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Dual-Reflected-Structure Erbium-Doped Fiber Laser in Single-Longitudinal-Mode for Wavelength-Tuning[1]

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Abstract—In this work, we propose and demonstrate a dual-reflected-structure erbium-doped fiber (EDF) laser with a linear cavity using a passive saturable-absorbor-based (SAB) filter to achieve single-longitudinal-mode (SLM) lasing. Here, we can observe the wavelength tuning range between 1530.0 and 1562.0 nm with the output powers of –13.7 to –7.6 dBm and optical signal to noise ratios (OSNRs) of 35.4 and 47.9 dB/0.05 nm, respectively. Moreover, when the lasing wavelength is tuned to the longer wavelength gradually, the obtained output power and SNR increase. This is because the Er^+ gain can be suppressed and moves to the longer wavelength via the proposed fiber laser structure. In addition, the output stability of the proposed laser has also been analyzed and studied.

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1. INTRODUCTION

Single-longitudinal-mode (SLM) fiber lasers with stable output and wide wavelength-tuning range are attractive light sources for the applications in wavelength-division-multiplexing (WDM) or dense WDM communications, optical testing, and fiber sensing systems [1–9]. In general, using tunable bandpass filter (TBF), fiber Fabry–Perot tunable filters (FFP-TF) and fiber Bragg grating (FBG) inside the ring laser cavity loop have been proposed to generate the wavelength lasing and tuning [10–12]. However, it is insufficient to stabilize the lasing wavelength of an erbium-doped fiber (EDF) ring laser owing to the mode-hopping and gain competition effects. To overcome the issue, several schemes have been proposed to achieve a stabilized SLM output. They include using a compound ring resonator composed of a dual-coupler fiber ring, integrating two cascaded FFP-TF of widely different free spectral ranges (FSRs) inside ring cavity, dual-ring scheme, using Saganc ring loop filter, and adding an extra periodic filter inside the cavity loop [13–17]. Here, we also could use the optical injection technology via the Fabry–Perot laser diose and EDFA to accomplish SLM output [18]. Furthermore, employing a shorter unpumped EDF inside fiber loop to act as a saturable-absorbor-based (SAB) filter to achieve SLM output has also been investigated [19–23].

In this paper, we propose and demonstrate a dual-reflected-structure EDF laser with a linear cavity employing a passive SAB filter and tunable bandpass filter (TBF) to achieve SLM lasing and wavelength tuning. Here, we can obtain the wavelength tuning range from 1530.0 to 1562.0 nm with the output powers of –13.7 to –7.6 dBm and optical signal to noise ratios (OSNR) of 35.4 and 47.9 dB/0.05 nm, respectively. Besides, for the traditional EDF ring laser [1, 17], the measured output powers at both ends of the EDF gain spectrum (1530 and 1560 nm) would drop rapidly due to the decrease of EDF effective gain. However, in this measurement, when the TBF is tuned to the longer wavelength, the measured output power of proposed EDF laser would also increase. This is because the Er^+ gain is suppressed and moves to the longer wavelength via the double-pass laser configuration. Moreover, the output stability of the proposed EDF laser has also been analyzed and studied.

2. EXPERIMENT AND RESULTS

Figure 1 presents the experimental setup of dual-reflected-structure EDF laser. The proposed fiber laser consisted of an erbium-doped fiber amplifier (EDFA), a TBF, a 1 × 2 and 50:50 optical coupler (OCP), a fiber mirror (FM) with 99.1% reflection in C-band, a polarization controller (PC), an optical circulator (OC), and a piece of 1.5 m unpumped EDF. Here, the FM and OC were used to serve as two reflected mirrors for the EDF fiber laser. And the EDFA, constructed by an optical isolator (ISO), a 980/1550 nm WDM coupler, a 980 nm pump laser diode (LD), and a 10 m long EDF (Produced by *Fibercore DC-1550F*), was employed to act as the gain medium of the EDF fiber laser. In the measurement, the total cavity length of the fiber laser was ~18 m long.

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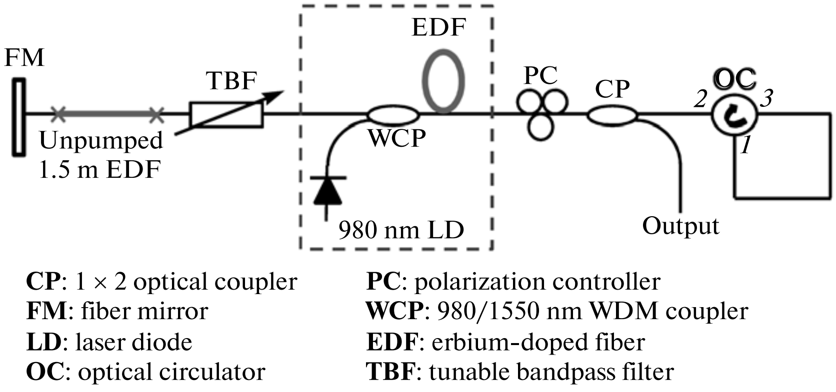

Fig. 1. Experimental setup of dual-reflected-structure EDF laser.

The unpumped EDF was served as the SAB filter for filtering the side-mode of lasing wavelength [1]. The PC was employed to control the polarization status and maintain the maximum output power. The 3 dB bandwidth and tuning range of TBF were 0.4 and 30.0 nm (1530.0 to 1560.0 nm), respectively. And TBF inside the EDF laser cavity was employed to suppress the amplified spontaneous emission (ASE) and for wavelength tuning. In this measurement, the output wavelength and power was measured by an optical spectrum analyzer (OSA) with a 0.05 nm resolution and a power meter (PM), respectively.

Figure 2 presents the output optical spectra of proposed dual-reflected-structure EDF laser in the wavelength range of 1530 to 1562 nm, when the pump power of 980 nm LD is 42 mW. Besides, Fig. 2 also shows the output ASE spectrum of EDFA before using in the proposed laser scheme, as shown in the dotted line. And we observe that the ASE power level of >–30 dBm is between 1528.0 and 1560.0 nm. Furthermore, the effective gain amplification is also distributed at the wavelength range. As illustrated in Fig. 2, when the lasing wavelength is tuned to the longer wavelength gradually, we can obtain a better suppression of ASE noise. And, we also observe the larger output power as the lasing wavelength is tuned to the longer wavelength.

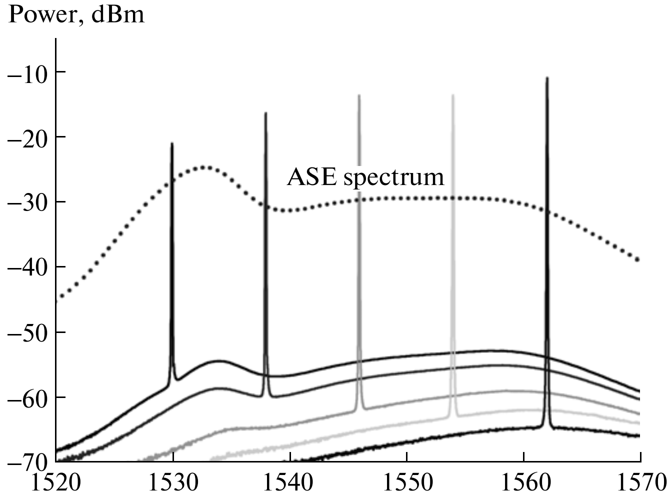

Fig. 2. Output spectra of proposed dual-reflected-structure EDF laser in the wavelength range of 1530 to 1562 nm, when the pump power of 980 nm LD is 42 mW. Dotted line is the ASE spectrum of original EDFA before using in the proposed laser scheme.

Figure 3 shows the output power and the measured OSNR versus different lasing wavelengths in the tuning range of 1530.0 to 1562.0 nm, while the pump power is 42 mW. As shown in Fig. 3, the observed output powers and SNRs are between –13.7 and –7.6 dBm and 35.4 and 47.9 dB/0.05 nm, respectively. Moreover, when the lasing wavelength is tuned to the longer wavelength gradually, the obtained output power and SNR increase in the whole C-band (1530.0 to 1560.0 nm). Actually, according to the past study of EDFA design

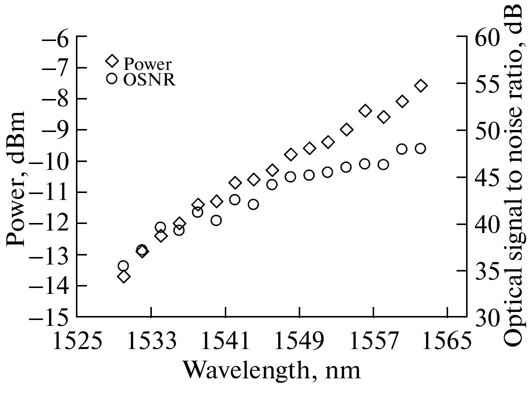

Fig. 3. Spectral profiles of output power and related signal to noise ratio (SNR) versus different lasing wavelengths in the tuning range of 1530 to 1562 nm, while a pump power is 42 mW.

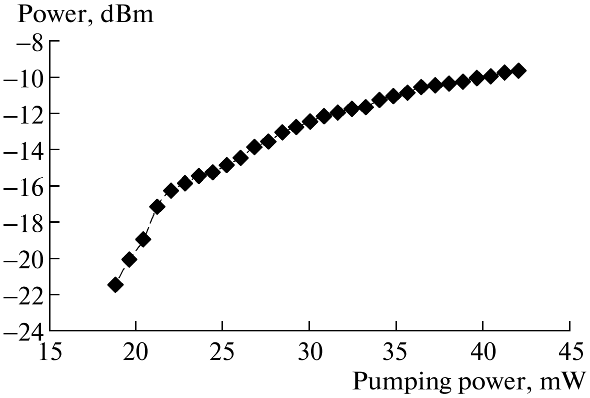

Fig. 4. Measured output powers and SNRs versus different pump powers for the proposed EDF laser, when the lasing wavelength is set at 1550 nm.

[18], the gain value in amplification bandwidth could be enhanced according to the double-pass propagation. Here, owing to the double-pass design of the EDF laser structure in linear cavity, the Er^+ gain can be suppressed and shifts to the longer wavelength. As a result, the observed output power will increase gradually towards the longer wavelength. Besides, due to the bandwidth limitation of the TBF used in the experiment, the lasing wavelength of >1562 nm cannot be measured. However, we believe that wavelength-tuning range of our proposed EDF laser can be extended to L-band.

Here, we also study the output powers versus different pump powers of the proposed EDF laser as illustrated in Fig. 4. The lasing wavelength is set at 1550.0 nm.

In this measurement, the pump powers are between 19 and 42 mW. The threshold pump power of proposed laser is 22 mW, as seen in Fig. 4. When the pump powers are 22, 32, and 42 mW, the measured lasing powers are −16.2, −11.7, and −9.6 dBm, respectively.

The output stability is also important for the EDF laser. Thus, in order to realize the optical stabilities of output power and lasing wavelength, a short-term observation of the proposed EDF laser is performed, as shown in Fig. 5, and the observation time is over 30 min. Here, the lasing wavelength is set at 1550.0 nm initially with −9.6 dBm output power. As shown in Fig. 5, the proposed configuration can reduce the wavelength variation ($\Delta\lambda$) of the laser within 0.05 nm and power fluctuation (ΔP) within 0.3 dB. Moreover, after two hours observation, the stabilized output of the proposed fiber laser is still maintained.

Furthermore, the inset of Fig. 5 is the delayed self-homodyne frequency spectrum of the proposed EDF laser with a passive SAB filter at the wavelength of 1550.0 nm at −9.6 dBm output power. So, the optical circuit for measurement was consisted of a photodetector (PD) with 3 dB bandwidth of 1 GHz and a Mach–Zehnder interferometer with 25 km long standard single-mode fiber (SSMF). Clearly, no beating noises are observed in relative intensity to noise (RIN) spectrum of the proposed EDF laser. Hence, the proposed fiber laser presents that a single frequency oscillation can be achieved within the measuring bandwidth of 500 MHz, as illustrated in the inset of Fig. 5.

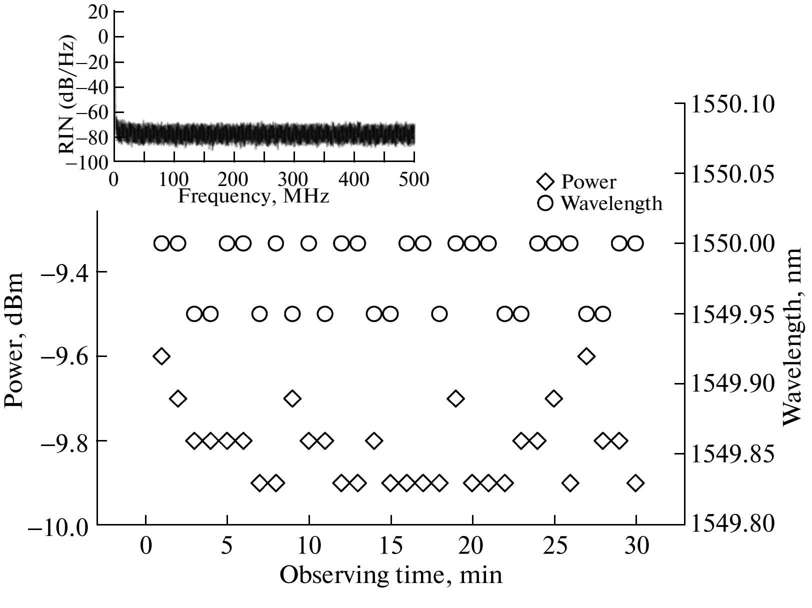

Fig. 5. Output stabilities of power and wavelength over the observation time of 30 min, when the lasing wavelength is 1550 nm with −9.6 dBm output power initially. Inset is the delayed self-homodyne frequency spectrum of the proposed EDF laser with a passive SAB filter.

3. CONCLUSIONS

We have proposed and experimentally demonstrated a dual-reflected-structure of EDF laser with a linear cavity employing a passive SAB filter and TBF for the SLM lasing and wavelength tuning. Here, we can obtain the wavelength tuning range from 1530.0 to 1562.0 nm with the output powers of –13.7 to –7.6 dBm and SNRs of 35.4 and 47.9 dB/0.05 nm, respectively. Moreover, when the lasing wavelength was tuned to the longer wavelength gradually, the obtained output power and OSNR increased in the entire C-band (1530 to 1560 nm). Due to the double-pass design of the EDF laser structure, the Er^+ gain was suppressed and shifted to the longer wavelength. As a result, the observed output power will increase gradually towards the longer wavelength. Besides, the output variations of power and wavelength were measured within 0.3 dB and 0.05 nm for the proposed EDF laser.

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