Wavelength-tunable erbium-doped fiber laser with FBG and HiBi fiber loop mirror as reflectors

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In this paper, a novel structure erbium-doped fiber laser with a linear cavity is demonstrated. The wavelength selective devices are a fiber Bragg grating (FBG) and a high birefringence (HiBi) fiber loop mirror. From 1543.8 to 1555.2 nm, 15 lasering wavelengths with side mode suppresion ratio (SMSR) > 54 dB and approximately 0.8-nm spacing have been obtained by using the comb-like reflection spectrum of fiber loop mirror and the intensity reaches about 2.5 dBm on an average. The reflectivity at different wavelengths can be tuned with different settings of polarization controller and the relative laser intensity can be controlled over a dynamic range of 13.5 dB.

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The numerous applications of tunable fiber laser in wavelength division multiplexing (WDM) system, spectroscopy, optical fiber sensors and optical component testing, have made it a subject of extensive studies[1]. With the development of fiber optic devices, various kinds of lasers based on fiber Bragg grating (FBG) have been designed[1−7]. Due to its excellent compatibility with transmission fiber, low insertion loss and precise wavelength selectivity, FBG has become the principal component to constitute cavity mirrors of all-fiber lasers. However the cavity reflectivity of conventional fiber lasers with FBGs cannot be changed. Both of the FBGs should have the same center wavelengths, otherwise unstable dual-wavelength oscillation induced by mode hopping may turn up, degrading the laser performance. With good performance, high birefringence (HiBi) fiber loop mirror has been applied as optical reflector[8] and WDM filter[9]. In this letter, by using a HiBi fiber loop mirror, whose reflectivity is a periodic function of the wavelength, a series of lasers with approximate 0.8 nm spacing are obtained. Furthermore, by adjusting the polarization controller, the reflectivity can be tuned continuously, thus the output laser power can be controlled. This novel laser has a simple structure and low cost; moreover its output laser power can be controlled more flexibly than conventional ones.

Figure 1 is the schematic diagram of our linear cavity erbium-doped fiber laser. A 980/1550 nm WDM is used as the wavelength combiner; a 980-nm laser diode (LD) with the maximum output power of 103 mW is used as the pump source. And a piece of about 9-m erbium-doped fiber (EDF) serves as the gain medium. Its absorption coefficient at 979 nm is 4 dB/m and cutoff wavelength is 942 nm. FBG is mounted and glued on an equivalent strength beam as the output mirror and the HiBi fiber loop mirror acts as the reflector on the other side of the cavity. By applying a strain with a high precision screw thruster on the free end of the beam, the grating length will be changed and the center wavelength of FBG can be tuned accordingly[10]. The HiBi fiber loop mirror is constructed by inserting a piece of high birefringence fiber between the two coupling arms of a 3-dB coupler.

The principle of HiBi fiber loop mirror can be described as follows. The input light from the EDF is divided into two counter-propagating beams by the coupler. After travelling through the birefringence fiber, their electric field vectors separate into the fast and slow axis components. Define the fast and slow axis of the HiBi fiber loop mirror as x and y axis, and suppose the electric field vectors of the beams travelling through the polarization controller from both directions will be rotated perpendicularly. The x component of the clockwise beam will become y-polarized after travelling through the polarization controller and it will propagate again into the 3-dB coupler after being transmitted by the slow axis of birefringence fiber. On the contrary, after being transmitted by the birefringence fiber, the x component of the counter-propagating beam will travel through the polarization controller and become y-polarized. Both of the beams will interfere when they recombine at the coupler. Meanwhile their individual y components will become x-polarized and interfere with each other when they travel into the coupler for the second time. Therefore,

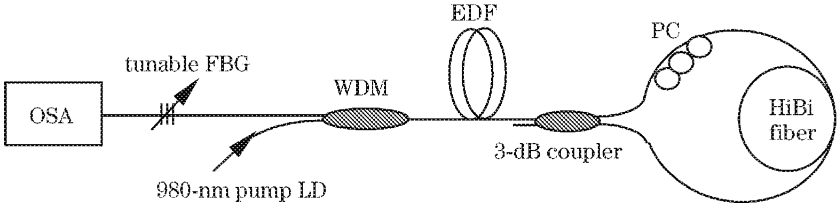

Fig. 1. Experimental setup of linear cavity erbium-doped fiber laser based on FBG and HiBi fiber loop mirror. OSA: optical spectrum analyzer; PC: polarization controller.

reflectivity of the fiber loop mirror can be described as[8]

$$R(\lambda) = 2K(1-K)[1+\cos\delta\phi(\lambda)], \qquad (1)$$

where $R(\lambda)$ is the reflectivity of the fiber loop mirror at a certain wavelength, and K is the coupling ratio of the coupler. $\delta\phi(\lambda)$ is the phase difference between the two x or y components, and it can be described as

$$\delta\phi(\lambda) = 2\pi\Delta nL/\lambda, \qquad (2)$$

where Δn is the refractive index difference between the fast and slow axes of birefringence fiber, and L is the length of birefringence fiber. When the polarization controller cannot produce a rotation of 90°, the beams travelling through it will only partially interfere, decreasing the contrast of the reflection spectrum. Thus by adjusting the polarization controller, it is convenient to control the reflectivity of the fiber loop mirror. From the above analysis, it is apparent that its reflection spectrum is a cosine function of the wavelength in a relative small wavelength range. So the birefringence fiber loop mirror can be utilized as the wavelength-selective device. Furthermore, based on Eq. (2), it is obvious that by changing the length of birefringence fiber, the wavelength spacing of the HiBi fiber loop mirror will be easily changed.

In this letter, we use FBG and HiBi fiber loop mirror as two wavelength-selective devices, well carrying forward their respective advantages.

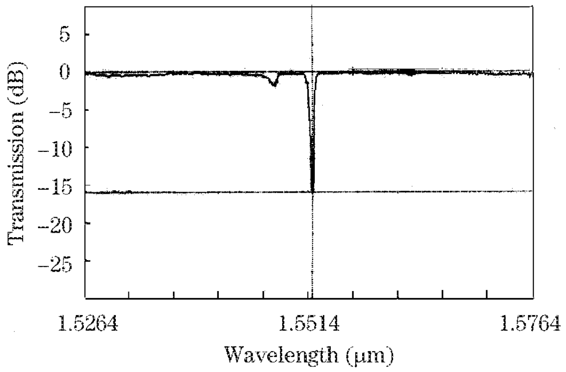

Fig. 2. Transmission characteristic of FBG1.

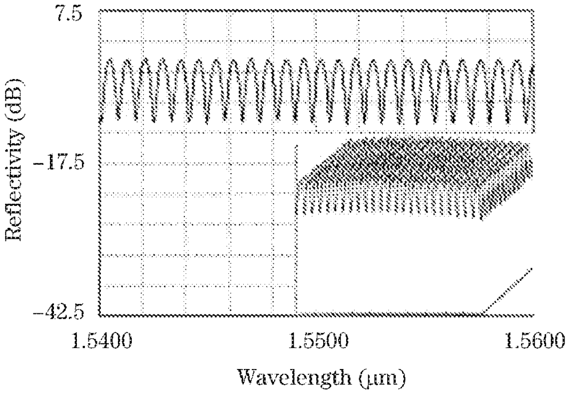

Fig. 3. Reflection spectrum of ~ 6-m HiBi fiber loop mirror. The inset represents 16 times repeated scans.

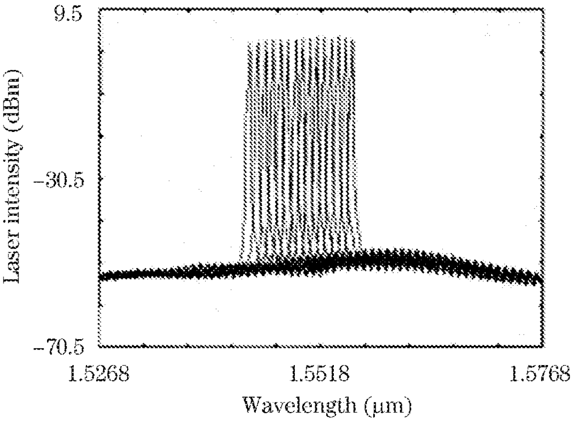

Fig. 4. Laser spectra of the EDFL with FBG and HiBi fiber loop mirror as the reflection mirrors.

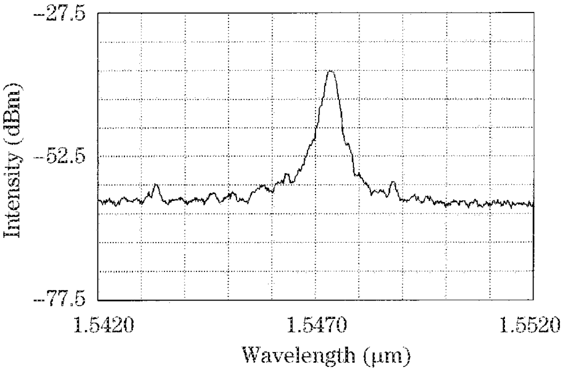

Fig. 5. Reflection spectrum of FBG2.

Figure 2 shows the transmission feature of the FBG1 used in our experiment. The center wavelength of the FBG with a linewidth of about 0.8 nm is around 1551.9 nm, and its reflectivity is about 97.5%. A piece of approximately 6-m birefringence fiber with beat length of about 3.1 mm at 1550 nm and Δn of 5×10^{-4} is used. The reflection spectrum of the HiBi fiber loop mirror is plotted in Fig. 3. The contrast of the reflection spectrum can be tuned to its highest value ~11 dB. According to Eqs. (1) and (2), the period of the reflection spectrum should be 0.8 nm, which conforms well with our experimental results. When FBG is used as the output mirror, the strongest laser should come forth when the convolution between the reflection spectra of FBG and fiber loop mirror is maximum. Figure 4 shows the output laser spectra with FBG and HiBi fiber loop mirror as reflectors. Within a range from 1543.8 to 1555.2 nm, lasering at 15 wavelengths with about 0.8-nm spacing has been achieved. The linewidth is less than 0.2 nm and the side mode suppression ratio (SMSR) is higher than 54 dB. It can be seen that the output laser intensity is about 2.5 dBm on an average. Some much weaker lasering, however, also appeared. We think that this phenomenon is caused by the relatively larger linewidth of the FBG and better discretely tunable lasers with narrower linewidth will be achieved by using a narrower line-width FBG or inserting an optical filter with narrower line-width inside the lasing cavity. The inset of Fig. 3 represents the repeated scans of reflection spectrum of ~ 6-m HiBi fiber loop mirror and the interval between every scan is 2 minutes. It is apparent that the fiber loop mirror has highly stable reflection performance.

We have also observed the variation of relative laser intensity by continuously tuning the reflectivity of fiber loop mirror for a certain wavelength. Figure 5 shows the reflection spectrum of FBG2 used in our experiment. The center wavelength of this FBG with a linewidth of about 0.28 nm is around 1547.36 nm, and its reflectivity is approximately 99%. A piece of ~ 18-m birefringence fiber with same parameters as above is used to construct the fiber loop mirror. Figure 6 is the measured reflection spectra of the fiber loop mirror with three different settings of polarization controller. The reflection spectrum (~ 0.24 nm) becomes denser with longer birefringence fiber. Obviously, by changing the length of birefringence fiber, the shape of its reflection spectrum can be varied conveniently. Figure 7 shows the relative laser intensity spectra with respect to a broadband reference light source by tuning the polarization controller. The laser intensity varies with the reflectivity of fiber loop mirror and it will become highest or lowest when the reflectivity of the fiber loop mirror is set to its maximum or minimum. From Fig. 7, we can see that the relative laser intensity varies beyond a range of 13.5 dB. Therefore it is effective to realize laser power control by using birefringence fiber loop mirror as the reflector.

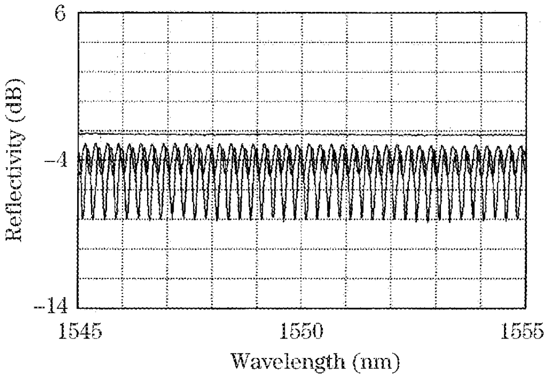

Fig. 6. The reflection spectra of HiBi fiber loop mirror with three different states of the polarization controller.

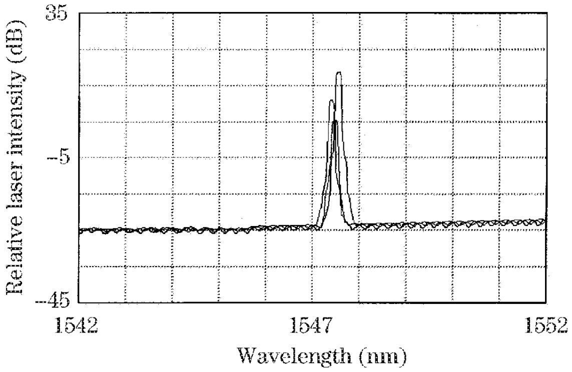

Fig. 7. The relative laser intensity spectra when tuning the polarization controller to three states.

In conclusion, a wavelength-tunable erbium-doped fiber laser with FBG and HiBi fiber loop mirror as reflectors is presented. A series of lasers with about 0.8-nm spacing have been achieved. The linewidth is less than 0.2 nm and the SMSR is higher than 54 dB. A dynamic range of over 13.5 dB of the relative output laser intensity has been realized by tuning the reflectivity of fiber loop mirror with polarization controller. The fiber laser with HiBi fiber loop mirror has many advantages such as simple structure, high flexibility, highly stable performance, low insertion loss and low cost, etc. And it is very useful for applications in the future optical communication systems.

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