

Utilizations of two-stage erbium amplifier and saturable-absorber filter for tunable and stable power-equalized fiber laser

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Abstract: We propose and investigate experimentally a tunable and stable fiber laser with single-longitudinal-mode (SLM) and power-equalized output based on a two-stage erbium amplifier and a saturable-absorber filter. Two-stage amplifier consists of an erbium-doped waveguide amplifier (EDWA) and erbium-doped fiber amplifier (EDFA) to generate a flatter amplified spontaneous emission (ASE) source for constant output. Saturable-absorber filter constructs by an unpumped EDF and a fiber reflected mirror (FRM) to provide a fine mode restriction and guarantee a SLM operation.

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1. Introduction

Single-longitudinal-mode (SLM) operation for fiber lasers is becoming necessary for optical fiber sensor, optical signal processing, laser spectroscopy, and wavelength division multiplexed (WDM) communication. Several techniques have been studied, such as using a passive multiple-ring cavity or a compound ring resonator composed of a dual-coupler fiber ring (DCFR) to guarantee SLM laser oscillation [1], [2], integrating two cascaded FFP filters

of wide different free spectral ranges (FSRs) into cavity to provide full tunable and SLM operation [3], and using an unpumped erbium-doped fiber (EDF) as a narrow bandwidth autotracking filter [4]-[6]. Recently, the power-equalized EDF ring lasers with constant output by varying the pumping power were also investigated [7], [8].

In this paper, we propose and experimentally demonstrate a tunable and single-frequency erbium-based fiber ring laser by using a saturable-absorber filter, which is composed of an unpumped EDF and a fiber reflected mirror (FRM). The behaviors of the output power and wavelength stabilities, tuning range, side-mode suppression ratio (SMSR), and RF spectrum have also been studied.

2. Experiment setup

Figure 1 illustrates the tunable and stable fiber laser architecture based on a two-stage erbium-based fiber amplifier (EBFA) for constant output. The proposed fiber laser constructs by a two-stage EBFA, a fiber Fabry-Perot tunable filter (FFP-TF), a polarization controller (PC), an optical circulator (OC), a saturable-absorber filter and a 1×2 and 10:90 optical coupler (CP). The proposed EBFA consists of an erbium-doped waveguide amplifier (EDWA) and a cascaded erbium-doped fiber amplifier (EDFA). The PC is used to align the properly state of polarization of the ring cavity. The FFP-TF is an all-fiber device having a widely tunable range, low insertion loss of < 0.5 dB, and low polarization-dependent loss of ~0.1 dB. This FFP-TF having the free spectral range (FSR) of 44 nm can provide wavelength selection in the ring laser cavity by controlling the external voltage (0 to 12 V) on the piezoelectric transducer (PZT) of this filter. The saturable-absorber filter constructs by an unpumped EDF and a fiber reflected mirror (FRM) to provide a fine mode restriction and guarantee a SLM operation. The used fiber reflected mirror (FRM) with a 99% reflectance can operate between 1520 to 1580 nm. In addition, an optical spectrum analyzer (OSA) with a 0.05 nm resolution is used to measure the output spectra of the ring laser.

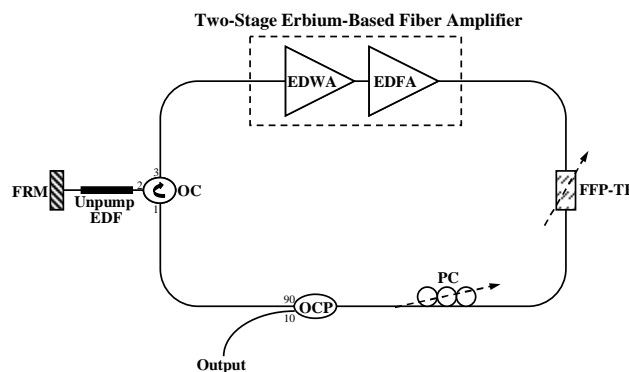


Fig. 1. Proposed experimental setup of an erbium-based fiber laser with tunable power-equalized output.

By using an EDWA and an EDFA in serial can generate a flatter ASE source in this experiment. The first EDWA stage, which is manufactured via two-step ion-exchange process, has the advantage of inheriting the known properties of the EDFA, such as low noise figure, slight polarization dependence, and no crosstalk between WDM channels. All optical performances are measured when the laser pump diode current equals to 440 mA at ambient temperature. Figure 2(a) shows the ASE spectrum and 8.3 dB maximal power variation of the EDWA in the wavelengths of 1530 to 1560 nm. The second EDFA stage consists of a 10 m long EDF, a 980 nm pump laser, a 980/1550 nm WDM coupler and an optical isolator (OIS). The ASE spectra of the EDFA are shown in Fig. 2 (b) under the pump power of 5, 10, 20 and 40 mW, respectively. Two-stage gain-flattened EDFA module was discussion in Ref. 9. Based

on the proposed amplifier, the entire gain were large than 35 dB and the maximal gain variation of ± 1.1 dB was retrieved, for -25 dBm input saturation power, in an operating range of 1528 to 1562 nm. The operating mechanism of gain flattening was that the EDWA and EDFA have complementary spectroscopy and the gain saturation effect to achieve the gain flattening [9]. When the two erbium amplifiers are cascaded in serial, the two-stage amplifier can obtain a flatter ASE profile as shown in Fig. 3 (the 980 nm pump power of EDFA is 10 mW). A maximum power variation of 3.2 dB in the wavelengths of 1530 to 1560 nm is also shown in Fig. 3. The flatter ASE source of the proposed amplifier is based on the gain saturation effect. Compared with an EDWA or EDFA, the two-stage amplifier also shows a larger and flatter ASE output over the wavelengths of 1530 to 1560 nm. Therefore, using the flatter ASE source into a laser ring cavity can retrieve tunable power-equalized output. Moreover, when the saturable-absorber filter is also used in the erbium-based ring cavity, this proposed erbium fiber ring laser not only can retrieve the constant output, but also guarantee the lasing wavelength in SLM oscillation.

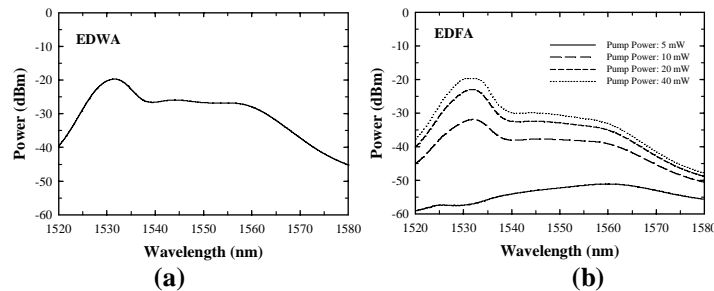


Fig. 2. (a). ASE spectrum of an EDWA. (b) ASE spectra of an EDFA with a 10 m long EDF when the pump powers are 5, 10, 20 and 40 mW, respectively.

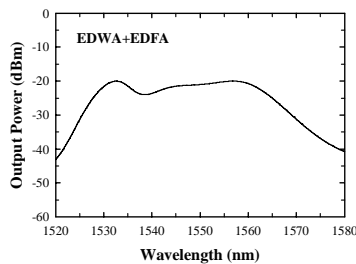


Fig. 3 ASE spectrum of a two-stage EBFA when the pump current of EDWA is 440 mA and the pump power of EDFA is 10 mW.

To demonstrate the effect of the unpumped EDF length, 1, 1.5 and 2 m long EDF are used to serve a saturable-absorber filter to observe the optical behavior, respectively. Figure 4(a) presents the output power and side-mode suppression ratio (SMSR) versus different wavelength for the proposed fiber laser without unpumped EDF. Figures 4(b) to 4(d) show the output power and SMSR versus different wavelength for the proposed fiber laser when the unpumped EDFs are 1, 1.5 and 2 m long, respectively. Figure 4(b) shows the output power and SMSR in an operating range of 1536.1 to 1574.1 nm with power variation of 0.5 dB and the SMSR of > 51 dB/0.05 nm. Figure 4(c) presents the output power and SMSR in an operating range of 1533.3 to 1574.6 nm with power variation of 0.5 dB and the SMSR of > 50.3 dB/0.05 nm. Figure 4(d) displays the output power and SMSR in an operating range of 1536.2 to 1576.2 nm with power variation of 0.53 dB and the SMSR of > 51.4 dB/0.05 nm. The maximal output powers of Figs. 4(b) to 4(d) are 0.58, 0.59 and 0.7 dB at 1554.9, 1558.3 and 1560.1 nm, respectively. When the unpumped EDFs are 1, 1.5 and 2 m long, the effectively operating range of the proposed laser are 38, 41.3, 40 nm, respectively, as shown

in Figs. 4. As a result, the proposed laser can retrieve the constant optical output (minimal variation of < 0.5 dB) with output power of > 0.12 dBm based on the two-stage erbium amplifier in an effectively operating range. Therefore, Figure 4(c) obtains the better experimental results compared with Figs. 4(b) and 4(d). Moreover, 0.6 dB power penalty is obtained from above results when the unpumped EDF is used, the measured slope efficiency of the laser is $\sim 1.45\%$, and the linewidth of 0.12 nm is measured by the OSA.

To verify the performance of output power and wavelength, the short-term stability of the proposed structure is measured in Fig. 5. The initial lasing wavelength is set at 1556.2 nm and the total observing time is over 20 minutes. Experimental results show that the proposed fiber laser has excellent stabilities. The output power fluctuation is less than 0.1 dB and the central wavelength variation is less than 0.08 nm.

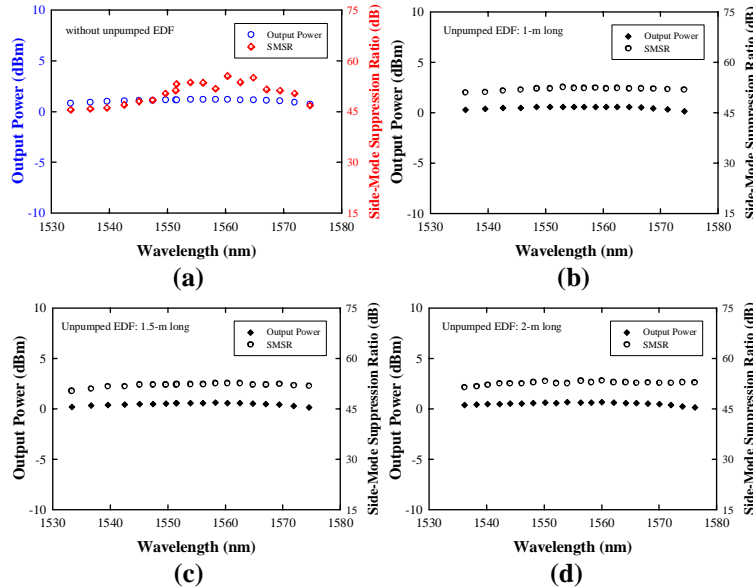


Fig. 4. Output power and SMSR versus the tuning wavelength in this proposed laser (a) without and with the unpumped EDF of (b) 1, (c) 1.5 and (d) 2 m long, respectively, while the various external voltages (0 to 12 V) applied on the PZT of FFP-TF.

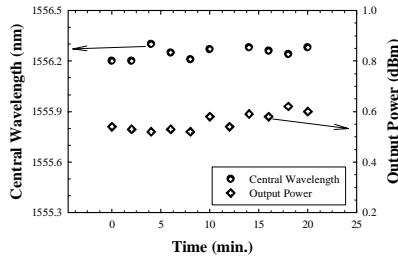


Fig. 5 Wavelength variation and the power fluctuation of the stabilized fiber ring laser while the lasing wavelength is 1556.2 nm initially and an observing time is over 20 minutes.

To verify the single-frequency performance, the linewidth spectrum of this proposed fiber laser was observed by using the delayed self-homodyne technique. The optical circuit for measurement is composed of a photodetector with 3 dB bandwidth of 1 GHz and a Mach-Zehnder interferometer with 25-km-long standard single-mode fiber (SMF). The linewidth spectrum of the fiber laser can be measured by a radio frequency spectrum analyzer. Figure 6 shows the self-homodyne spectra of the fiber laser without (short dash line) and with (solid

line) saturable-absorber filter and the operating wavelength is at 1556.2 nm. A noisy and unstable waveform with spikes is observed in the spectrum of ring laser without saturable-absorber filter. When it is combined with a saturable-absorber filter, the proposed resonator can guarantee a single-longitudinal-mode laser oscillation. Simultaneously, the fiber laser effectively suppresses side-mode frequencies of 1 GHz, shown in Fig. 6.

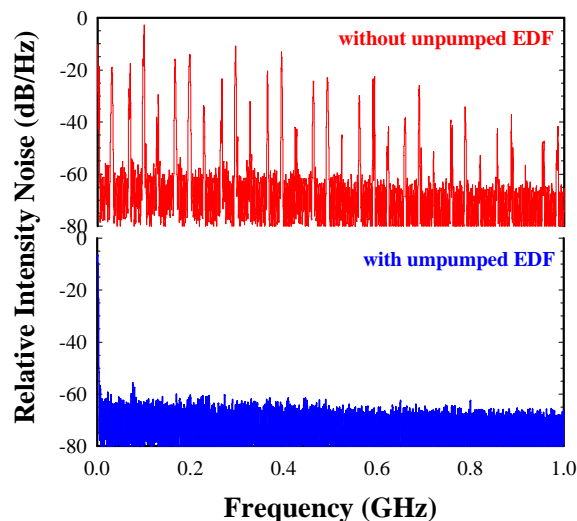


Fig. 6 The self-homodyne spectra of the fiber laser without saturable-absorber filter and with saturable-absorber filter at 1556.2 nm when an unpumped EDF is 1.5 m long.

3. Conclusion

We have proposed and investigated experimentally a tunable and stable fiber laser with SLM and power-equalized output based on a two-stage erbium amplifier and a saturable-absorber filter. Two-stage amplifier consists of an EDWA and EDFA to generate a flatter ASE source for constant output. Saturable-absorber filter constructs by an unpumped EDF and a fiber reflected mirror to provide a fine mode restriction and guarantee a SLM operation. The output power of larger than 0.12 dBm and the SMSR of larger than 50.3 dB/0.05 nm over the operating range from 1533.3 to 1574.6 nm can be obtained when an unpumped EDF is 1.5 m long. And the maximum output power and SMSR are 0.59 dBm and 52.6 dB/0.05 nm at 1558.3 nm. In the effectively operating range, the proposed tunable laser retrieves constant output power with <0.5 dB power variation. Moreover, the power fluctuation of less than 0.1 dB and the central wavelength variation of less than 0.08 nm also are observed for lasing wavelength.

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