A switchable dual-wavelength erbium-doped fiber laser based on Sagnac loop inserted with two FBGs*

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A novel switchable dual-wavelength erbium-doped fiber (EDF) laser is demonstrated. The wavelength selection element consists of two fiber Bragg gratings (FBGs), a polarization controller (PC) and a 3 dB coupler forming a Sagnac loop inserted with two FBGs. We study the effect of coupling ratio on filtering performance in this paper. By adjusting PC, we can change the wavelength-dependent loss, and then using nonlinear polarization rotation effect to suppress the mode competition caused by the homogeneous broadening of EDF, we obtain single- and double-wavelength laser outputs. At room temperature, under 200 mW pump power, dual-wavelength laser is achieved, and the center wavelengths are 1545.34 nm and 1548.20 nm, respectively. The peak power values are –13.36 dBm and –14.58 dBm, and side mode suppression ratios (SMSRs) are 41.10 dB and 39.88 dB, respectively. Within two hours, the maximum fluctuation of peak power is less than 0.7 dB, which shows that the demonstrated fiber laser is stable. Moreover, by adjusting PC, singel-wavelength laser output is obtained, the peak power is –6.27 dBm or –5.45 dBm, and SMSR is 40.03 dB or 39.96 dB at 1545.34 nm or 1548.20 nm, respectively.
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Tunable erbium-doped fiber (EDF) lasers[1-4] with high output power, low-intensity noise and easy compatibility with communication fiber optic devices are widely used in wavelength division multiplexing (WDM) systems, fiber optic sensing, spectroscopy and optical device detection. Various wavelength tuning stability programs have been proposed, including Fabry-Perot (FP) interferometer[5], Mach-Zehnder (MZ) interferometer[6], Lyot filter[7], tunable fiber Bragg gratings (TFBGs)[8] and other wavelength tuning devices. Fiber Bragg grating (FBG), which has good wavelength selectivity, fiber compatibility and easy tuning, is widely used as filter selection element to design wavelength tunable fiber laser and overcome the shortcomings of low coupling efficiency of the non-fiber device and optical fiber, greatly reducing the laser threshold[9,10].

2011, He Xiaoying designed a tunable dual-wavelength single-longitudinal-mode fiber laser based on fiber Bragg grating Sagnac interferometer, and the laser obtained tunable dual-wavelength laser output with the wavelength interval in the range of 0.08–0.11 nm, but it has more stringent requirement for the Sagnac FBG ring arm length difference, which is difficult to achieve in general laboratories[11]. Compared with it, the required arm length difference of the structure in this paper is large enough, which is easy to achieve. 2013, Feng Sujuan achieved a tunable laser output with wavelength range of 30 nm by using a composite cavity and a tunable FBG with wide range, but this tunable FBG is difficult to prepare[12]. Then, the elements in this paper are simple, and we achieve switchable single- and double-wavelength lasers. 2013, Dae Seung Moon used four-wave mixing of the dispersion-shifted fiber to obtain stable single- and double-wavelength lasers, but it generated larger intensity of two side modes caused by the four-wave mixing[13].

In this paper, we insert two FBGs in the Sagnac loop without a variable optical attenuator or the circulator. We can control the gain and loss of the cavity by adjusting the polarization controller (PC) in the Sagnac loop, and use nonlinear polarization rotation to effectively suppress the mode competition and solve the problem of greater intensity of side modes. Finally the single- and double-wavelength laser outputs can be achieved.

The experimental structure of the switchable dual-wavelength EDF laser based on Sagnac loop inserted with two FBGs is shown in Fig.1. 7 m-long EDF is the gain medium, and it is pumped by a 980 nm laser diode (LD) through a 980/1550 nm wavelength division multiplexer (WDM). The isolator (ISO) ensures unidirectional operation of the laser cavity. The Sagnac loop inserted with two FBGs and PC1 acts as a frequency-selective element. The center wavelengths of FBGs are 1545.34

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nm and 1548.20 nm, and the 3 dB bandwidths are 0.216 nm and 0.23 nm, respectively. PC2, polarizer, PC3 and ordinary single-mode fiber construct the structure for nonlinear polarization rotation, which can stabilize the dual-wavelength output. 10% of the final port via the coupler is output to the optical spectrum analyzer (OSA), and the rest is fed back into the laser cavity.

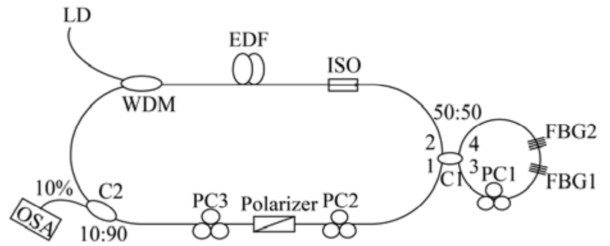


Fig.1 Schematic diagram of setup of the proposed EDF laser

The schematic diagram of the fiber Sagnac interferometer inserted with FBGs (FBG-FSI) is shown in Fig.2. Compared with traditional series-parallel structures of two FBGs, we use a cheaper 3 dB coupler instead of the circulator, and we can achieve switchable single- and double-wavelength lasers by using only one PC in the Sagnac loop. FBG-FSI acts as a band-pass filter, whose transmission spectrum is the same as the reflection spectra of two FBGs. The incident light enters the coupler through port 1, and via the coupler splits into two beams through ports 3 and 4. Those matching with the center wavelengths of FBGs can be reflected again and output through the coupler. Similar to Mach-Zehnder interferometer, the period of the interference peaks within the passband of the FBGs[14] is

$$\Delta\lambda = \frac{\lambda^2}{n_{\text{eff}}\Delta L_{12}}, \quad (1)$$

where λ is the working wavelength, n_{eff} is the effective refractive index of single-mode fiber, and ΔL_{12} is the difference between L_1 and L_2. From Eq.(1) we can see that the interval between two interference peaks is smaller when ΔL_{12} is greater. When ΔL_{12} is large enough, the wavelength interval will be much smaller than the minimum resolution of the OSA. The interference peaks can not be observed from the OSA, so the FBG-FSI is similar to a band-pass filter. In addition, by adjusting PC1, the transmittance of the light can be controlled. It can change the gain and loss of the cavity to achieve switchable single- and double-wavelength outputs.

In order to design a filter with better filtering performance, we study the effect of different coupling ratios on transmission characteristics of the filter. Fig.3 shows the transmission spectra when the coupling ratios are 0.2, 0.3 and 0.5, respectively. It shows that when the coupling ratio is 0.5, the filtering performance is better, and the extinction ratio is much larger than that with coupling ratios of 0.2 and 0.3. Therefore, we use the coupler with coupling ratio of 0.5 to construct the filter system, and the wavelengths of transmission peaks are 1545.34 nm and 1548.20 nm, respectively.

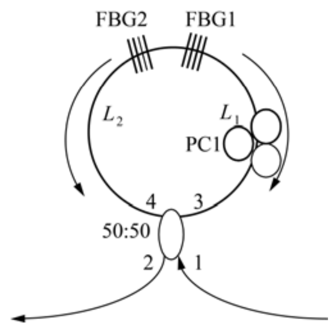


Fig.2 Schematic diagram of the FBG-FSI

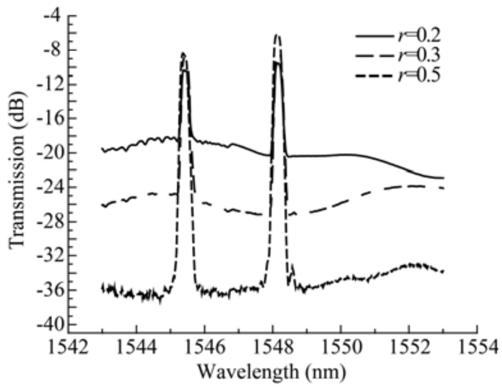


Fig.3 Transmission spectra of FBG-FSI with different coupling ratios

Meanwhile, in order to easily obtain the stable dual-wavelength laser output, the main cavity is used in the structure for nonlinear polarization rotation[15]. The intensity-dependent loss is used to suppress the homogeneous broadening of EDF more effectively.

At room temperature, under 200 mW pump power and by adjusting PC1, we obtain dual-wavelength laser whose peak power is a little stable and uniform. Then, slowly adjust PC2 and PC3 to obtain the stable dual-wavelength laser. Its output spectrum is shown in Fig.4. The center wavelengths are 1545.34 nm and 1548.20 nm, respectively. Peak power

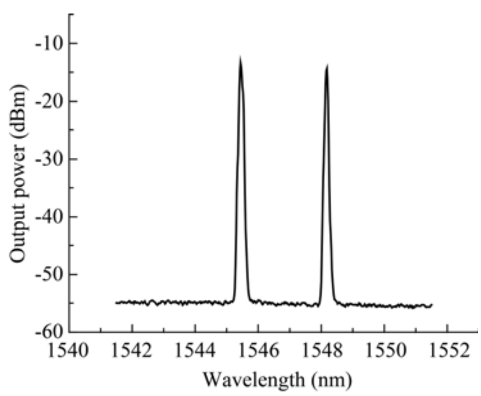


Fig.4 Output spectrum of the dual-wavelength EDF laser

values are –13.36 dBm and –14.58 dBm, and side mode suppression ratios (SMSRs) are 41.10 dB and 39.88 dB, respectively. Keeping the pump power stable, we study the stability of peak power of the output wavelength. As shown in Fig.5, in 2 h, we observe the laser output every 20 min, and the experimental data show that the dual-wavelength peak power fluctuation is less than 0.7 dB, which means the structure of the EDF laser can be stable at room temperature.

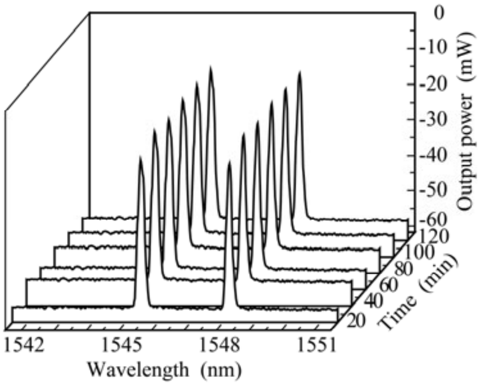


Fig.5 The dual-wavelength laser output spectrum every 20 min in 2 h

Then readjust the pump power. When the pump power reaches 18 mW, the dual-wavelength laser starts to lase. As shown in Fig.6, when the pump power reaches 125 mW, the laser peak power increases relatively slowly with the increase of the pump power, which is due to the gain effect of gain medium tends to be saturation with the light intensity's enhancement.

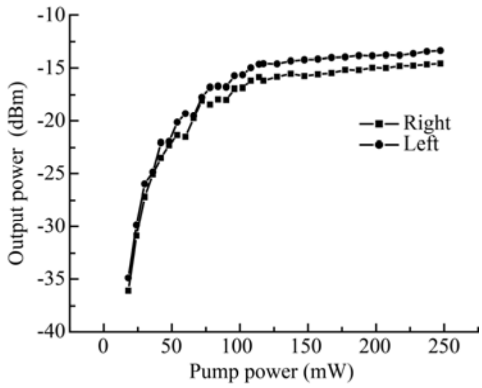


Fig.6 Variation of output power of the dual-wavelength laser

In addition, we also obtain the single-wavelength laser. By adjusting PC1 in the Sagnac loop, we obtain single-wavelength lasers at wavelengths 1545.34 nm and 1548.20 nm, whose spectra are shown in Fig.7. The peak power at 1545.34 nm of the laser is –5.45 dBm, and SMSR is 39.96 dB. While the peak power at 1548.20 nm is –6.27 dBm, and SMSR is 40.03 dB. We also plot the variations of output power of the single-wavelength lasers at 1545.34 nm and 1548.20 nm, which are shown in Fig.8.

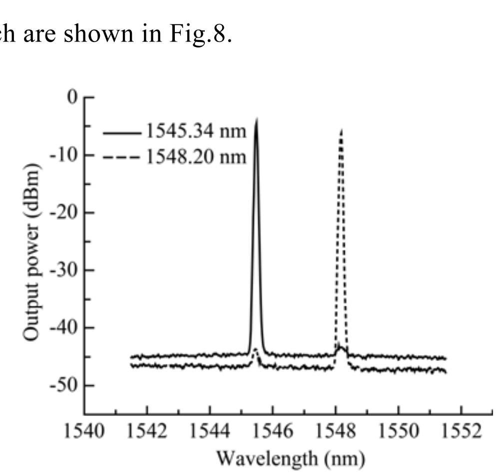
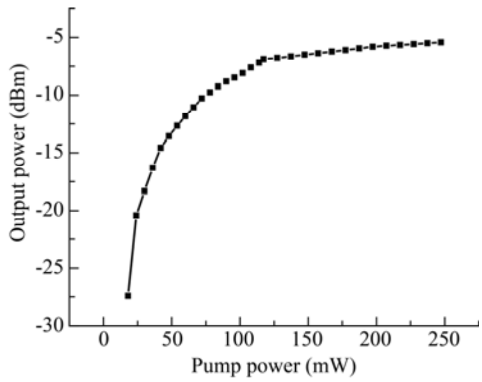
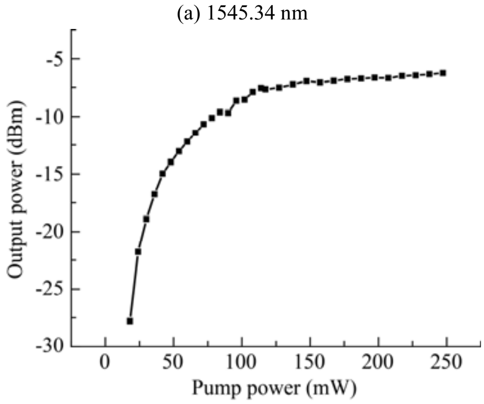


Fig.7 Output spectra of the single-wavelength lasers



(a) 1545.34 nm



(b) 1548.20 nm

Fig.8 Variations of output power of single-wavelength lasers at 1545.34 nm and 1548.20 nm

This paper proposes a switchable dual-wavelength EDF laser based on Sagnac loop inserted with two FBGs. A 3 dB coupler, a PC and two FBGs constitute a band-pass filter. By adjusting the PC in the Sagnac loop, we achieve switchable single- and double-wavelength laser outputs. We also study the effect of different coupling ratios on transmission characteristics of the filter to optimize filter system. We take advantage of nonlinear polarization rotation to suppress mode competition and obtain stable dual-wavelength laser at room temperature. Compared with the conventional structures, this structure removes the circulator, which reduces the cost. And it can control the gain and loss of each wavelength without a variable optical attenuator.

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