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Wavelength-Selection Erbium Fiber Laser with Single-Mode Operation Using Simple Ring Design[1]

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Abstract—In this demonstration, we propose and experimentally investigate a wavelength-selection erbium-doped fiber (EDF) laser in single-longitudinal-mode (SLM) by using simple fiber ring scheme design. We use a tunable bandpass filter (TBF) inside the gain cavity to restrict the lasing frequency. The proposed ring cavities can also serve as the mode filters for side mode suppression. Based on the simple ring cavity design, the mode hopping can be avoided to achieve SLM output. The TBF inside the laser scheme also obtains the wavelength tuning in the range of 1520.02 to 1562.02 nm. In addition, the output performance of the proposed fiber laser has also been discussed.

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1. INTRODUCTION

Nowadays, the tunable wavelength-selectable fiber ring lasers have been proposed and investigated [1–6]. Hence, the fiber lasers have attracted much interest for the applications of wavelength division multiplexed (WDM) communications, optical fiber sensor, instrument testing, microwave photonic systems and so on. However, the fiber ring laser would result in multimode output due to the mode hopping, longer cavity length and very narrow longitudinal mode-spacing [7]. Furthermore, the optical filter and ring scheme design are used in the laser cavity to obtain the single-longitudinal-mode (SLM) output, such as using fiber Bragg grating (FBG), Fabry–Perot etalon filter, or fiber ring scheme filter, etc. [8–13]. Moreover, the SLM fiber laser using a short length of unpumped erbium-doped fiber (EDF) to act as a saturable-absorber filter has also been studied to overcome the limited spectral width of the mode selection filters inside the gain cavity [10, 12, 13].

In this letter, we propose and experimentally investigate a wavelength-selectable EDF ring laser by using simple two-ring design to guarantee a SLM lasing in the tuning range between 1520.02 and 1562.02 nm. The use of a tunable bandpass filter (TBF) and a simple ring scheme obtain a SLM output. In addition, the characteristics of output power, wavelength, side-mode suppression ratio (SMSR) and RF spectrum are performed and analyzed.

[1] The article is published in the original.

2. EXPERIMENTS AND RESULTS

Figure 1a presents the experimental setup of proposed wavelength-tunable EDF ring laser scheme. The laser is consisted of an erbium-doped fiber amplifier (EDFA), a 3-dB 1 × 2 optical coupler (CP), a 3-dB 2 × 2 CP, two 3 port optical circulators (OC), a TBF, and a polarization controller (PC). The EDFA is constructed by a 980/1550 nm WDM coupler (WC), a 980 nm pumping laser diode (LD), an optical isolator (ISO) and a length of EDF with 10 m long. In the experiment we use nearly 41 mW pumping power in the EDFA. Thus, the output amplified spontaneous emission (ASE) is shown in the dash line of Fig. 2. The ASE output level of > –35 dBm is between 1523.5 and 1569.1 nm. Thus, the EDFA also presents the effectively bandwidth is between 1525 and 1565 nm. As illustrated in Fig. 1, two CPs are connected to produce to two ring cavities. And we also utilize two OCs and a TBF to constitute two various transmission paths (P_1 and P_2) in the proposed fiber laser scheme, as seen in Fig. 1a. The tuning range and insertion loss of TBF used in ring cavity are 1520 to 1560 nm (40 nm) and 3.6 dB, respectively. The PC is adjusted to obtain the maximum output power and maintain the polarization state.

The TBF not only determines the output wavelength lasing and tuning, but also serves as a mode-restricting component to provide the first restriction on the possible laser modes. Due to the combination of a TBF and the proposed two-ring scheme; together with sub-ring, the SLM lasing in the proposed laser can be guaranteed. It is essential that the two transmission paths (P_1 and P_2) can be served as the mode filters, as seen in Fig. 1a. The transmission lengths of P_1 and

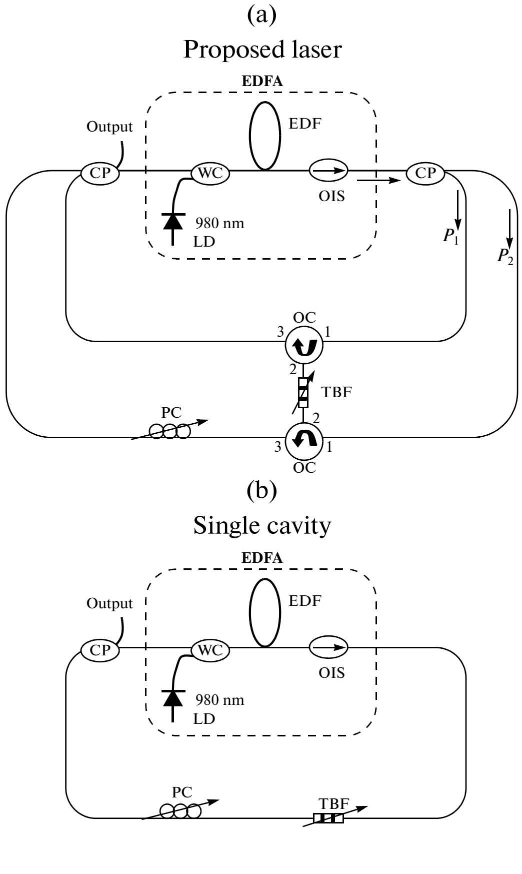

Fig. 1. Experimental setup of proposed wavelength-tunable EDF ring laser scheme.

P_2 are 24.2 and 24.0 m long in the laser scheme. The two fiber cavities have the free spectral ranges (FSRs), FSR = c/nL, where c is the light speed in vacuum, n is the average refractive index of the single-mode fiber (SMF) of 1.468, and L is the fiber cavity length. Here, the two corresponding FSRs of ring cavities will be 8.44 and 8.51 MHz, respectively. Hence, to perform and realize the SLM operation of proposed fiber laser, the lasing output performance can be measured by using the self-homodyne detection. The optical circuit of self-homodyne is consisted of a photodetector (PD) with 3 dB bandwidth of 10 GHz and a Mach–Zehnder interferometer with about 20 km long single-mode fiber (SMF). Besides, the optical output wavelengths and powers of the proposed laser scheme are measured by an optical spectrum analyzer (OSA) with a 0.05 nm resolution.

In the experiment, Fig. 2 also shows the output spectra of the proposed laser versus different wavelengths in the tuning range of 1520.02 to 1562.02 nm with 2 nm tuning step. Moreover, the ring laser has the high ASE output power at the high gain region around 1532 nm. Figure 3 shows the output wavelength and power versus selecting wavelength between 1520.02 and 1562.02 nm. We can obtain the distributions of output power and SMSR between –23.9 and –3.0 dBm and 46.8 and 60.6 dB/0.05 nm, respectively. Besides, we can also observe a ravine of power profile at the wavelength of 1544.04 nm. In Fig. 3, the maximum output power is –3.0 dBm at 1562.02 nm with 59.8 dB/0.05 nm SMSR. However, due to the limita-

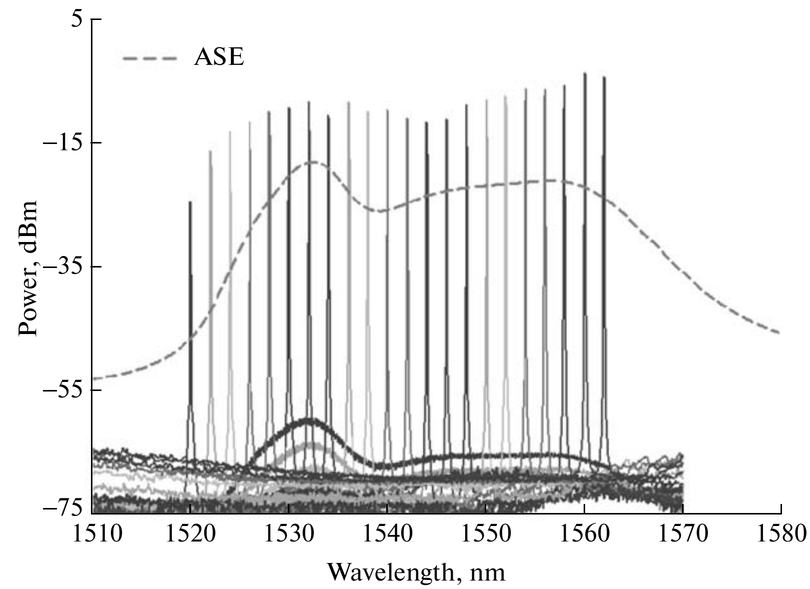

Fig. 2. The output ASE spectrum of EDFA (as illustrated in dash line) and output optical spectra of the proposed fiber laser versus different wavelengths in the tuning range of 1520.02 to 1562.02 nm.

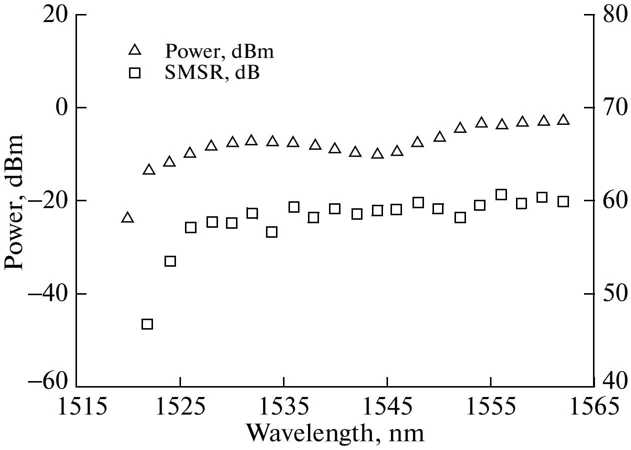

Fig. 3. Output wavelength and power versus selecting wavelength between 1520.02 and 1562.02 nm in the proposed fiber laser.

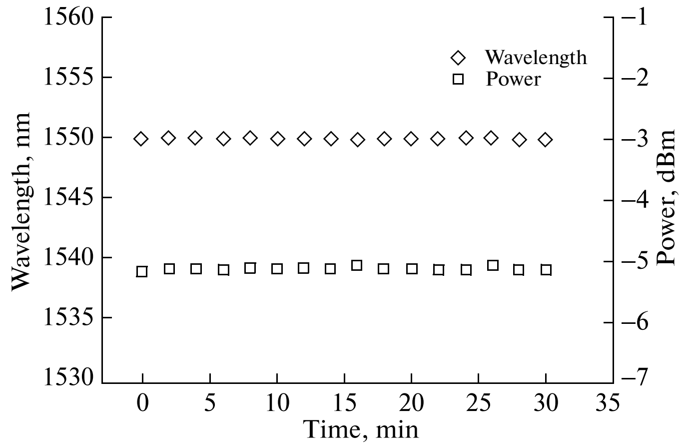

Fig. 4. Output stability measurements of the fiber laser over 30 min observation time.

tion of tuning range on TBF used, the wavelength tuning would stop in 1562.02 nm. Based on the measured results of Fig. 2, we can predict the tuning range, which can extend to 1580 nm, according the output power level of ASE of > −45 dBm.

To realize and investigate the stabilities of output power and output wavelength in the proposed fiber laser, a short-term stability measurement of the proposed ring laser is experimented as shown in Fig. 4. Here, the observation time is over 30 min at the lasing wavelength of 1545.98 nm with −5.1 dBm output power initially. Thus, the observed power variation and wavelength perturbation are observed of <0.1 dB and <0.05 nm, respectively. In addition, during the obser-

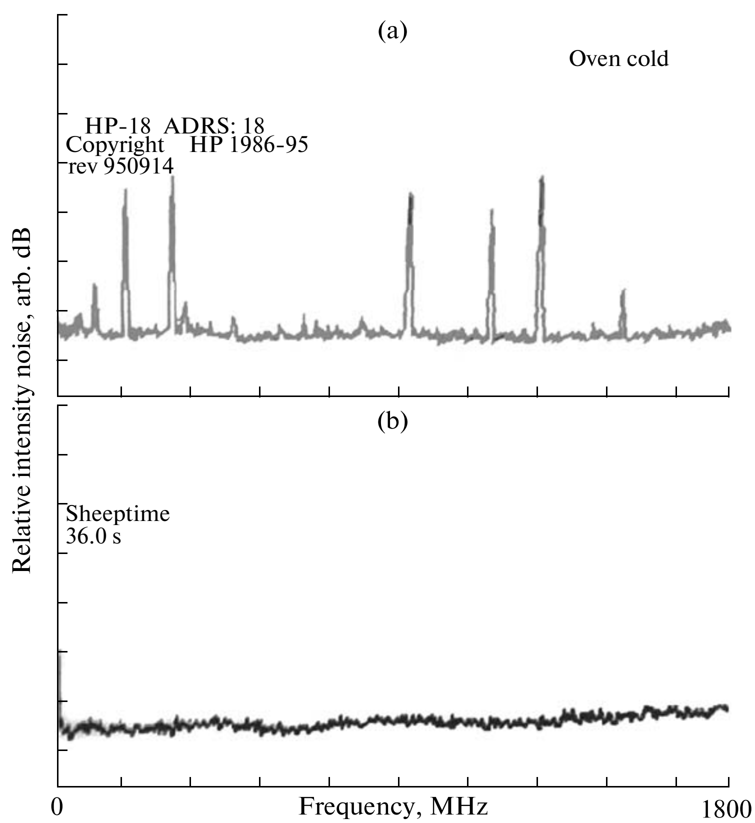

Fig. 5. The detected self-homodyne frequency spectra of (a) conventional fiber laser and (b) our proposed laser.

vation time of 60 min, the output stability of the proposed fiber laser is still kept and maintained.

As shown in Fig. 1b, when the fiber cavity is changed to single-ring (conventional) scheme, the ring laser would result in mode hopping due to longer cavity length. Therefore, Fig. 5a shows the measured self-homodyne frequency spectrum of the proposed laser at the wavelength of 1545.98 nm in the laser scheme of Fig. 1b. Figure 5a produces a noisy and unstable output signal due to the mode hopping. The behavior of mode hopping can be affected by the environment disturbances of temperature and vibration. Here, when the proposed fiber laser scheme is performed in the experiment, the SLM oscillation is much easier to achieve compared with conventional single-ring laser scheme. Clearly, no beating noises are observed in RIN spectrum of the proposed laser which indicates that single frequency oscillation can be retrieved, as illustrated in Fig. 5b. Thus, Fig. 5b presents a stable SLM output spectrum with side mode suppression in the measuring bandwidth of 1800 MHz.

3. CONCLUSIONS

In summary, we have proposed and demonstrated a wavelength-selection EDF ring laser in SLM operation by using simple fiber ring scheme design. We use a TBF inside the gain cavity to restrict the lasing frequency. The proposed ring cavities can also serve as the mode filters for side-mode suppression. Based on the simple ring cavity design, the mode hopping can be avoided to achieve SLM output. The TBF inside the laser scheme also obtains the wavelength tuning in the range of 1520.02 to 1562.02 nm. The output power and SMSR are distributed at −23.9 and −3.0 dBm and 46.8 and 60.6 dB/0.05 nm, respectively, in the tuning range. Besides, the power fluctuation of less than 0.1 dB and the central wavelength variation of less than 0.05 nm are observed for lasing SLM wavelength.

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