Vol 14 No 5, May 2005
1009-1963/2005/14(05)/0991-04

Chinese Physics

© 2005 Chin. Phys. Soc.
and IOP Publishing Ltd

Output-power controllable erbium-doped fibre laser via a high-birefringence fibre loop mirror with applied stress*

Liu Yan-Ge(刘艳格)†, Feng Xin-Huan(冯新焕), Li Yao(李 尧),
Yuan Shu-Zhong(袁树忠), Zhang Wei-Gang(张伟刚),
Kai Gui-Yun(开桂云), and Dong Xiao-Yi(董孝义)

Institute of Modern Optics, Nankai University, Tianjin 300071, *China*

(Received 13 September 2004; revised manuscript received 14 January 2005)

In this paper, a novel output-power controllable erbium-doped fibre laser, based on a strain-applied high-birefringence fibre loop mirror (HBFLM), was proposed and demonstrated. The reflectivity of HBFLM could be changed from about 0.8% to 100% because the fibre length and birefringence of the high-birefringence fibre (HBF) were altered via bonding a part of HBF to the centric surface of an uniform-strength cantilever beam and applying different stress at end of the beam. As a result, the laser output power could be adjusted and controlled in a dynamic range of more than 33 dB. The laser is not only a controllable and adjustable output-power laser with simple configuration and low cost, but also can be used for optimizing the output characteristics of a linear cavity laser via easily finding out the optimized reflectivity of the reflectors.

Keywords: erbium-doped fibre laser, high-birefringence fibre loop mirror, applied stress
PACC: 4260, 4281, 4255N

1. Introduction

Erbium-doped fibre lasers (EDFLs) are useful sources in wavelength-division-multiplexed (WDM) fibre communication systems, fibre sensors, and optical instrument testing.[1−4] In many fields, especially in optical instrument testing applications, the requirements for controllable and adjustable output-power lasers are very rigorous. There are two methods considered to achieve the output-power controllable EDFL. Firstly, the most straightforward approach is to control the pump output power of the lasers via the pump driving circuit. But in this method, the gain spectral shape is also altered with the change of pump power, which may sometimes induce instable lasing. Secondly, an EDFL plus a variable optical attenuator can also realize the function. However, a lower cost and simpler laser configuration is desired. In addition, the output performance of a linear cavity laser is related intimately to the reflectivity of two cavity mirrors,[5,6] so one expect the optimized reflectivity of the mirrors to be easily found out for obtaining the optimal output performance.

In this paper, a novel EDFL configuration, based on a strain-applied high-birefringence fibre loop mirror (HBFLM), is proposed and successfully demonstrated. The laser is not only a controllable and adjustable output-power laser with simple configuration and low cost, but also can be used for optimizing the output characteristics of a linear cavity laser.

2. Experimental setup and operation principle

In Fig.1, the configuration of the proposed laser is shown schematically. The linear cavity laser consists of a fibre Bragg grating (FBG), a 1480nm/1550nm wavelength division multiplexing (WDM) coupler, a length of 5m of erbium-doped fibre (EDF) and a single-section HBFLM in which a strain is applied

*Project supported by the State Key Development Programme for Basic Research of China (Grant No 2003CB314906), the National High Technology Development Programme of China (Grant No 2003AA312100), the National Natural Science Foundation of China (Grant Nos 60137010 and 60407005), and the Tianjin Natural Science Foundation (Grant No 033800211).

†E-mail: ygliu@nankai.edu.cn

to the high-birefringence fibre (HBF) via an uniform-strength cantilever beam. Reflectivity of the FBG is more than 99% and is used for specifying the lasing wavelength. The EDF, with an Er^{3+} concentration of ~1600ppm, is pumped by a laser diode, with an output power of 132.6mW at 1480nm, through the WDM coupler. The HBFLM acts as a broadband reflector with a changeable reflectivity for signals, which is also used as the output coupler. Spectral characteristic is measured using an ADVANTEST Q8383 optical spectrum analyzer with a resolution of 0.1nm.

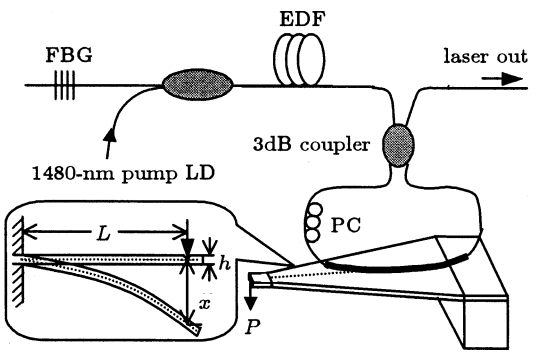


Fig.1. Schematic diagram of the proposed Laser.

The HBFLM consists of a fused taper coupler made up of standard single-mode fibre (SMF) and a section of HBF, in which the output ports of the component coupler and the HBF are connected to form a closed loop. The principle of the HBFLM with a changeable reflectivity is described as follows. An output light from EDF is divided into two counter-propagating beams by the coupler. After travelling through the birefringence fibre, their electric field vectors separate into a fast and a slow axis components. The counter-propagating beams recombine together at the coupler and show interference according to phase difference, which is proportional to the HBF length.[7,8] The reflectivity and transmissivity of the HBFLM can be written as

$$R = 1 - [\sin(\theta)\cos(\pi l B/\lambda)]^2, \tag{1}$$

$$T = [\sin(\theta)\cos(\pi l B/\lambda)]^2, \tag{2}$$

where θ is the angle between the fast and slow axes of the input and output planes. It can be controlled and adjusted by the inserted polarization controller (PC). $B = n_0 - n_e$, n_o and n_e are the refractive index of ordinary (o) and extraordinary (e) light, respectively. l is the length of the HBF and λ is wavelength.

If a part of the HBF, whose length is l_1 ($l_1 < l$), was bonded to the centric surface of the uniform-strength cantilever beam made of plexiglass as shown in Fig.1. The length and thickness of the beam are L and h, respectively. A stress P acted on the end of the beam and caused the beam bending. If the deflection at the end of the beam is x, which is far smaller than L, the strain ε at each point on the centric surface of the beam can be expressed as[9]

$$\varepsilon = \frac{h}{L^2}x. \tag{3}$$

The change of the fibre length induced by the strain is given by

$$\Delta l = l_1\varepsilon = \frac{l_1 h}{L^2}x = C_1 l_1 x, \tag{4}$$

where $C_1 = h/L^2$. On the other hand, due to the bending of the beam, the birefringence of the HBF is also altered by a value

$$\Delta B(\varepsilon(x)) = \Delta(n_e - n_o) = C_2 x, \tag{5}$$

where C_2 is a quantity being related to the geometric parameters of the beam and the intrinsic parameters of the HBF such as Poisson's ratio, photoelastic coefficient, outer diameter and stress-induced birefringence characteristics.

Additionally, if the angle θ is set to 90° via carefully adjusting the PC and considering the change of the fibre length and the birefringence of the HBF induced by the strain, Eqs.(1) and (2) can be expressed as

$$R = \left[\sin\left(\frac{\pi}{\lambda}[lB + (C_1 l_1 B + C_2 l)x + C_1 C_2 l_1 x^2]\right)\right]^2, \tag{6}$$

$$T = \left[\cos\left(\frac{\pi}{\lambda}[lB + (C_1 l_1 B + C_2 l)x + C_1 C_2 l_1 x^2]\right)\right]^2. \tag{7}$$

As can be seen from Eqs.(6) and (7), the reflectivity and transmissivity of the HBFLM at a specified wavelength λ are changed accordingly with the deflection x. Therefore, the output power of the laser can be adjusted and controlled by altering the deflection at the end of the beam.

3. Experimental results and discussions

In our experiment, h=3mm, L=112mm, the HBF is PANDA polarization maintaining fibre and its normal beat length is 3.1mm at wavelength 1550nm, the total length of the HBF used is about 127mm and the fibre length bonded to the beam is 57mm. Figure

2 shows the experimental data and the fourth-order polynomial data-fitting curve for the measured reflectivity at wavelength 1550nm of the HBFLM versus the deflection. As can be seen from the experimental data, the reflectivity could be continuously adjusted and controlled in the range from about 0.8% to 100% by tuning the deflection of the beam. The control precision of the reflectivity depends on the precision of the tuning device at the end of the beam.

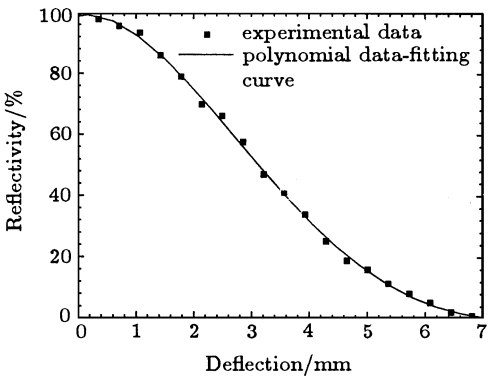


Fig.2. The measured reflectivity at λ=1550nm versus the deflection.

Figure 3 shows the optical spectra of the laser with different output powers when the deflection at the end of the beam is set to three different values. The output powers at λ=1553.46nm are −1.61dBm, -10.03dBm and −26.03dBm, respectively. Figure 4 shows the experimental data and sixth-order polynomial data-fitting curve of the measured laser output power versus the reflectivity of the HBFLM. The curve indicates that the laser output power changes nonlinearly with the reflectivity of the HBFLM. A maximum output power of 24.5mW has been obtained when the reflectivity of the HBFLM is 6.7%. The laser output power could be changed and controlled in the range from 0.01 to 24.5mW with a dynamic range of more than 33 dB.

The laser configuration can also be used to optimize the output performance of a linear cavity laser. When the reflectivity of one of the cavity mirrors, the gain fibre length and the pump power are fixed in a fibre laser, the optimal output power will be determined by the reflectivity of another cavity mirror. It is often difficult to find out the optimal reflectivity. The proposed laser configuration provides a convenient approach to find out the optimized reflectivity. By continuously tuning the deflection at the end of the uniform strength beam, the reflectively of HBFLM can be varied in the range from 0 to 100% and accordingly the maximum laser output power can be obtained.

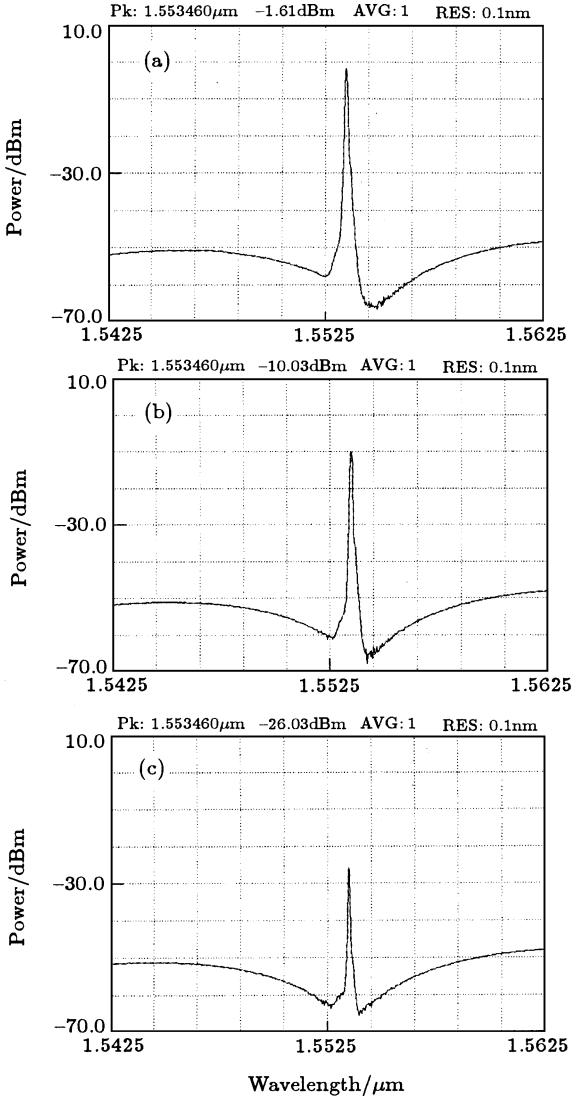


Fig.3. Output spectra of the laser with different output powers.

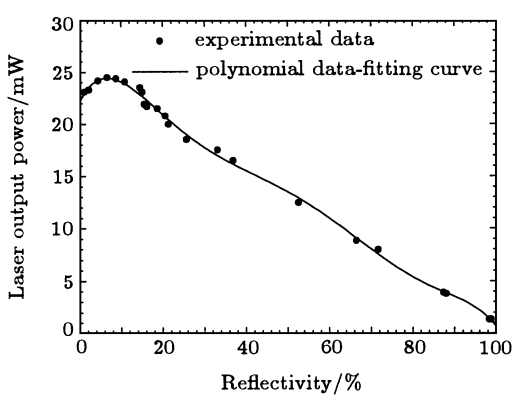


Fig.4. Output power of the laser versus the reflectivity of HBFLM.

4. Conclusion

In conclusion, a simple output-power controllable erbium-doped fibre laser has been developed. The laser is based on a strain-applied high-birefringence fibre loop mirror. The laser output power could be easily controlled and adjusted in a dynamic range of more than 33dB via continuously tuning the deflection at the end of a uniform-strength cantilever beam. This technique also provides a convenient approach to find out the optimized reflectivity of a fibre laser and has the advantages of simple configuration, low cost and easy operation.

References

[1] Zhang H, Yu L, Liu Y G, Liu L H, Yuan S Z and Dong X Y 2004 *Chin. Optics Lett.* **2** 9

[2] Liu Y G, Feng X H, Yuan S Z, Kai G Y and Dong X Y 2004 *Optics Express* **12** 2057

[3] Dong X Y, Zhao C L, Guan B O, Tan H Y, Yuan S Z, Kai G Y and Dong X Y 2002 *Acta Phys. Sin.* **51** 2750 (in Chinese)

[4] Lee Y W and Lee B 2003 *IEEE Photon. Technol. Lett.* **15** 795

[5] Sun J Q 1996 *Acta Phys. Sin.* **45** 1313 (in Chinese)

[6] Mignon M and Desurvire E 1992 *IEEE Photon. Technol. Lett.* **4** 850

[7] Li S, Chiang K S and Gambling W A 2001 *IEEE Photon. Technol. Lett.* **13** 942

[8] Chung S, Kim J, Yu B A and Lee B 2001 *IEEE Photon. Technol. Lett.* **13** 1343

[9] Zhang W G, Wu Z G, Liang L, Zhao Z L, Kai G Y, Liu Z G and Dong X Y 2001 *Proc. SPIE* **4579** 269