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Simple Erbium-Doped Dual-Ring Fiber Laser Configuration for Stable and Tunable Dual-wavelength Output[1]

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Abstract—We propose and experimentally investigate a stable and tunable dual-wavelength erbium-doped fiber (EDF) dual-ring laser scheme. Here, two tunable bandpass filters (TBFs) are used inside the dual-ring gain cavity to generate dual-wavelength lasing. And, due to the gain competition of the EDF gain cavity, the mode-spacing ($\Delta\lambda_s$) of lasing dual-wavelength will be limited at different operating wavelengths. Hence, the minimum and maximum mode-spacing in the proposed EDF laser scheme are 0.75 and 15.35 nm in C-band range. Besides, the output performances of proposed fiber laser have also been studied and analyzed.

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1. INTRODUCTION

Recently, erbium-doped fiber (EDF) ring lasers with multi-wavelength operation have much considerable interest in the wavelength-division-multiplexing (WDM) communication systems and fiber-optics sensor applications. However, the maximum number of lasing wavelength only could reach two or three because of the homogeneous broadening characteristic of EDF [1–3]. Hence, to overcome the limitation of primarily homogeneous broadening of EDF at room temperature, several methods have been studied and investigated [1–6]. Using an independent gain segment was the most straightforward method to for each wavelength, where EDF ring lasers may be achieved by pumping with appropriate wavelength multiplexing and demultiplexing [4, 7], However, most of the approaches resulted in inhomogeneity in a single EDF, when various elements such as acousto-optic frequency shifters, comb or interferometer filters, array waveguide grating (AWG), nonlinear soliton, high-birefringence fiber loop mirror, intracavity loss optimization and Sagnac loop reflectors were used inside gain cavity [2, 8–18]. To enhance the stability of the multi-wavelength EDF lasers, many different techniques of reducing mode competition, such as cooling the EDF at 77 K, introducing active overlapping linear cavities, using the polarization hole burning principle, and using Fabry–Perot laser diode (FP-LD) with Sagnac loop, have been investigated [5, 19–21]. In addition, using self-injected FP-LD and saturable-absorber filter (SAF) could achieve the broadband and single-longitudinal-mode (SLM) operation [22–25].

In this study, a stable and tunable dual-wavelength EDF dual-ring laser is proposed and experimentally investigated. Here, two tunable filters are used inside the dual-ring gain cavity to generate dual-wavelength lasing. And, due to the gain competition of the EDF gain cavity, the mode-spacing ($\Delta\lambda_s$) of lasing dual-wavelength will be limited at different operating wavelengths. Hence, the minimum and maximum mode-spacing in the proposed EDF laser scheme are obtained at 0.75 and 15.35 nm, respectively, in C-band operation. Moreover, the stability performances of fiber laser have also been demonstrated and analyzed.

2. EXPERIMENT AND DISCUSSIONS

Figure 1 shows the experimental setup of proposed tunable dual-wavelength EDF dual-ring laser configuration. The proposed fiber laser scheme was constructed by an erbium-doped fiber amplifier (EDFA), two 1 × 2 optical couplers (OCPs), two polarization controllers (PCs), and two tunable bandpass filters (TBFs). The EDFA consisted of a 10 m long EDF, two optical isolators (OISs), a 1550/980 nm WDM coupler (WCP) and a 980 nm pumping laser diode with 76.4 mW output power to serve as a gain medium. In the experiment, we used two 1 × 2 OCPs to produce dual-ring scheme and two TBFs were utilized inside

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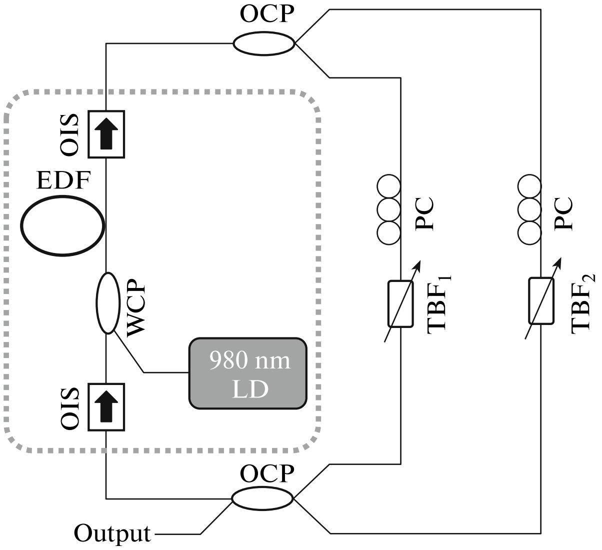

Fig. 1. Experimental setup of proposed EDF dual-ring laser configuration.

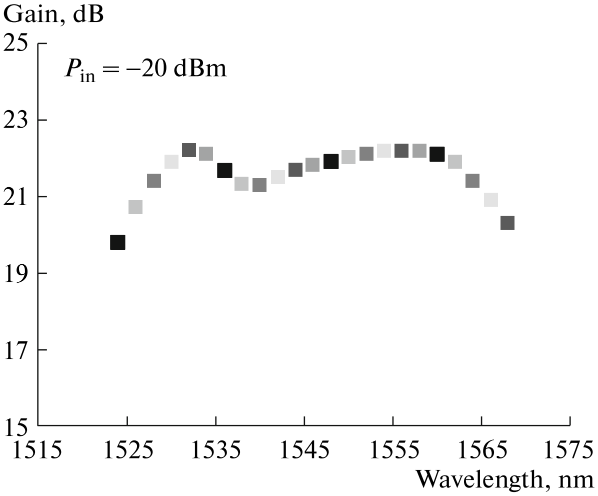

Fig. 2. Measured gain spectrum of EDFA used in the measurement when the injected power of probe wavelength was −20 dBm the wavelength range of 1524 to 1568 nm.

the gain cavity to generate dual-wavelength output. The wavelength tuning ranges and 3 dB bandwidths of two TBFs were both 35 nm (1525 to 1560 nm) and 0.4 nm. Besides, the two PCs were used to adjust the properly polarization status and obtain maximum output power of lasing dual-wavelength. In the measurement, we used an optical spectrum analyzer (OSA) with a 0.05 nm resolution to measure the lasing dual-wavelength.

Figure 2 presents the gain spectrum of EDFA used in the measurement, when the injected power of probe wavelength was −20 dBm the wavelength range of 1524 to 1568 nm. We could also observe the gain value of >20 dB in the operating wavelength bandwidth. Thus, to realize the output characteristic of lasing dual-wavelength in the proposed fiber laser, first we fixed the passband of TBF$_2$ at the wavelength of 1560.35 nm (λ_2). Then, we varied and tuned the passband of TBF$_1$ from 1560.35 nm to the shorter wavelengths gradually in order to generate different mode-spacing ($\Delta\lambda$) of lasing dual-wavelength. Hence, Fig. 3 shows the output spectra of lasing dual-wavelength in the proposed fiber laser while the TBF$_1$ is tuned to shorter wavelengths. When the TBF$_1$ is tuned to 1551.45 nm, we can observe the first dual-wavelength lasing at 1551.45 and 1560.35 nm (mode-spacing $\Delta\lambda_s$ = 8.9 nm) with −15.1 and −17.2 dBm peak powers, respectively, as shown in Fig. 3. And then, when the passband of TBF$_1$ was shifted to shorter wavelengths, the lasing wavelength (λ_1) via a TBF$_1$ only could be generated at the wavelength λ_1 of 1551.75, 1540.05, 1536.35, and 1532.25 nm with the peak power of −49.6, −60.8, −62.7, and −68.6 dBm, respectively. At this time, the peak power of fixed wavelength λ_2 was both kept at −12.9 dBm. As illustrated in Fig. 3, we can obtain the measured power variations (ΔP_s) of five dual-wavelengths, which are 1.7, 36.7, 48.1, 49.8, and 55.7 dB, respectively, increasing fast while the TBF$_1$ is tuned to shorter wavelengths. And the corresponding mode-spacing of the five lasing dual-wavelengths are 8.9, 8.7, 20.3, 24.0, and 28.1 nm, respectively. As mentioned before, we know that the lasing dual-wavelength cannot be selected and tuned arbitrarily via the two TBFs. This is because the gain competition, of Er^+ in the proposed laser scheme.

In the measurement, we could fix the TBF$_2$ at different passbands in the effectively gain range of EDFA used to generate λ_2, and then we varied the TBF$_1$ to produce properly λ_1 for dual-wavelength lasing of the proposed EDF laser. And, the tuning step of TBF$_2$ was 2 nm from 1538.35 to 1556.35 nm. Besides, we defined the mode-spacing ($\Delta\lambda_s$), which was equal to ($\lambda_1 - \lambda_2$), and the measured power difference (ΔP) of dual-wavelength must be less than 2.2 dB in the measurement. Therefore, Fig. 4 shows the different mode-spacing of lasing dual-wavelength, having the ΔP within 2.1 dB, when the wavelength λ_2 is placed at the wavelength range of 1538.35 to 1560.35 nm with 2 nm tuning step. In Fig. 4, we can observe the maximum and minimum mode-spacing are 15.35 and 0.75 nm when the λ_2 are both kept at 1550.35 nm. Moreover, when the wavelength λ_2 is set at 1538.35, 1546.35, 1558.35, and 1560.35 nm, respectively, only we can get a set of dual-wavelength lasing, as seen in Fig. 4. In addition, Fig. 5 also presents the output spectra of related dual-wavelengths in accordance with the measured results of Fig. 4.

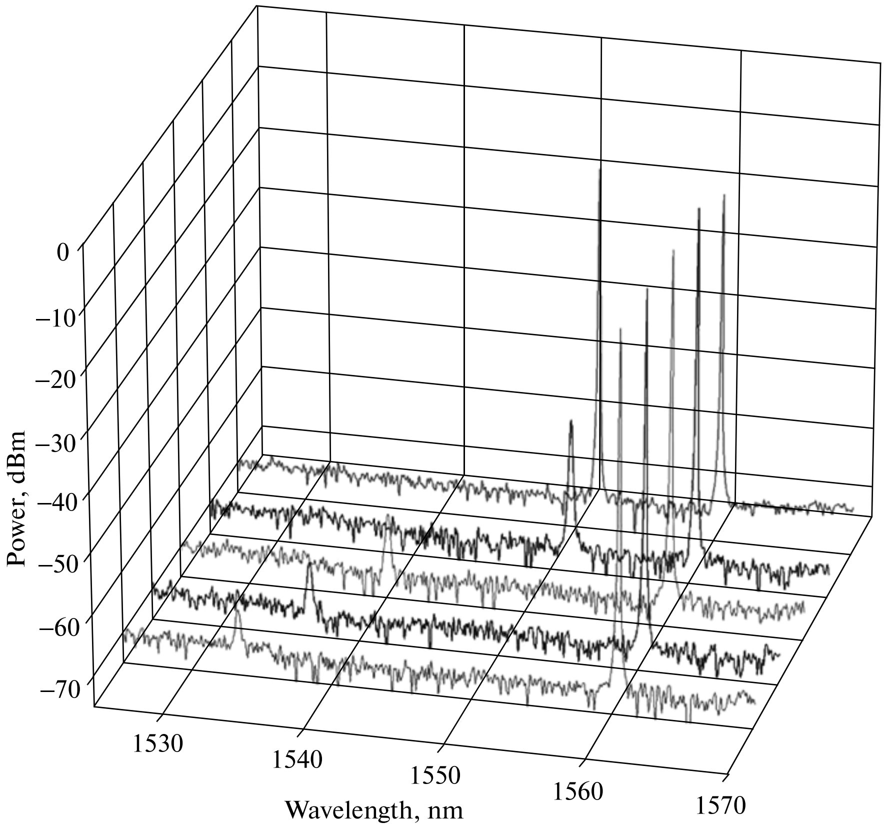

Fig. 3. Output spectra of lasing dual-wavelength in the proposed fiber laser while the passband of TBF_2 at the wavelength of 1560.35 nm and the TBF_1 is tuned to shorter wavelengths.

To realize the relationship of pumping power of 980 nm laser diode and output power of dual-wavelength in the proposed EDF laser, we set the two lasing wavelengths at 1556.35 (λ_1) and 1547.40 nm (λ_2) with −10.0 and −10.4 dBm peak powers initially, when the pumping power was 76.4 mW. And so, Fig. 6 shows the different pumping power versus two output powers of dual-wavelength. The threshold pumping power was around 29.8 mW for the proposed dual-wavelength fiber laser, as shown in Fig. 6. We can also obtain the power difference of dual-wavelength between 0.03 and 1.46 dB under the pumping power of 29.8 to 76.4 mW.

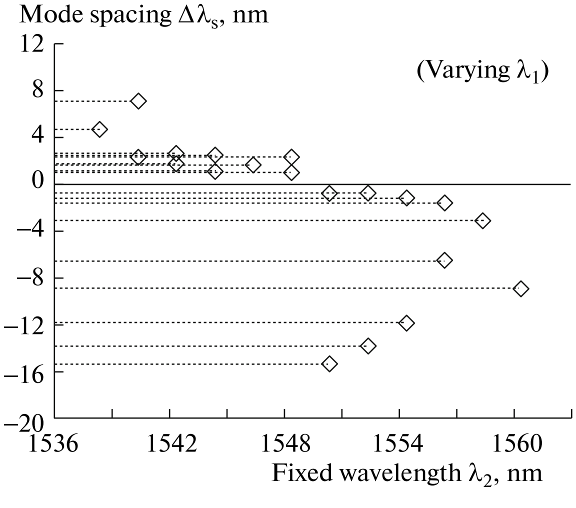

Fig. 4. Measured different mode-spacing of lasing dual-wavelength, having the ΔP within 2.1 dB, when the wavelength λ_2 is placed at the wavelength range of 1538.35 to 1560.35 nm with 2 nm tuning step.

Finally, we investigated and experimentally discussed the stability performances of output wavelength and power in the proposed dual-wavelength EDF ring laser. In this experiment, we also set the lasing dual-wavelength at 1556.35 (λ_1) and 1547.40 nm (λ_2) with −10.0 and −10.4 dBm peak powers initially, when the pumping power was operated at 76.4 mW. First, we can observe the maximum wavelength variation and power fluctuation of dual-wavelength are 0 nm and 1.5 dB after 30 min short-term observation time, as shown in Fig. 7a. Besides, Fig. 7b also shows the corresponding mode-spacing ($\Delta\lambda_s$) and power difference (ΔP) of dual-wavelength in the observation time of 30 min. And, the measured $\Delta\lambda_s$ is no change keeping at 8.75 nm and the ΔP is between 0.3 and 2.1 dB under the observing-time.

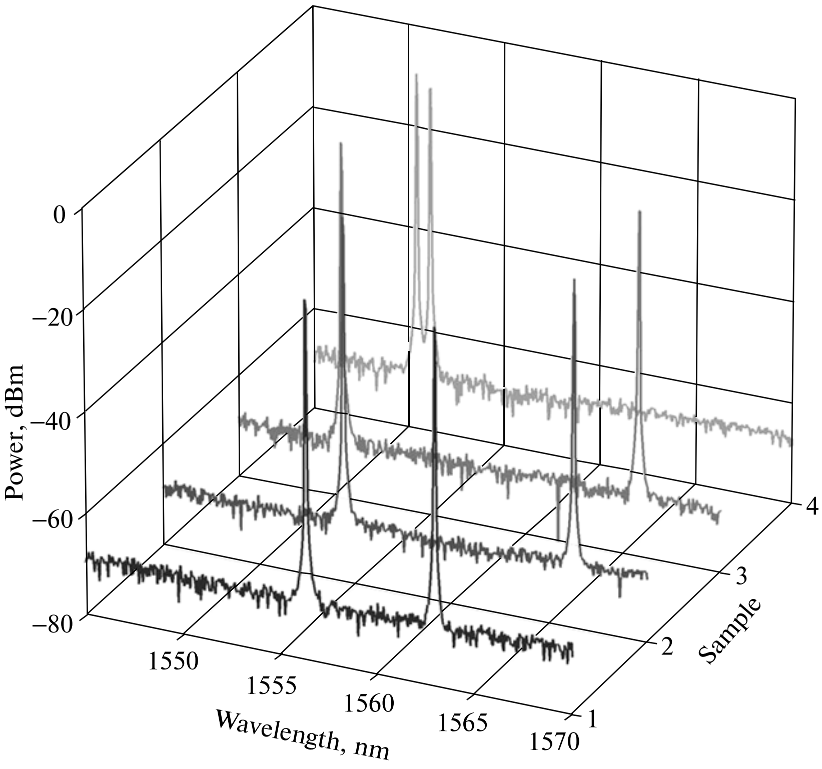

Fig. 5. Output spectra of related dual-wavelengths in accordance with the measured results of Fig. 4.

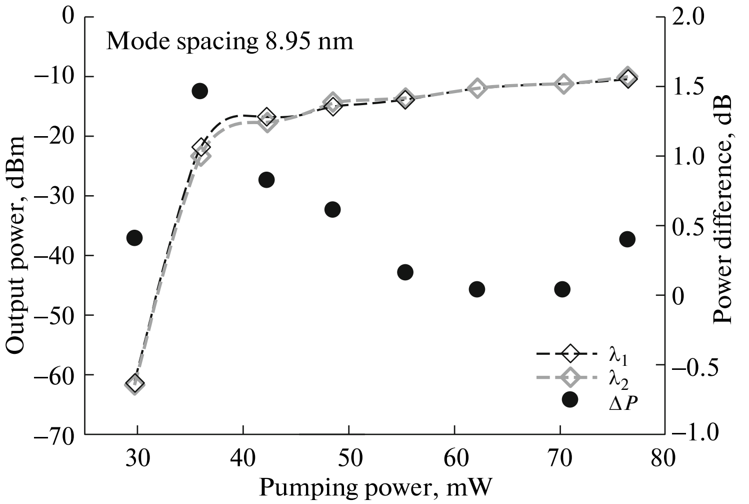

Fig. 6. Measured different pumping power versus two output powers of dual-wavelength at the wavelengths of 1556.35 (λ_1) and 1547.40 nm (λ_2) with −10.0 and −10.4 dBm peak powers initially, when the pumping power was 76.4 mW.

3. CONCLUSIONS

We have proposed and experimentally investigated a stable and tunable dual-wavelength EDF dual-ring laser source. Here, two TBFs were used inside the dual-ring gain cavity to produce dual-wavelength lasing. Furthermore, due to the gain competition of the EDF gain cavity, the mode-spacing ($\Delta\lambda_s$) of dual-wavelength could be limited at different wavelength locations. And, the minimum and maximum mode-spacing in the proposed laser scheme are 0.75 and

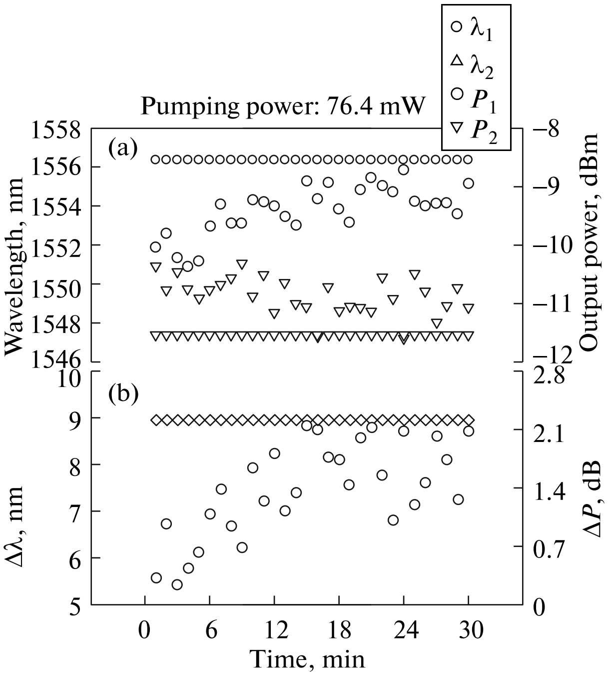

Fig. 7. (a) Output wavelength variation and power fluctuation of dual-wavelength after 30 min short-term observation time when the dual-wavelength is set at 1556.35 (λ_1) and 1547.40 nm (λ_2) with −10.0 and −10.4 dBm peak powers initially and the pumping power was operated at 76.4 mW. (b) The corresponding mode-spacing ($\Delta\lambda_s$) and power difference (ΔP) of dual-wavelength in the observation time.

15.35 nm in C-band operation. The power difference (ΔP) of dual-wavelength could be kept within 2.2 dB in the entire tuning steps. Besides, the output stabilities of proposed EDF ring laser have also been studied and analyzed.

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