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Stable and wavelength-tunable erbium-doped fiber double-ring laser in S-band window operation

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Abstract

A stable and tunable S-band erbium-doped fiber (EDF) double-ring laser has been proposed and experimentally demonstrated. Based on the double-ring configuration, the EDF ring laser exhibits more stable output wavelengths and powers than those of the single-ring. Wide tunable range of 1484–1518 nm, the side-mode suppression ratio (SMSR) of larger than 44.7 dB/0.05 nm and the output power of larger than −2.2 dB m over the operation range of 1484–1510 nm have been retrieved.

Keywords: EDF; Fiber laser; S-band; Double-ring

1. Introduction

Broadband tunable laser sources are the major devices in optical transmission systems. The stable output frequency and power of the fiber ring lasers are always required for wavelength division multiplexing (WDM) networks and sensing systems. Recently, several stabilization techniques, such as integrating two cascaded FFP filters of wide different free spectral ranges (FSRs) into cavity [1], using passive multiple-ring cavity [2], have been reported. In [3], we also demonstrated a stabilization technique employing a Fabry–Perot laser (FP-LD) and an FFP filter for the multi-mode erbium-doped fiber (EDF) ring laser. However, the tuning

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steps of the proposed fiber ring laser were subjected to the mode-spacing of FP-LD. Because of the bandwidth limitation of erbium-doped fiber amplifiers (EDFAs), the operation region of EDF ring lasers only covers both the C- to L-band (1530–1610 nm) [4,5], and is not sufficient until an EDFA and a fiber ring laser for S-band operation are proposed [6,7]. In this letter, we propose and experimentally investigate a stable and tunable S-band (1484–1518 nm) EDF ring laser with double-ring configuration. This fiber ring laser has free tuning steps and features stable output powers and wavelengths in S-band. The behavior of the output power and wavelength stabilities, tuning range and side-mode suppression ratio (SMSR) has also been experimentally studied.

2. Experiments

Fig. 1 shows the experimental setup for the stable and tunable S-band EDF double-ring laser. This apparatus consists of two 2×2 and 50:50 optical couplers, a polarization controller (PC), two fiber Fabry–Perot filters (FFP-TP), and an S-band EDFA module with two amplifier stages and a power-sharing 980 nm pump laser. The total pump power of this S-band amplifier can be up to 280 mW while the bias current is operated at 356 mA. The S-band EDF inside EDFA module has a depressed cladding design in order to provide a sharp, high attenuation, long wavelength cutoff filter into active fibers. Furthermore, the EDFA module comes in two stages EDF of different properties. The fiber in the first stage is 20 m long, and both low noise figure and medium gain are contributed by forward pumping. The fiber in the second stage has the fiber length of 30 m, and large output power can be generated through backward pumping. Besides, the optical isolator is arranged between these two stages in order to reduce backward amplified spontaneous emission (ASE). Both high gain of 32 dB and low noise figure of 5.7 dB at 1500 nm can be obtained while the input power of −25 dB m is provided. The saturated output power at 1500 nm can reach 14 dB m for input signal power of 0 dB m. Moreover, two FFP filters are all-fiber components with widely tunable range, FSR of 44.5 nm, finesse of 200, low polarization-dependent loss of ~0.1 dB and insertion loss of <0.5 dB. Wavelength selection in the double-ring laser cavity can be achieved by applying external voltage (0–12 V) on the piezoelectric transducer (PZT) of two FFP filters. Two FFP filters are nearly tuned to the same wavelength for single frequency output. The stable output wavelength and power of the laser can be easily achieved while the state of polarization adjusted by the PC in the dual-ring cavity is maintained. In addition, an optical spectrum analyzer (OSA) with 0.05 nm resolution and a power meter (PM) are used to measure the output wavelengths and powers of the proposed ring laser.

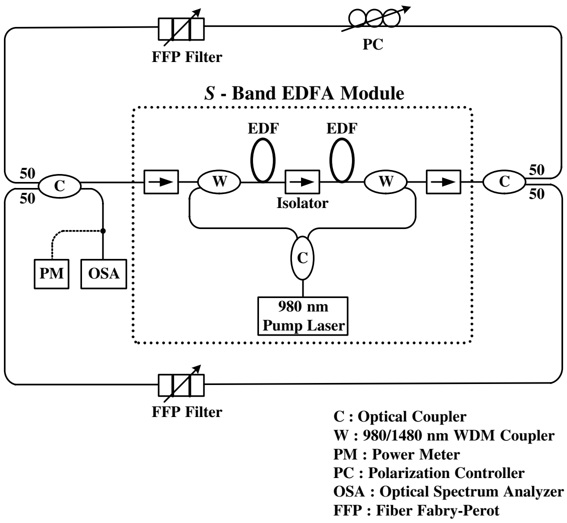

Fig. 1. Experimental setup of the S-band EDF double-ring laser.

3. Results and discussions

Double-ring configuration can serve as a mode filter and only the particular modes, which coincide with the central frequencies of two filters, can oscillate. The double-ring configuration shown in Fig. 1 can be viewed as the combination of two single-ring cavities called main-ring (52 m long) and sub-ring (60 m long) cavities, respectively. Moreover, as schematically depicted in Fig. 2, the main- and sub-ring cavities have FSRs of

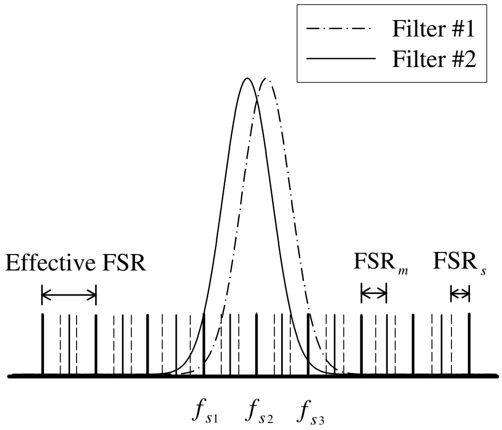

Fig. 2. Schematic diagram of mode selection in the double-ring laser cavity.

FSR_m and FSR_s, respectively. Owing to Vernier effect [2], the value of effective FSR becomes the least common multiple number of both FSR_m and FSR_s. As a result, the mode suppression can be achieved and governed by the length of the main-ring and sub-ring cavities we choose. In addition, two lasing spectra from FFP filter #1 and #2 are nearly overlapped to provide further mode restriction on possible laser modes. Finally, only 3 modes f_{s1-3} are selected for oscillation and mode f_{s2} dominates. Comparing with the single-ring case, the proposed fiber ring laser has fewer selected mode and less mode competition effect. Thus, the mode stability can be guaranteed. Therefore, two lasing lights from two ring cavities can interfere mutually to retrieve the stabilized frequency output as long as a static state of polarization is provided.

Fig. 3 shows the optical spectra of the stable and tunable S-band EDF double-ring laser over the operation region of 1484–1518 nm when the voltages of 0–12 V are applied on two PZTs of two FFP filters, respectively. The insert of Fig. 3 is the ASE spectrum of the S-band amplifier. Fig. 4 shows the output power and SMSR versus the tuning wavelength for this double-ring laser over the bandwidth from 1484 to 1518 nm. As seen in Fig. 4, the maximum output power of 0 dB m is retrieved at around 1498 nm, and the output powers drop to −8.71 dB m at 1518 nm. The output power level can be kept larger than −2.2 dB m over the

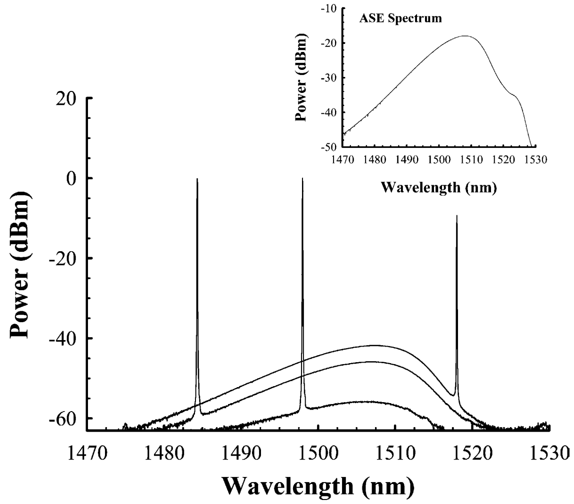

Fig. 3. The output wavelength spectra of the S-band EDF double-ring laser.

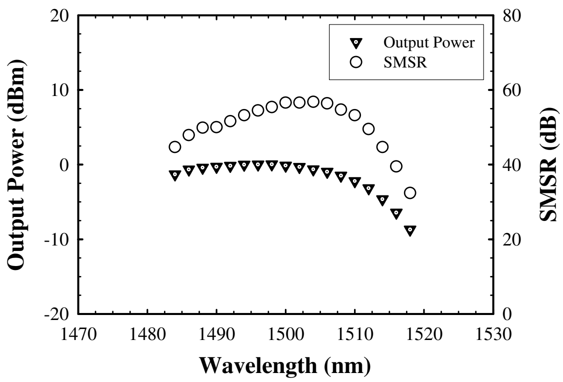

Fig. 4. The output power and SMSR versus the tuning wavelength for this proposed ring laser over the tuning range from 1484 to 1518 nm.

tuning range of 1484–1510 nm. Owing to the ASE compression and gain competition effect, the maximum SMSR value can be up to 56.8 dB/0.05 nm at near 1504 nm. The SMSR can be kept larger than 44.7 dB/0.05 nm in a wide tuning range over 30 nm (1484–1514 nm).

To investigate the behaviors of output power and wavelength stabilities, the short-term stability of the proposed configuration (in Fig. 1) is measured and compared with the traditional architecture [6]. The operating conditions such as a pump power of 280 mW and lasing wavelength of 1948 nm are set equally for both single-ring and double-ring configurations. The measured slope efficiencies are about 2.02% and 1.13% for the *S*-band fiber laser with single-ring and double-ring structures, respectively; the threshold pump power of the proposed fiber laser is 142 mW and that of the traditional one is 122 mW. As indicated in Fig. 5(a), the average output power of the single-ring and double-ring lasers are 4.28 and 0.02 dB m, respectively. Moreover, the normalized power fluctuation of the single-ring laser is 7.85%, while that of the double-ring laser is only 0.92%. The observing time is over 900 s. In addition, Fig. 5(b) shows that the wavelength variations of two configurations are 0.03 and 0.06 nm, respectively. Obviously, the intra-cavity loss of the double-ring configuration resulting from polarization dependant components is higher than that of the single-ring structure. Accordingly, the results reveal that increasing the intra-cavity loss will allow more stability but sacrifice the threshold pump power and slope efficiency of the fiber laser. During 3-h observation, the stable output of the proposed double-ring laser is still maintained. Therefore, compared with traditional fiber ring laser, this laser has better stability.

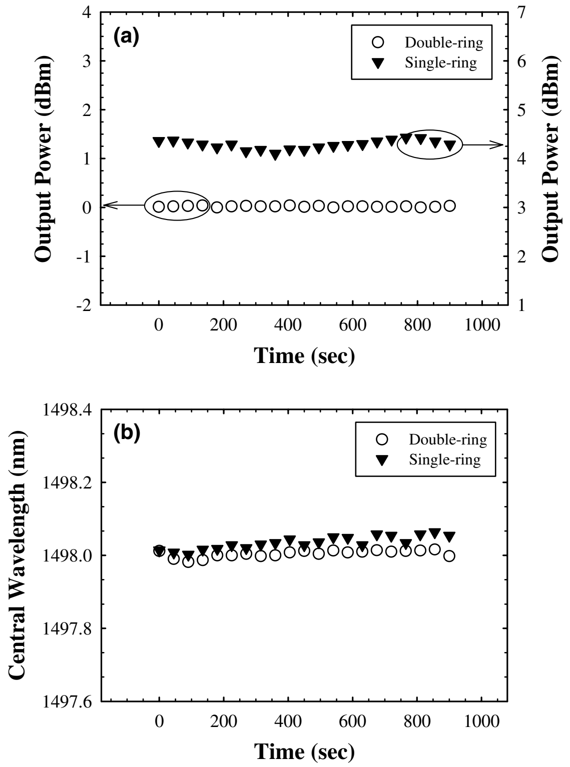

Fig. 5. (a) The output power fluctuation and (b) the wavelength variation of the proposed and traditional configurations as the wavelength is set at 1498 nm, respectively.

4. Conclusion

In conclusion, we propose and experimentally demonstrate a stable and tunable S-band EDF double-ring laser. Based on the proposed configuration, this fiber ring laser exhibits more stable output power than that of the traditional one. Wide tunable range of 1484–1518 nm, the SMSR of larger than 44.7 dB/0.05 nm and the output power of larger than −2.2 dB m over the operation range of 1484–1510 nm have been retrieved.

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