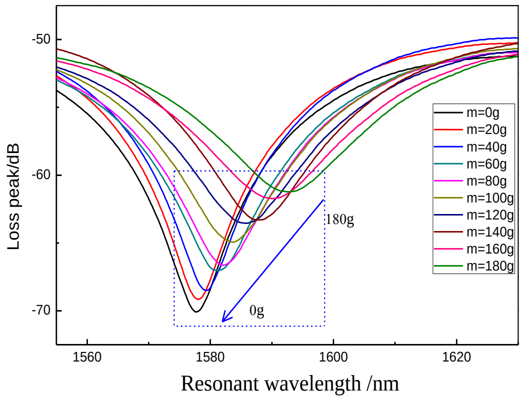
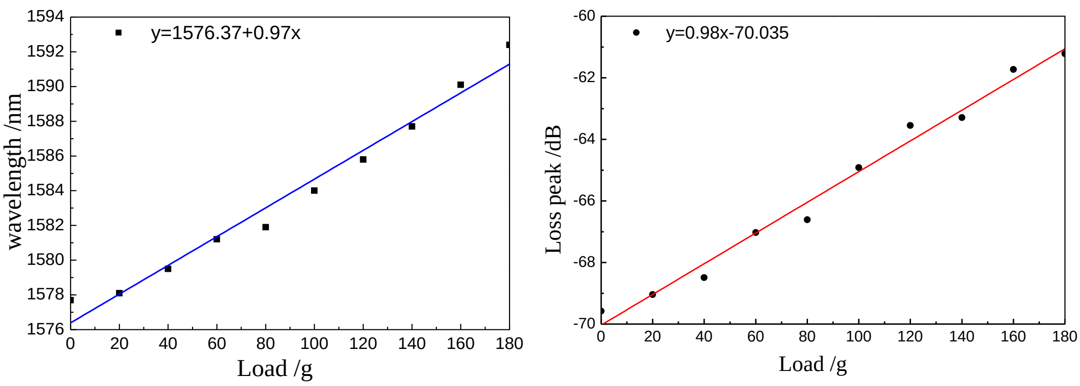


Fig. 5 Changes of Transmission Spectra with the load increases



(a) Resonance wavelength variation curve (b) The amplitude of the resonant peak varies

Fig. 6 The curve of grooved grating characteristic

4. Conclusion

With the increase of the mass load, the transmission spectrum of the grooved grating pattern will be changed greatly. the bandwidth of 3dB increases gradually, and the resonant wavelength and the amplitude of the resonant peak also change with the change of load. When the load increases from 0g to 180g, its resonant wavelength changes from 1591nm to 1557.2nm with the sensitivity of the resonant wavelength 0.187nm /g. The experiment result shows the variation of the resonant peak amplitude of grooved grating transmission increases linearly as the load increases. When the load increases from 0g to 180g, the resonant peak amplitude decreases from -63.48dB to -70.503dB,with the sensitivity of the loss peak0.039dB/g.

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