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Employing Dual-Saturable-Absorber-Based Filter for Stable and Tunable Erbium-Doped Fiber Ring Laser in Single-Frequency[1]

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Abstract—In this demonstration, a stable and wavelength-tunable erbium-doped fiber (EDF) ring laser using dual-saturable-absorber-based (DSAB) filter inside loop cavity is proposed and experimentally investigated. The proposed DSAB filter not only can filter the side-mode in single-frequency output, but also can obtain the flattened output power spectrum within 1 dB variation in the effectively range of 1529 to 1563 nm. In addition, the output stabilities of wavelength and power are also measured experimentally and discussed.

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1. INTRODUCTION

Stable and wavelength-tunable single-longitudinal-mode (SLM) operations were required for erbium-doped fiber (EDF) ring lasers for the applications of wavelength-division-multiplexing (WDM) communication systems and fiber-optic sensor systems [1–4]. Generally, the tunable bandpass filter (TBF), fiber Fabry–Perot tunable filters (FFP-TF) and fiber Bragg grating (FBG) could be employed inside the fiber cavity to generate wavelength-tuning [5–7]. However, it was insufficient to stabilize the lasing wavelength and output power of a EDF ring laser due to the mode-hopping and gain competition effects. In order to solve the unstable optical output, several methods were used to obtain a SLM operation, such as integrating two cascaded FFP-TF of widely different free spectral ranges (FSRs) inside ring cavity, using a compound ring resonator composed of a dual-coupler fiber ring and dual-ring scheme, and adding an extra ITU-grid periodic filter in the ring loop [8–10]. Moreover, utilizing a unpumped EDF inside fiber loop to serve as a saturable-absorbor-based filter to achieve SLM output, have been proposed and investigated [11, 12]. However, these past researches could not be flattened outputs due to homogeneous broadening effect. In such wavelength-tunable fiber laser, the flattened output performance is also important issue for WDM networks and sensor systems. Hence, the past EDF ring laser schemes, which were proposed, with flatter output spectrum could be achieved by varying the pumping power [13, 14]. But the lasing wavelengths of above studies were not SLM. In addition, using Sagnac loop mirror, Mach–Zehnder interferometer and all-polarization-maintaining loop methods inside fiber ring cavity also could generate the single- and multi-wavelength output in single-mode operations [15–19].

In this study, we propose and experimentally investigate an erbium-doped fiber (EDF) ring laser scheme using a dual-saturable-absorber-based (DSAB) filter inside gain cavity for the stable single-frequency oper-

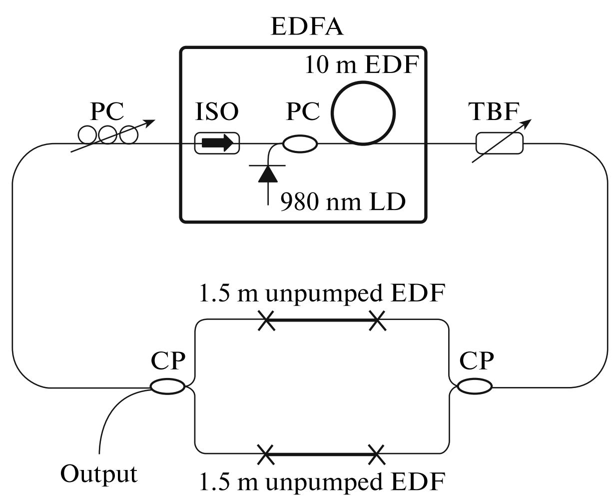

Fig. 1. Experimental setup of proposed stable and wavelength-tunable EDF ring laser configuration.

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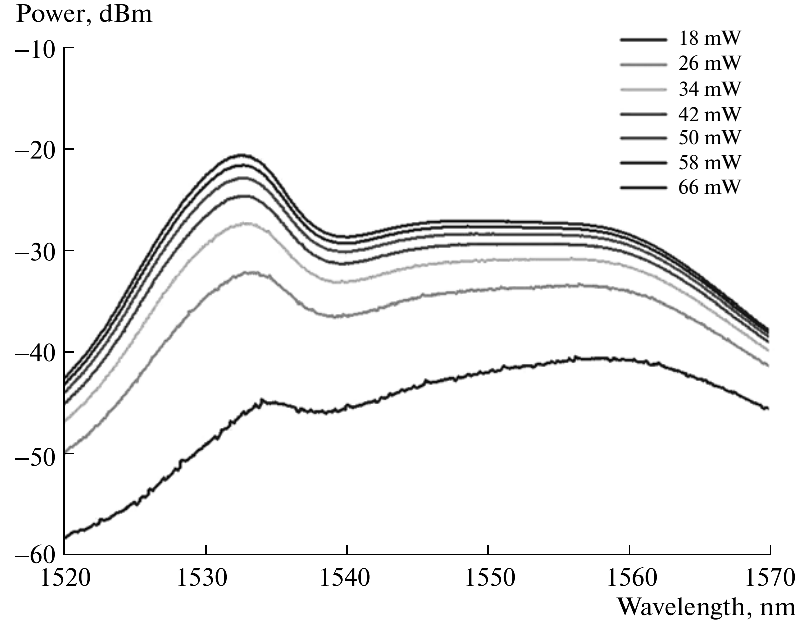

Fig. 2. Output amplified spontaneous emission (ASE) spectra of the EDFA used without the ring structure since the 980 nm pumping laser diode is operated at different power levels between 18 and 66 mW.

ation. The DSAB filter only can obtain the flattened output spectrum within dB power variation among 1529 to 1563 nm by the DSAB filter scheme, but also can achieve the side-mode suppression ratio (SMSR) of >38 dB/0.01 nm. In addition, the output characteristics of the proposed fiber laser have also been analyzed and discussed.

2. EXPERIMENT AND RESULTS

Figure 1 presents the experimental setup of proposed stable and wavelength-tunable EDF ring laser configuration. The proposed fiber laser was consisted of an erbium-doped fiber amplifier (EDFA), a tunable-bandpass filter (TBF), a 2 × 2 and 50:50 optical coupler (OCP), a 1 × 2 and 50:50 OCP, a polarization controllers (PC), and two unpumped EDFs with 1.5 m long. Two unpumped EDFs and two OCPs were used to act as the DSAB filter for filtering the side-mode of lasing lightwave. The PC in the experiment was employed to control and adjust the polarization status and maintain the maximum output power. The TBF, having a 3-dB bandwidth of 0.4 nm, which can be operated in the tuning range of 1525 and 1560 nm, inside the EDF ring cavity, was employed to filter ASE spectrum and generate lasing-wavelength. Here, the EDFA was constructed by an optical isolator (ISO), a 980/1550 nm WDM coupler, a 980 nm pumping laser diode, and a 10 m long EDF (Produced by *FiberCore DC-1550F*). In this measurement, the output wavelengths and powers could be measured by an optical-spectrum analyzer (OSA) with a 0.01 nm resolution and a power meter (PM).

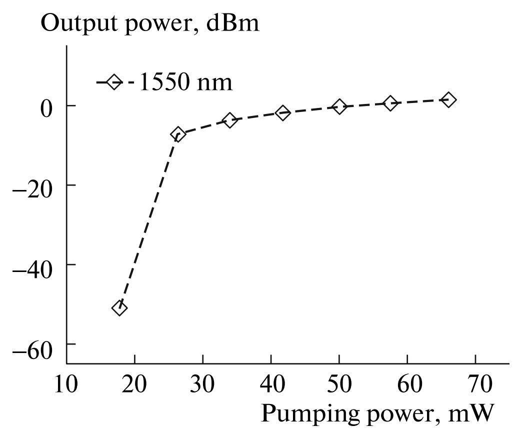

Fig. 3. Output power under different pumping powers of 18 to 66 mW at the lasing wavelength of 1550 nm.

Here, Fig. 2 shows the amplified spontaneous emission (ASE) spectra of the EDFA used without the ring structure since the 980 nm pumping laser diode is operated at different powers between 18 and 66 mW. As shown in Fig. 2, with increase of pumping power gradually, die observed ASE power is also increase. Besides, the measured maximum power level of around 1533 nm could be observed under different pumping powers.

In the experiment, we also measure the output power under different pumping powers of 18 to 66 mW at the lasing wavelength of 1550 nm, as illustrated in Fig. 3. The threshold power of 980 nm LD is 26 mW in the proposed EDF laser scheme. So, with the increase

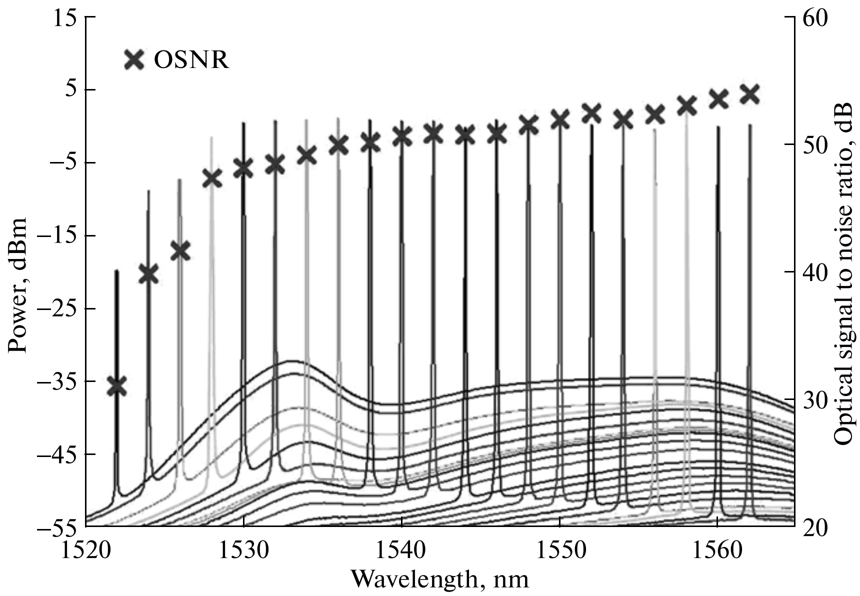

Fig. 4. Output spectra of proposed EDF ring laser with dual SABF scheme in the wavelength range of 1522 to 1563 nm, while the pumping power of 980 nm LD is 66 mW.

of pumping power, the retrieved lasing power is also increase. When the pumping powers are 26, 41, and 66 mW, respectively, the observed lasing powers are −7.2, −1.8, and 1.4 dBm, as seen in Fig. 3.

Then, when the TBF was utilized inside cavity loop, the different lasing wavelengths could be retrieved by the proposed EDF ring laser scheme. Thus, Fig. 4 shows the output spectra of proposed EDF ring laser with DSAB filter scheme in the wavelength range of 1522 to 1563 nm, while the pumping power of 980 nm LD is 66 mW. As shown in Fig. 4, we can observe the larger ASE noise is introduced around 1533 nm, when the lasing wavelength region is shorter than 1533 nm. It would cause the worse side-mode suppression ratio (SMSR) in the effective lasing range. With the drift of lasing wavelength in longer wave-band gradually, the presented ASE of around 1533 nm could be suppressed simultaneously, as seen in Fig. 4. Besides, Fig. 4 also shows the related optical signal to noise ratios (OSNRs) in the lasing wavelength range of the proposed EDF laser scheme. Here, the OSNRs are measured between 47.8 and 54.2 dB in the wavelengths of 1529 to 1563 nm.

Figure 5 shows the output power and related SMSR curves under the different wavelengths for the proposed EDF ring laser in 1522 to 1563 nm. Here, the measured output powers and SMSRs are between −12.3 and 2.1 dBm and 12.5 and 54.8 dB/0.05 nm,

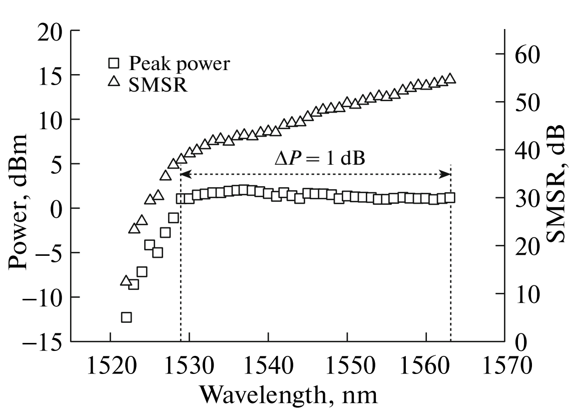

Fig. 5. Output powers and related SMSRs versus the different wavelengths for the proposed EDF laser in the operating range of 1522 to 1563 nm.

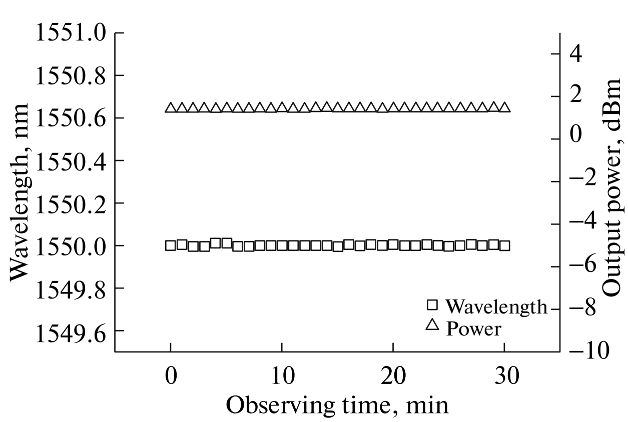

Fig. 6. Short-term observation of the proposed fiber laser is measured at the lasing wavelength of 1550 nm initially.

respectively. Due to the smaller gain region of 1522 to 1530 nm, we could get the smaller output powers (−12.3 and −1.1 dBm) in the region. Moreover, we can obtain the flatter output power range in the wavelengths of 1529 to 1563 nm (with 34 nm wavelength bandwidth). Hence, the measured powers and SMSRs are between 1.1 and 2.1 dBm, and 38.0 and 54.8 dB/0.01 nm, respectively, in the range of 1529 to 1563 nm. Here, the maximum power variation (ΔP_{out}) of 1 dB can be maintained in the lasing bandwidth of 1529 to 1563 nm. Comparing with the past studies [3, 14], the proposed EDF ring laser not only can achieve SLM operation, but also can obtain flatter output levels.

To investigate and realize the optical stabilities of output power and lasing wavelength, a short-term observation of the proposed EDF ring laser is measured as shown in Fig. 6. The lasing wavelength is at 1550 nm initially with 1.4 dBm output power and the observation time is over 30 min. In Fig. 6, the proposed fiber ring laser can dramatically reduce the wavelength variation ($\Delta\lambda$) of 0.01 nm and power fluctuation (ΔP) of 0.1 dB. During the one hour observation time, the stabilized output of the proposed ring laser is still maintained in SLM output.

3. CONCLUSIONS

In summary, we have investigated and demonstrated a stable and wavelength-tunable EDF ring laser scheme using DSAB filter inside loop cavity to achieve SLM output. The proposed DSAB filter not only can obtain single-frequency output, but also can obtain the flattened output power spectrum within 1 dB variation (from 1.1 to 2.1 dBm) in the effectively range of 1529 to 1563 nm. In this region, the SMSR is obtained between 38.0 and 54.8 dB/0.01 nm. In addition, the stabilities of output power and wavelength have been measured within 0.1 dB and 0.01 nm in the observing time of 30 min in the experiment.

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