Switchable dual-wavelength erbium-doped fiber laser based on polarization-maintaining fiber Sagnac loop mirror and fiber Bragg gratings

Ou Xu (许 鸥)[1*] and Suchun Feng (冯素春)[2]

[1] *Faculty of information engineering, Guangdong University of Technology, Guangzhou 510006, China*

[2] *Institute of Lightwave Technology, Key Lab of All Optical Network & Advanced Telecommunication Network of EMC, Beijing Jiaotong University, Beijing 100044, China*

[*] *Corresponding author: xuou@gdut.edu.cn*

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A switchable dual-wavelength erbium-doped fiber laser is proposed and experimentally demonstrated, which is constructed by a polarization-maintaining fiber Sagnac loop mirror (PMF-SLM) and two FBGs with different wavelengths. Wavelength switching operation is achieved by properly adjusting the polarization controller (PC) in the PMF-SLM. Stable single- or dual-wavelength lasing output can be realized. The maximum amplitude variation for every lasing wavelength is less than 1 dB, and the signal-to-amplified spontaneous emission (ASE) ratio is about 35 dB.

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Dynamic fiber-optics components, especially wavelength management and control devices such as switchable lasers, are in increasing demand in wavelength-division-multiplexing (WDM) fiber communication systems, fiber sensor applications, and optical instrument and system diagnostics. Wavelength-switchable fiber lasers are cost-effective and flexible sources. A wide variety of switchable technologies have been developed to meet various needs with fiber Bragg grating (FBG) devices, such as cascaded FBG cavities[1], highly birefringent operation[2], acoustooptic superlattice modulators[3], multiple π–phase shifts along a uniform FBG[4], introducing a spectral polarization dependent loss (PDL) element[5].

In this letter, we propose a wavelength-switchable erbium-doped fiber laser composed of a polarization-maintaining fiber Sagnac loop mirror (PMF-SLM) and two FBGs of different wavelengths. By adjusting the polarization controller (PC) in the PMF-SLM, the experimental results show that the laser can be made to emit simultaneous dual-wavelength or switch between the two wavelengths, with about 1.3-nm spacing. And the separation between switching wavelengths of the proposed fiber laser can be smaller or larger by properly choosing the characteristics of PMF and the corresponding Bragg wavelengths of the FBGs. The laser offers an optical signal-to-ASE ratio of about 35 dB, an output power uniformity for dual-wavelength operation was measured less than 1 dB, and the amplitude variation of both laser lines less than 1 dB.

The configuration of the proposed laser is shown schematically in Fig. 1. A polarization-maintaining fiber Sagnac loop mirror (PMF-SLM) and two FBGs form the linear cavity of the fiber laser. Up to 120 mW of pump power at 980 nm is coupled into the laser, and the signal coupled out, via a 980/1 550-nm wavelength-division multiplexer (WDM). The gain is provided by a 2-m home-made EDF with an absorption coefficient of 16 dB/m at 1 530 nm.

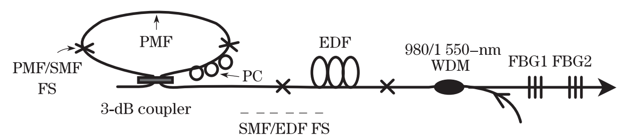

Fig. 1. Schematic diagram of the proposed laser. FS: fusion splice.

The PMF-SLM is constructed by incorporating a piece of high birefringence fiber between the two coupling arms of the 3-dB coupler. The operation principles of PMF-SLM have been in detail described in many articles[6−8]. By choosing PMF lengths, birefringence parameter, and controlling the polarization states of the launched optical field, different reflection profiles of the PMF-SLM can be designed. In the experiments, one PC and a 5-m long PMF with the beat-length of 4.21-mm are used in the fiber loop mirror. Figure 2(a) shows the measured typical reflection spectra of the PMF-SLM. The wavelength spacing of the peaks is found to be about 2 nm, and the peak-to-notch contrast of the spectrum is larger than 22 dB. By properly adjusting the PC, different peak-to-notch contrasts in the reflection spectrum can be achieved, and spectrum shift on the whole can also be realized. Figure 2(b) shows repeated scans of the reflection spectrum for half an hour with scan interval of 2 min under ordinary laboratory conditions without any temperature stabilization. It is clear that no significant change appears in the whole scan process. Thus, the PMF-SLM here is more stable than the unbalanced Mach-Zehnder interferometer (MZI), which is very sensitive to environmental changes. This is because in the PMF-SLM, the two optical paths that induce the interference are in the same fiber rather than two different fiber arms of MZI. Hence the effect of environmental changes is reduced.

Two FBGs of the same length about 4 cm written in a hydrogen loaded SMF were fabricated through the phase mask scanning method using KrF excimer laser. The central wavelengths of the FBG1 and FBG2 are 1 543.61, 1 544.91 nm, with a 3-dB bandwidth of 0.06, 0.062 nm, and 95.5%, 96% reflectivity, respectively. The transmission spectrum of the FBGs is shown in Fig. 3.

Firstly, by appropriately adjusting the states of the PC in PMF-SLM, switchable single-wavelength lasing operation can be easily obtained. Two separate single-wavelength lasing lines at 1 543.61 and 1 544.91 nm, with corresponding output power of −8.7 and −12.1 dBm, respectively, are illustrated in Figs. 4(a) and (b). In these situations, the pump power works at about 100 mW. Figures 4(c) and (d) show the 16 times repeated scan of the single-wavelength lasing at these two wavelengths with a 5-s interval. The maximum power fluctuation of the lasing lines is less than 0.5 dB. By monitoring the

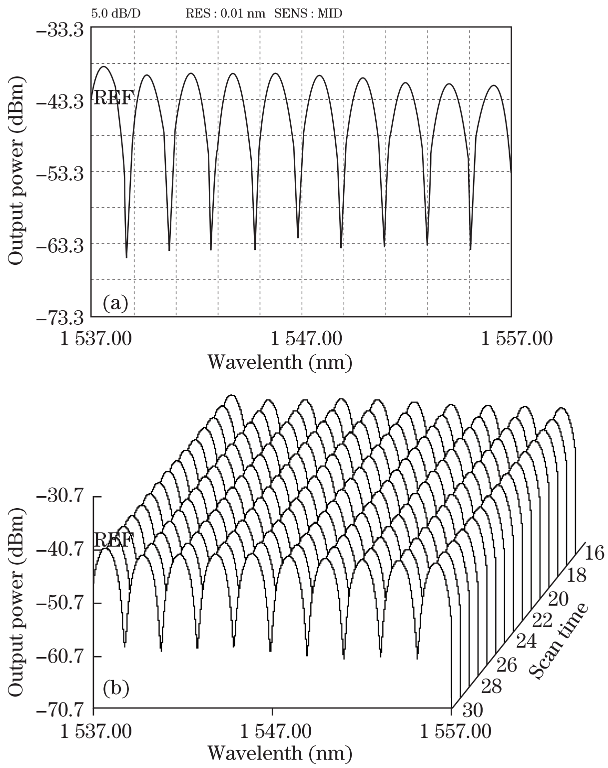

Fig. 2. (a) Reflection spectrum of the PMF-SLM in dB scale. (b) Repeated scans of the reflection spectrum for half an hour.

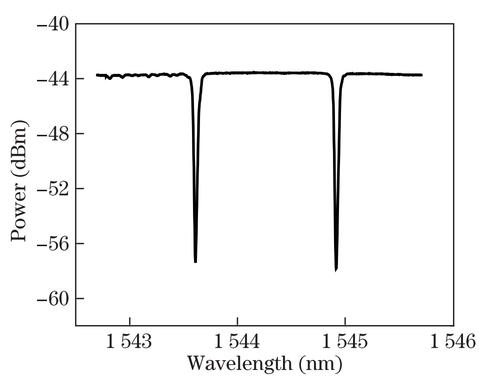

Fig. 3. Transmission spectrum of the FBG.

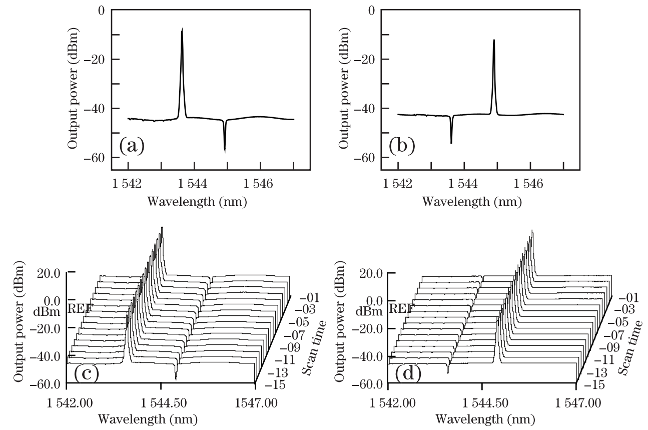

Fig. 4. Single-wavelength lasing operation of the proposed fiber laser: (a) lasing line at 1 543.61 nm, (b) lasing line at 1 44.91 nm, (c) the stability of lasing line at 1 543.61 nm, (d) the stability of lasing line at 1 544.91 nm (16 times repeated scans)

laser spectra over about 10 min, the results indicate stable operations of the single-wavelength lasing.

The mechanism of realizing the switchable single-wavelength lasing operations is based on the proper control of the cavity losses experienced by the two wavelengths, through adjusting the PC. Figure 5 presents the reflection spectrum of the PMF-SLM (dotted lines) and corresponding lasing operation (solid lines). Since the reflection spectrum is a periodic cosine function of wavelength, the PMF- SLM has a comb like filer characteristic. In the Fig. 5(a), the Bragg wavelength of the FBG2 just falls into the dip region of the PMF-SLM, while the Bragg wavelength of FBG1 lies in the peak region. Therefore, the light with the Bragg wavelength of FBG2 cannot oscillate due to the more cavity loss, while that of FBG1 can. By adjusting the PC in PMF-SLM, its reflection spectrum shifts towards long wavelength region about half of the period, i.e. 1 nm. Since the spacing between Bragg wavelengths of FBG1 and FBG2 is about 1.3 nm, the Bragg wavelength of FBG2 can oscillate, but FBG1 cannot, as shown in Fig. 5(b). It is expected that the larger separation between switching wavelengths can be obtained as long as the Bragg wavelengths of the FBGs are varied and the spacing between two Bragg wavelengths is about the odd times of half period of the PMF-SLM. Furthermore, if the length or birefringence parameter of the PMF is changed, the separation between switching wavelengths can be made even smaller than 1.3 nm, by choosing the corresponding FBGs.

Additionally, the stable dual-wavelength laser can also be achieved by carefully adjusting the PC. Figure 6(a) shows two lasing lines at 1 543.61 and 1 544.91 nm, respectively, with corresponding output powers of −12.34 and −13.20 dBm. The wavelength separation is about 1.3 nm. To study the stability, the dual-wavelength lasing were monitored in about 20 min, and stable operation can be found. As shown in Fig. 6(b), the wavelengths remain stable, and the output power stability at each lasing line is within 1 dB. In all, no significant drifts in the wavelengths and the amplitudes are detected, indicating that the dual-wavelength operation of the laser is stable.

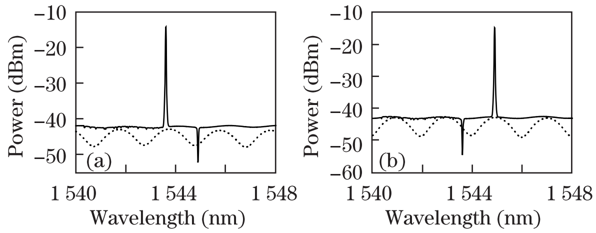

Fig. 5. The reflection spectrum of the PMF-SLM (dotted line) and corresponding lasing operation (solid line).

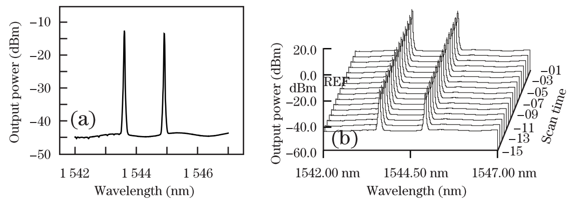

Fig. 6. (a) Dual-wavelength lasing operation of the proposed fiber laser and (b) stability of dual-wavelength lasing operation (16 times repeated scans).

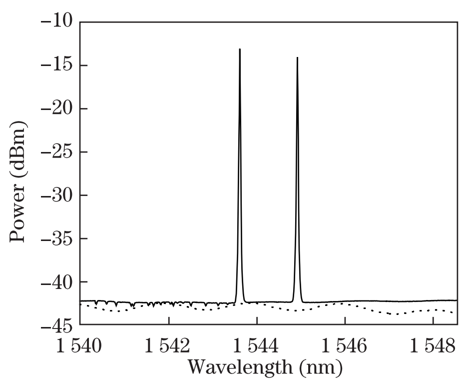

Fig. 7. Reflection spectrum of the PMF-SLM (dotted line) and corresponding lasing operation (solid line).

When operating at the stable dual-wavelength lasing condition, Fig. 7 presents the reflection spectrum of the PMF-SLM (dotted line) and corresponding lasing operation (solid line). It is obvious that, by adjusting the PC, the peak-to-notch contrast of the PMF-SLM reflection spectrum is greatly reduced. Thus, the gain obtained from the EDF can be made compensate the cavity loss for both Bragg wavelengths of the FBGs. When the spatial interference pattern is generated by the counter-propagation optical fields, absorption coefficient with periodic variation which leads to spatial hole burning is formed. So, the dual-wavelength oscillation is operated steadily.

In conclusion, we demonstrate that single- or dual-wavelength laser output is obtained by the proposed fiber laser, which consists of a PMF-SLM and two FBGs. Wavelength-switching operation is accomplished by appropriately adjusting the PC in the PMF-SLM. The amplitude variation of laser lines in both single and dual operation is measured to be less than 1 dB, and signal-to-ASE ratio is about 35 dB.

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