Stabilized dual-wavelength erbium-doped dual-ring fiber laser

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Abstract: A stable dual-wavelength erbium-doped fiber (EDF) compound ring laser using a double-ring filter (DRF) is proposed and demonstrated experimentally. By using a ring filter incorporated within the ring cavity, the fiber laser can lase two wavelengths simultaneously. The dual-wavelength output exhibits a good performance having the optical side-mode suppression ratios (SMSRs) of 45.3 and 46.3 dB and output powers of –8.1 and –7.1 dBm, respectively. In addition, the optical output stabilities of the ring laser have been also discussed.

OCIS codes: (140.4480) Optical amplifiers; (060.2320) Fiber optics amplifiers and oscillators

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1. Introduction

Multiwavelength fiber lasers have attracted much attention because of their potential applications in fiber-optic sensors, optical spectroscopy, and microwave photonics systems. Various techniques for the reduction of wavelength competition have been used to achieve stable multiwavelength oscillations. The wavelength competition originates from the homogeneous gain broadening of erbium-doped fibers (EDFs) [1]. A great deal of research has been focused on the technique by inserting a filter into the EDF laser cavity for multiwavelength oscillations [2–9]. In such arrangements, the cavity losses corresponding to the different wavelengths have to be balanced with the cavity gains simultaneously. As a result, the lasing wavelengths are not earily controlled. Recently, the self-seeded Fabry-Pérot laser diodes (FP-LDs) using fiber Bragg gratings have been proposed to generate tunable multiwavelength short pulses [10–12].

In this study, we demonstrate a novel and simple configuration of a dual-wavelength fiber ring laser by using the double-ring filter (DRF). Furthermore, in contrast with the conventional setup, our proposed scheme is easy to be constructed with low cost. Based on the laser scheme, the lasing dual-wavelength doesn't need using any active or passive filter into cavity.

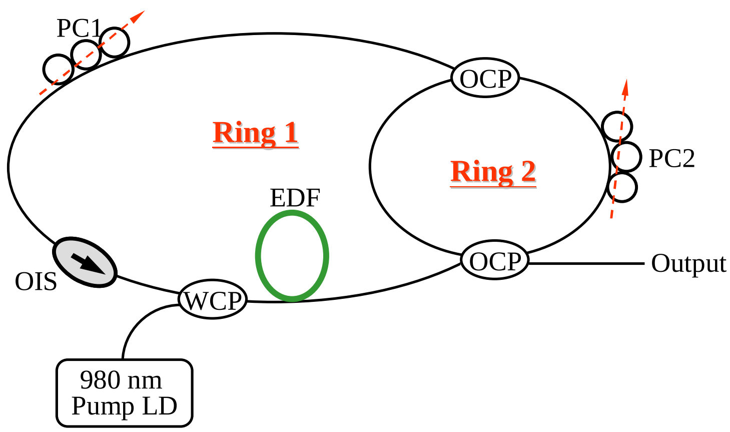

Fig. 1. Stable dual-wavelength fiber ring laser scheme.

2. Experiments and Results

The schematic of our experimental setup for the dual-wavelength fiber ring laser is shown in Fig. 1. The proposed laser scheme consists of an erbium-doped fiber amplifier (EDFA), two 3-dB optical couplers (OCPs) and two polarization controllers (PCs). The EDFA is constructed by an EDF (*model DF 1500F of Fibercore Ltd.*) with 10 m long, a 980/1550 nm WDM coupler, an optical isolator (OIS) and a 980 nm pumping laser with 110 mW. The compound ring is completed with the double-ring filter which serves as an in-line mode selector. Both rings have the laser light propagate in a counterclockwise direction oriented by the optical isolator (OIS). The two cavities have the free spectral ranges (FSRs), FSR = c/nL, where c is the speed of light in vacuum, n is the average refractive index of the single-mode fiber of 1.468 and L is the total cavity length. The proposed DRF can be used to serve as a mode filer. Maximum selectivity occurs when the cavity lengths of L_1 (ring-1) and L_2 (ring-2) are incommensurate, producing by the vernier effect. Therefore, this can be written $L_1/L_2 = m_c/p_c$, where m_c and p_c are integers which don't have common factors. For each ring, ring, the FSR is inversely proportional to its length, and so $\mathrm{FSR}_L = V/L$ (V is the fiber mode group velocity). Thus, the effective FSR of the double-ring cavity is FSR = $p_c\,\mathrm{FSR}_{L2} = mc\ \mathrm{FRS}_{L1}$. Based on the DRF method, the proposed fiber laser architecture can lase dual-wavelength operation. Owing to vernier effect, the value of effective FSR becomes the least common

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multiple number of both FSR_{L1} and FSR_{L2}. As a result, the mode suppression can be achieved and governed by the length of the main-ring and sub-ring cavities we choose. The laser mode oscillates only at a frequency that satisfies the resonant conditions of the main cavity and all of the subring cavities simultaneously. In the experiment, the ring-2 has a ring length of 6 m, which gives a FSR of 34.1 MHz. The total length of ring-1 is about 22 m long, corresponding to a passive cavity mode spacing of 9.3 MHz. Based on the optimal cavity lengths of two fiber ring loops, the dual-wavelength can lase in the proposed laser without using any active or passive component in the intracavity. In addition, two in-line polarization controllers are used to control the intracavity polarization states. Moreover, the output power and wavelength of proposed compound-ring laser are measured by an optical spectrum analyzer (OSA) with a 0.05 nm resolution.

However, due to the homogeneous broadening of erbium ion, the number of lasing mode in the proposed ring laser will be less than four generally. If we want to three or four lasing modes, the proposed dual ring laser perhaps needs to add one to two ring cavities. Because the limitation of cavity length is fixed, the tunability of laser is also limited.

In the compound ring laser, since the proposed double-ring filter (DRF) is polarization-dependent, the output power can be adjusted by varying the eigenstate of the polarization in the ring. Therefore, by rotating the two PCs to align the maximal output power of eigenstate of the polarization can always be obtained.

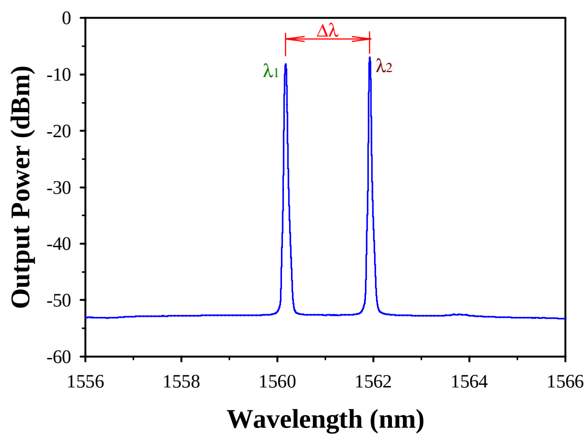

Fig. 2. Output dual-wavelength of the proposed laser at 110 mW pumping power.

When the 980 nm pumping power increases to 110 mW, the output dual-wavelength of proposed fiber laser is shown in Fig. 2. The output dual-wavelength of the proposed laser is 1560.17 (λ_1) and 1561.93 nm (λ_2) and the output power is −8.1 (P_1) and −7.1 dBm (P_2), respectively. The mode spacing ($\Delta\lambda$) and output power variation (ΔP) in the dual-wavelength are 1.76 nm and 1 dB at 110 mW pumping level. From the experimental results, the $\Delta\lambda$ is 1.76 nm ($\Delta\nu \cong 220$ GHz). The wavelength spacing also satisfies the lease common multiple number of both FSR_{L1} and FSR_{L2}. In Fig. 2, the SMSR of this dual-wavelength is larger than 45.3 dB. Figure 3 shows the output spectra versus the different pumping power operated at 28 to 110 mW for the ring filter laser. When the pumping power is below 28 mW, the dual-wavelength will be not observed. When the 980 nm pumping power operates between 28 to 110 mW, the output power and SMSR of λ_1 and λ_2 are distributed at −19.5 to −8.1 dBm and 33 to 45 dB, and −27.8 to −7.1 dBm and 32 to 42 dB, respectively, as shown in Fig. 4. Moreover, the maximum and minimum output power variations of 8.3 and 1 dB are also observed at 28 and 110 mW pumping level, respectively.

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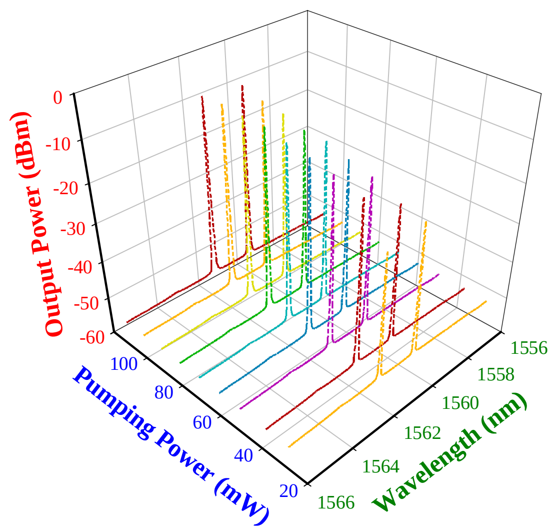

Fig. 3. Output spectra versus the different pumping power operated from 28 to 110 mW for the ring filter fiber laser.

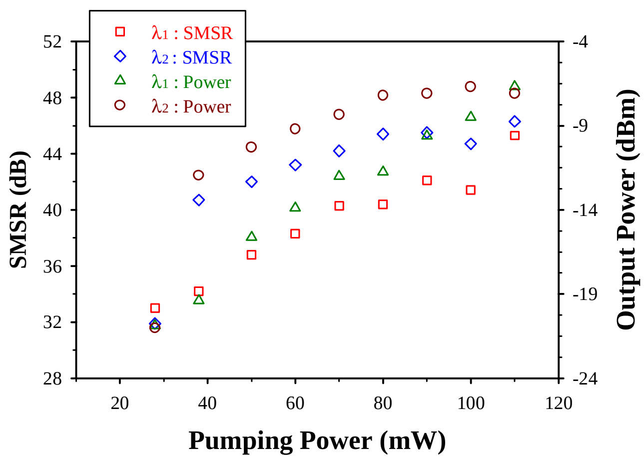

Fig. 4. Output power and SMSR of λ_1 and λ_2 for the proposed dual-wavelength laser versus the different pumping power operated from 28 to 110 mW.

To investigate the laser performances of output power and output wavelength stabilities, the short-term stability of the proposed structure is measured and shown in Fig. 5. The lasing wavelengths are 1560.17 nm (λ_1) and 1561.93 nm (λ_2) initially and the observing time is over 20 minutes for the stability observation. Therefore, the output central wavelength variations and the output power fluctuations of the two lasing wavelengths are smaller than 0.11 and 0.11 nm and 0.5 and 0.4 dB, respectively, as shown in Fig. 5. Due to the vernier effect of the DRF fiber laser, the proposed lasing dual-wavelength output can be locked. Therefore, the proposed laser shows the better stability of output wavelength and power. During an hour observation, the stabilized output of the ring laser is still maintained. As a result, the proposed fiber laser not only can obtain dual-wavelength output, but also has the better output stability in a long-term observing time. In addition, the proposed laser has the advantages of simply architecture and cost-effective for stable dual-wavelength output.

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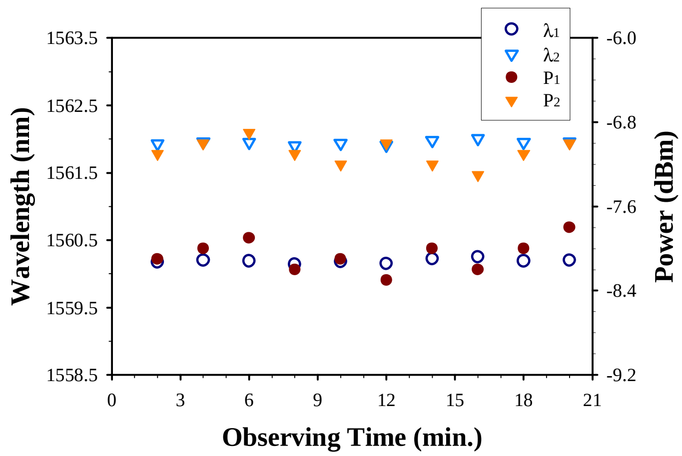

Fig. 5. Observing short-term stability of the proposed structure when the lasing wavelengths are 1560.17 nm (λ_1) and 1561.93 nm (λ_2) initially and the observing time is over 20 minutes.

3. Conclusion

In summary, we have proposed and investigated a stable dual-wavelength fiber ring laser for more than an hour. By using a ring filter incorporated within the ring cavity, the fiber laser can lase in two wavelengths simultaneously. The two lasing wavelengths are 1560.17 and 1561.93 nm. And the dual-wavelength output exhibits a good performance having the optical side-mode suppression ratios (SMSRs) of 45.3 and 46.3 dB and output powers of −8.1 and −7.1 dBm, respectively. Moreover, the behaviors of the output power and wavelength stabilities have also been studied.

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