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Experimental Investigation of Bending Characteristics of Distributed Feed Back Fiber Lasers

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Abstract：The bending characteristics of distributed feed back fiber lasers were investigated. Firstly，a theoretical model of fiber lasers output wavelength and bending radius was presented. It shows a linear correlation between the output wavelength variation of fiber lasers and the inverse square of the bending radius，and as the bending radius increases，the Bragg wavelength experiences a blue shift. In corresponding experiments，3 fiber lasers were used to test output wavelength with bending radii between 10 mm and 90 mm；these experiments demonstrate the accuracy of the theoretical analysis. Secondly，fiber lasers output power and bending radius were studied. One fiber laser was used as reference to eliminate environmental interference. The experiment shows fluctuation ranges of fiber lasers output power are less than 2 dB during the experimental time in 32 days. Finally，the slope efficiency is investigated，showing excellent bending insensitivity. The results provide an important reference for DFB fiber lasers in applications of bending sensing.

Key words：Distributed feedback fiber lasers；Bending characteristics；Output wavelength；Output power；Slope efficiency

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0 Introduction

Distributed feed back (DFB) fiber lasers have been studied in recent years for their applications as sensing elements[1-3]. Their small sizes allow them to be embedded within the structure，showing potential in modern smart structure monitoring. Mechanical bending is an important parameter of fiber-optic devices used to diagnose structural health[4]. However，even in the bending applications，the bending characteristics of DFB fiber lasers are rarely mentioned in the literature. There have been many reports about fiber-optic bending sensing schemes such as the use of long period fiber gratings[5-6]，fiber Bragg gratings fabricated in multicore fibers[7-8]，optical fiber Michelson interferometer[9] and distributed Bragg reflector (DBR) fiber lasers with low polarization beat frequencies[10]. However，such fiber bending sensors are generally sensitive to temperature and may encounter problems in practical applications.

In this paper，we have studied the characteristics，such as output wavelength，output power and slope efficiency of DFB fiber lasers with different bending radii. The investigations of DFB fiber lasers are organized as follows. We firstly give theoretical analysis of the DFB fiber laser in the bending state，and then we present ours experimental results in studying the bending characteristics of DFB fiber lasers.

1 Theory

Output wavelength is one of the most important parameters for DFB fiber lasers. The DFB fiber laser uses doped fiber as the gain medium，a phase-shift grating as a resonator，and a semiconductor laser as the pump source to achieve lasing. Outside signals applied to the DFB fiber laser induce laser wavelength shifts.

$$\lambda=\lambda_B+\delta\lambda \tag{1}$$

The Bragg wavelength λ_B of a DFB fiber laser is given by

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

where Λ is the grating pitch, and n_{eff} is the effective refractive index of the fiber laser. The output wavelength of a DFB fiber laser changes in response to an applied strain ε by

$$\delta\lambda = \lambda_B(1-\rho_e)\varepsilon \qquad (3)$$

where ρ_e is the photoelastic coefficient of the fiber. Fig. 1 shows a sketch of a bending DFB fiber laser, where e is the distance between neutral axis and the central axis, D is the diameter of the fiber laser and R is the bending radius of the DFB fiber laser.

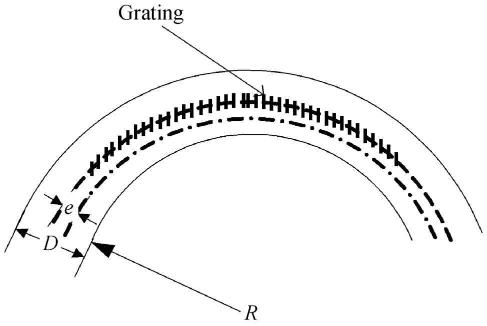


Fig. 1 Sketch of a bending DFB fiber laser

e can be expressed as[11]

$$e = \frac{1}{2}\left[R - \sqrt{R^2 - \frac{D^2}{4}}\right] \qquad (4)$$

ε can be expressed as[12]

$$\varepsilon = \frac{e}{R} \qquad (5)$$

Accordingly, we have

$$\varepsilon \approx \frac{D^2}{16R^2} \qquad (6)$$

$$\lambda = \lambda_B + \lambda_B(1-\rho_e)\frac{D^2}{16R^2} \qquad (7)$$

As strain ε is a function of the bending radius, the wavelength will be different with different bending radius as shown in Fig. 2. Table 1 is the parameters used in Fig. 2.

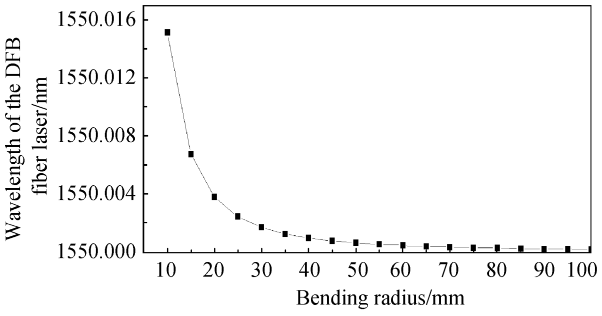


Fig. 2 The theoretical result of output wavelength vs different bending radius

Table 1 Parameters used in Fig. 2

Parameters	Value
D	125 μm
λ_B	1 550 nm
ρ_e	1 pm/μstain

From Fig. 2, we can see the output wavelength experiences a blue shift as the bending radius increases. The relationship between the output wavelength variation of the DFB fiber laser and the inverse square of its bending radius is linear. Thus, we can calculate the bending radii from the output wavelengths of lasers. The output power of DFB fiber lasers is also investigated versus the bending radii.

2 Experiment and result

2.1 Experimental setup

Fig. 3 shows our experimental setup used to investigate the spectrum characteristics of DFB fiber lasers. The DFB fiber laser is pumped by a 980 nm laser diode with an output power of 400 mW. The pump laser output is split by a 3 dB coupler (C): one part is monitored by an Optical Power Meter (OPM), and the other is used to pump the DFB fiber laser. A 980/1550 nm wavelength division multiplexer (WDM) is used to separate the returned output laser of the DFB fiber laser and the 980 nm pump laser. The DFB fiber laser output is monitored by an optical spectrum analyzer (OSA).

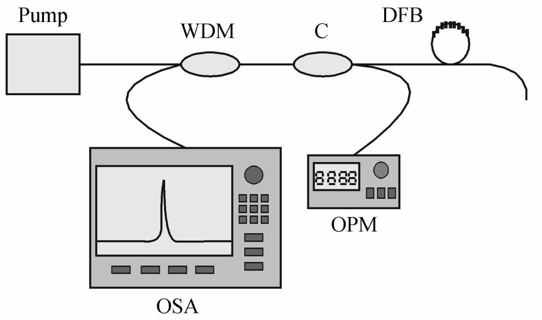
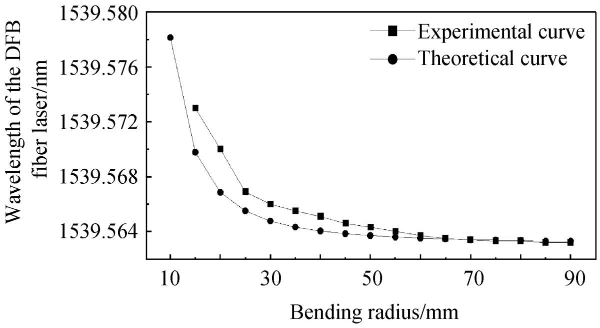


Fig. 3 Experimental setup

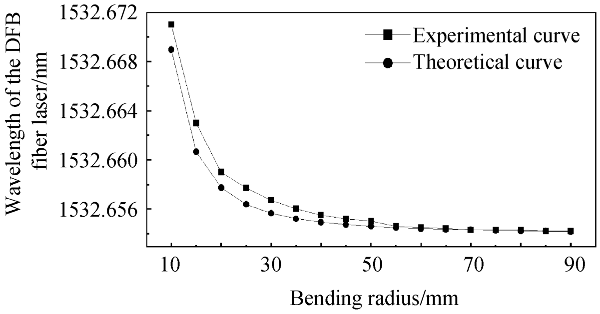
2.2 Output wavelength

In this experiment, the output wavelength with different bending radii is investigated. We choose three DFB fiber lasers numbered Laser 1, Laser 2 and Laser 3 with Bragg wavelengths of 1 539.561 nm, 1 532.654 nm and 1 530.291 nm respectively. The length of each DFB fiber laser's active region is 44 mm. Fig. 4 shows the output wavelength of the DFB fiber lasers when the bending radii of the three lasers are between 10mm and 90 mm.

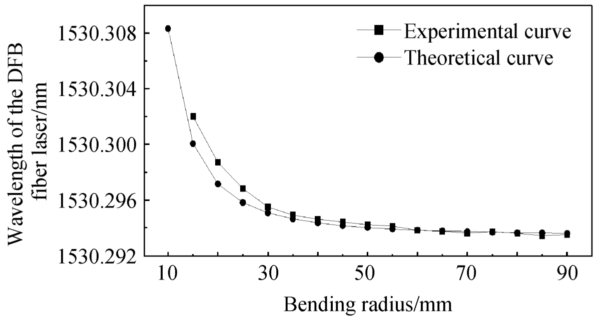
By inspecting Fig. 4, we can see that as DFB fiber lasers are subjected to bending radii, and as the bending radii increases, the output wavelengths experience a blue shift which is consistent with the theoretical curve. The smaller the bending radius is the bigger the variation in the output wavelength is. Therefore, DFB fiber lasers are suitable for detecting small radius bending. However, during the experiment, we found that more than half of bare DFB lasers will be broken when bending radii are smaller than 10 mm, such as Laser 1 and Laser 3. One way to solve this problem is to coat DFB fiber lasers with bending-resistant material such as metals.



(a) Laser 1



(b) Laser 2



(c) Laser 3

Fig. 4　The output wavelengths for different bending radii of Laser 1, Laser 2, Laser 3

2.3　Output power

In this experiment, we choose six DFB fiber lasers with a Bragg wavelength of ～1 550 nm, and each of them has a grating length of 40 mm. The six DFB fiber lasers are numbered from Laser 4 to Laser 9. Laser 4 is used as a reference object to test the effects of environmental conditions. Lasers 5 to 9 were wrapped around cylinders with the radii of 20mm, 25 mm, 30 mm, 35 mm, 40 mm respectively. We then used the same experimental conditions for the six lasers to test their changes in output power during a period of 32 days, from Apr. to May, 2010. Fig. 5 shows the output power of the reference DFB fiber laser. The output powers of Laser 5 to Laser 9 are subtract from the output power of the reference (Laser 4) to show the change in output power under the influence of bending. This is shown in Fig. 6.

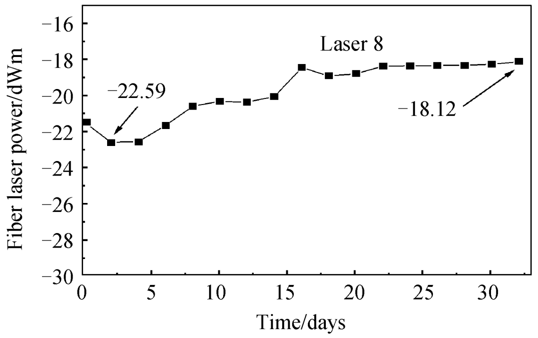


Fig. 5　The output power of the reference DFB fiber laser

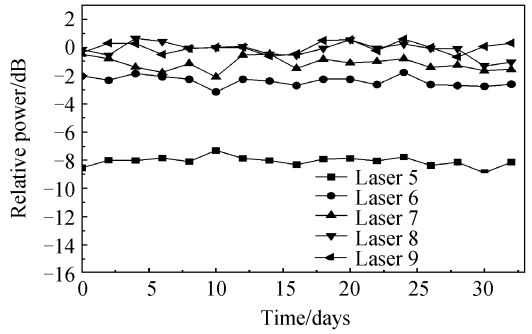


Fig. 6　The output power of DFB fiber lasers in bending state

From the Fig. 5, we can see that the output power of the reference Laser 4 shows an obviously upward trend over time and the maximum fluctuation range is 4.47 dB. The fluctuation is caused by the stress relaxation and the room temperature rising. From the Fig. 6, we can see that when we eliminate the effect of environmental conditions, the output power of other five lasers and the bending radii of the active regions are independent though the bending radii of the five DFB fiber laser are all different. The power fluctuation ranges over time of Laser 5 to Laser 9 are less than 2 dB as shown in Table 2.

Table 2　Min and max relative power of Laser 5 to Laser 9

Lasers	Min power/dB	Max power/dB
Laser 5	－8.894	－7.291
Laser 6	－3.156	－1.771
Laser 7	－2.093	－0.472
Laser 8	－0.146	0.638
Laser 9	－0.671	0.586

2.4　Slope efficiency

In this experiment, we chose four DFB fiber lasers with Bragg wavelengths of ～ 1550 nm numbered from Laser 10 to Laser 13. Each laser was wrapped around a cylinder with the radius of 20 mm, 40 mm and infinity (not bending). From the Fig. 7, we can see the slope efficiency of DFB fiber lasers is not affected by bending of the active regions. Thus the slope efficiency of DFB fiber lasers shows excellent bending insensitivity.

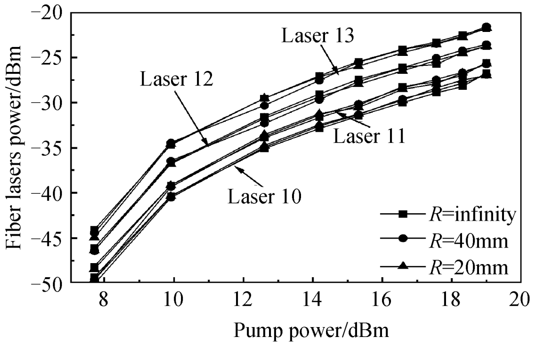


Fig. 7 Slope efficiency of DFB fiber lasers at different bending radii

3 Conclusion

In this paper, we have studied the bending characteristics of DFB fiber lasers, including output wavelengths, output power and slope efficiency. We have proposed a theoretical analysis of output wavelengths versus bending radii. The experiment shows that the output wavelength of a DFB fiber laser experiences a blue shift as the bending radius increases. The output power and the slope efficiency are immune to the bending state. The result provides an important reference for DFB fiber lasers in applications of using bend sensing.

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分布反馈光纤激光器弯曲特性的实验研究

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摘 要:为了研究分布反馈光纤激光器的弯曲特性,对光纤激光器输出波长和弯曲半径的关系进行了理论分析和实验研究.理论分析表明,光纤激光器输出波长变化量与弯曲半径平方的倒数为线性相关,并且随着弯曲半径的增大布拉格波长向短波长方向移动;实验中通过对3支不同波长的光纤激光器在弯曲半径分别为10 mm、20 mm、90 mm时输出波长的测量,验证了理论分析的正确性.实验中采用参考光纤激光器法排除环境干扰,对光纤激光器的激射功率进行了耐弯曲测试,并验证了光纤激光器斜率效率优越的抗弯曲特性.结果表明,在测试的32天内,待测光纤激光器激射功率变化量均小于2 dB,为分布反馈光纤激光器做为弯曲类传感应用的研究提供了重要的参考依据.

关键词:分布反馈光纤激光器;弯曲特性;输出波长;输出功率;斜率效率