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Dual-Wavelength S-Band Erbium-Doped Fiber Double-Ring Laser

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Abstract—We propose and demonstrate an S-band CW dual-wavelength erbium-doped fiber (EDF) dual-ring laser using a compound-ring filter (CRF) with various coupling losses inside the gain cavity. Employing a ring filter combined within the cavity, the fiber laser can lase a dual wavelength without any filter inside the ring loop. The dual-wavelength output exhibits a good performance having optical side-mode suppression ratios (SMSRs) of 31.6 and 31.8 dB and output powers of –9.6 and –9.3 dBm at 1505.58 and 1506.43 nm, respectively, when the coupling loss is 30% inside the cavity. In addition, the output stabilities of the dual-wavelength laser have also been analyzed.

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1. INTRODUCTION

Multiwavelength fiber-ring lasers are very important due to their potential applications in fiber sensor, optical spectroscopy, microwave fiber access networks, wavelength division-multiplexed (WDM) communications, etc. The main issue to achieve a multiwavelength operation at room temperature with a single piece of an erbium-doped fiber (EDF) is the reduced stability at narrower lasing wavelength intervals due to homogeneous broadening [1, 2]. Various techniques have been proposed to meet this challenge [3–5], and to reduce wavelength competition in order to achieve stable multiwavelength oscillations. Many researchers have focused on the technique by inserting the optical filter into the cavity loop [6–13] and using the dual-ring filter method [9] for multiwavelength oscillations. In addition, the effective amplification bandwidths are distributed at the S-(1480–1530 nm), C-(1530–1560 nm), and L-bands (1560–1620 nm); and in such arrangements, the cavity losses corresponding to the different wavelengths must be balanced with the cavity gains simultaneously. Therefore, the multiple lasing wavelengths are not easily controlled. In addition, using the fiber-Bragg gratings (FBG) and Fabry–Perot (FP) laser to obtain the tunable-multiwavelength short pulses were also analyzed and reported [14, 15].

In this study, we propose and experimentally demonstrate a simple configuration for an S-band continuous-wave (CW) dual-wavelength fiber-ring laser with different coupling ratios inside the loop cavity. The compound-ring filter (CRF) technique is also used. Compared with the previous laser schemes, the proposed laser is not only easy to construct, but is also cost effective. Using the CRF laser, the dual-wavelength laser does not need any optical filter into the cavity for

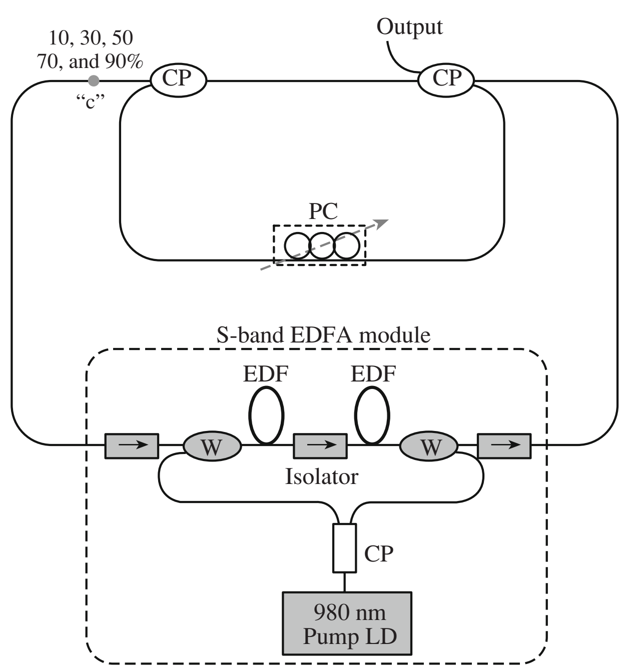

Fig. 1. Experimental setup for a stabilized S-band dual-wavelength EDF ring laser.

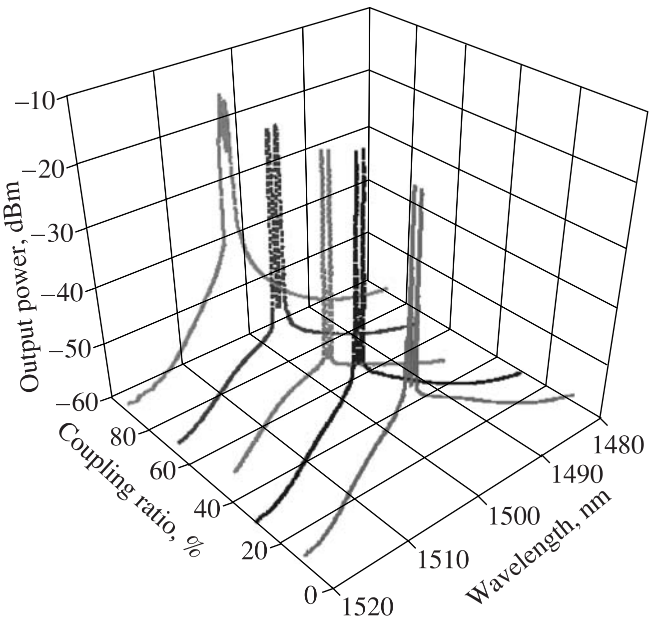

Fig. 2. Different S-band dual-wavelength lasing spectra in the EDF CRF laser when the pumping current operates at 356 mA and the different coupling ratio at point a is 10, 30, 50, 70, and 90%, respectively.

generating a multiwavelength. Moreover, the output stabilities of the fiber laser have also been measured and discussed.

2. EXPERIMENTS AND RESULTS

Figure 1 shows the schematic of the experimental setup for the stable S-band dual-wavelength EDF ring laser. The proposed S-band fiber laser consisted of an S-band erbium-doped fiber amplifier (EDFA), a 2 × 2 optical coupler (CP), a 1 × 2 CP with variable coupling ratios, and a polarization controller (PC). The 1 × 2 CP at point "a" has the coupling ratios of 10, 30, 50, 70, and 90%, respectively, as shown in Fig. 1. The S-band EDF inside an EDFA module has a depressed-cladding design in order to provide a sharp, high-attenuation, long-wavelength cutoff filter into active fibers. The EDF in the first and second stages have different characteristics. The fiber (20 m) in the first stage can provide a low noise figure and medium gain by forward pumping. The fiber (30 m) in the second stage can produce a large output power by backward pumping [10]. In addition, the optical isolator between these two stages can reduce the backward amplified spontaneous emission (ASE) and improve the noise figure performance. The total pump power of this amplifier module can be up to 280 mW, while the bias current is operated at 356 mA.

As shown in Fig. 1, the two cavities of the proposed S-band fiber-ring laser have different free-spectral ranges (FSRs), FSR = c/nL, where c is the speed of light

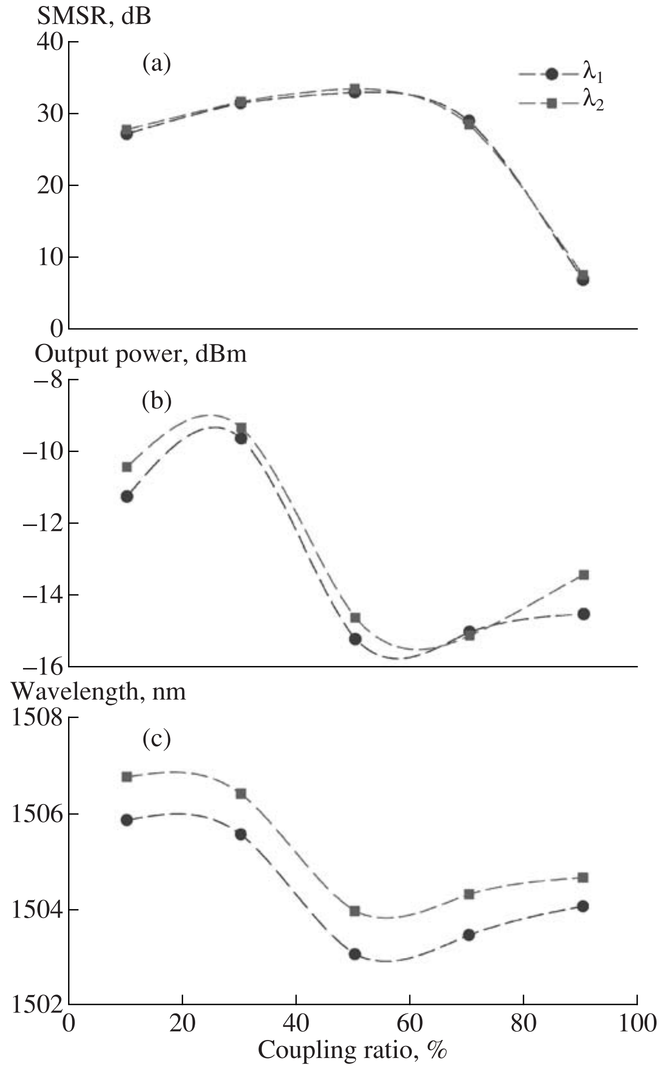

Fig. 3. (a) SMSR, (b) output power, and (c) output wavelength of the proposed S-band dual-wavelength erbium-fiber laser under the coupling ratio of 10, 30, 50, 70, and 90%, respectively.

in a vacuum, n is the average refractive index of the single-mode fiber (n = 1.468), and L is the total cavity length. The proposed CRP structure can be used as a mode filter. Th maximum selectivity occurs when the cavity lengths of L_1 (ring 1) and L_2 (ring 2) are incommensurate produced by the Vernier effect. In each ring, the FSR can also be defined as $FSR_L = \nu/L$ (ν is the fiber-mode group velocity). In the proposed CRF method, the fiber laser can lase a dual wavelength simultaneously. Due to the Vernier effect, the effective FSR becomes the least common multiple number of both the FSR_{L1} and FSR_{L2}. As a result, the mode suppression can be achieved and controlled by the lengths of ring 1 and ring 2. In the experiment, ring 2 is 8 m, which gives a FSR of 25.5 MHz. The total length of ring 1 is about 62 m, corresponding to a passive cavity mode spacing of 3.3 MHz. By optimizing the cavity

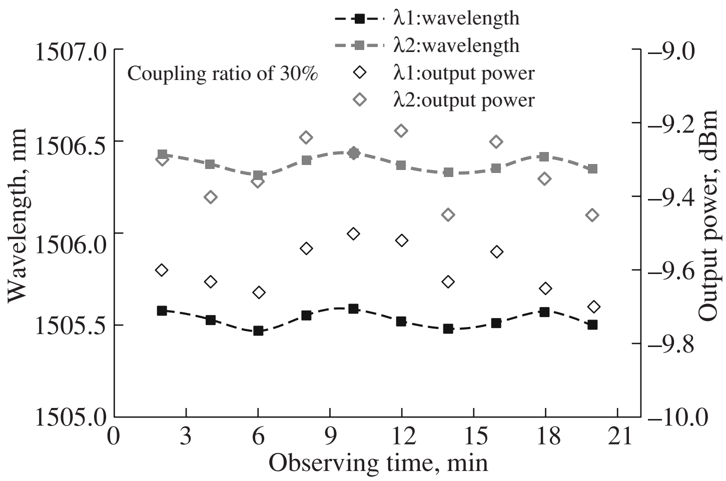

Fig. 4. Output power and wavelength stabilities in a short-term observation for a stable S-band dual-wavelength laser scheme under the coupling ratio of 30%. The lasing wavelengths are 1505.58 (λ_1) and 1506.43 nm (λ_2) initially and the observation time is 20 min.

lengths of the two fiber rings, the dual wavelength can be lased in the proposed laser without using any active or passive component inside the cavities. In addition, the two in-line PCs are used to control and maintain the intracavity polarization states. We used an optical spectrum analyzer (OSA) with a 0.05-nm resolution to measure the output power and wavelength of the proposed dual-ring laser.

Figure 2 shows the S-band dual-wavelength output spectra of the CRF laser at different coupling ratios at point a (10, 30, 50, 70, and 90%) when the pumping current is 356 mA. The corresponding mode spacings ($\Delta\lambda$) are 0.90, 0.85, 0.90, and 0.6 nm, respectively. Figure 2 also shows that the best output power is at a coupling ratio of 30% and the best SMSR is at a coupling ratio of 50%. When the coupling ratio is 90%, the fiber laser shows the worst optical output power. The wavelengths of the lasing modes nearly overlap.

Figure 3 shows the (a) SMSR, (b) the output power, and (c) an output wavelength for the dual-wavelength fiber laser under the coupling ratios of 10, 30, 50, 70, and 90%, respectively. Figure 3a presents the SMSR of >30 dB at ratios of 30 and 50%. By increasing the coupling ratio, the SMSR will increase gradually to a maximum value and, then, decrease. Figure 3b shows a maximum output power of >–9.6 dBm at a 30% coupling ratio. The dual-wavelength output powers are –9.6 (P_1) and –9.3 dBm (P_2) at a wavelength of 1505.58 (λ_1) and 1506.43 nm (λ_2), respectively. Figure 3b also presents the maximum and minimum power differences (ΔP) of the lasing dual wavelength are 1.1 and 0.1 dB with coupling ratios of 90 and 70%, respectively. When the ratio is 50%, the lasing dual wavelength shifts to a shorter wavelength as shown in Fig. 3c. In addition, by decreasing the coupling ratio, the lasing wavelength will shift to a longer wavelength range. Hence, the lasing wavelength is tunable by adjusting the coupling ratios, with a maximum wavelength tuning range of 2.8 nm as illustrated in Fig. 3c.

To evaluate the output stabilities of the proposed laser, a short-term stability measurement of the dual-wavelength laser at the coupling ratio of 30% is performed as shown in Fig. 4. The lasing wavelengths are 1505.58 (λ_1) and 1506.43 nm (λ_2) initially and the observation time is over 20 min for the stability measurement. The output wavelength variations and the output power fluctuations of the two lasing wavelengths are smaller than 0.1 and 0.1 nm and 0.20 and 0.25 dB, respectively, as shown in Fig. 4. After a 40-min observation, the stabilized output of the ring laser is still maintained. We can see that the proposed laser shows a good stability for the output wavelength and power.

3. CONCLUSIONS

We have proposed and demonstrated a stable S-band dual-wavelength EDF dual-ring laser using a CRF method with various coupling ratios inside the ring cavities. The CRF simplifies the laser architecture and allows a dual-wavelength output. The dual-wavelength output exhibits a good performance, having the optical SMSRs of 31.6 and 31.8 dB and output powers of –9.6 and –9.3 dBm at 1505.58 and 1506.43 nm, respectively, when the coupling ratio is 30%. In addition, the optical output power is stable over an observation time of 40 min.

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