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Broadband C- plus L-band double-ring fiber laser based on a two-stage hybrid amplifier

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Abstract. A stable and wavelength-tunable C- plus L-band fiber double-ring laser, which uses a two-stage hybrid amplifier with a semiconductor optical amplifier and an erbium-doped fiber amplifier, has been proposed and experimentally demonstrated. Based on the double-ring configuration, the proposed fiber ring laser exhibits more stable output wavelengths and powers than the single-ring laser. A wide tunable range of 1540 to 1620 nm, a side-mode suppression ratio (SMSR) of >31.2 dB/0.05 nm over a wide tuning range from 1550 to 1612 nm, and an output power of >2 dBm over the operation range of 1546 to 1608 nm have been achieved. [DOI: 10.1117/1.2083307]

Subject terms: erbium-doped fiber (EDF); fiber ring laser; L band; double ring.

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1 Introduction

Broadband tunable fiber lasers are the major optical devices in optical communication systems. Stable output frequency and power of optical fiber ring lasers are essential for wavelength division multiplexing (WDM) networks and sensor systems. In general, a fiber Fabry-Perot (FFP) filter inside the ring cavity of the fiber ring lasers can be used to provide wavelength selection. However, that is not enough to provide stable output wavelength and power of a fiber ring laser. Recently, several techniques have been studied, such as integrating two cascaded FFP filters of different wide free spectral ranges (FSRs) into a cavity, to provide full tunability and single-longitudinal-mode (SLM) selection,[1,2] using a compound ring resonator composed of a dual-coupler fiber ring (DCFR) or passive multiple-ring cavity to guarantee SLM laser oscillation.[3,4] Due to the bandwidth limitation of erbium-doped fiber (EDFs), EDF ring lasers can only be operated at S (1480 to 1530 nm), C (1530 to 1560 nm), or L band (1560 to 1610 nm); see Refs. 3, 5, and 6, respectively.

In this paper, we propose and experimentally investigate a widely stable and wavelength-tunable C- plus L-band fiber double-ring laser using a two-stage hybrid amplifier module, which is composed of a semiconductor optical amplifier (SOA) and an erbium-doped fiber amplifier (EDFA). The behavior of the output power, wavelength stability, tuning range, and side-mode suppression ratio (SMSR) has also been experimentally studied.

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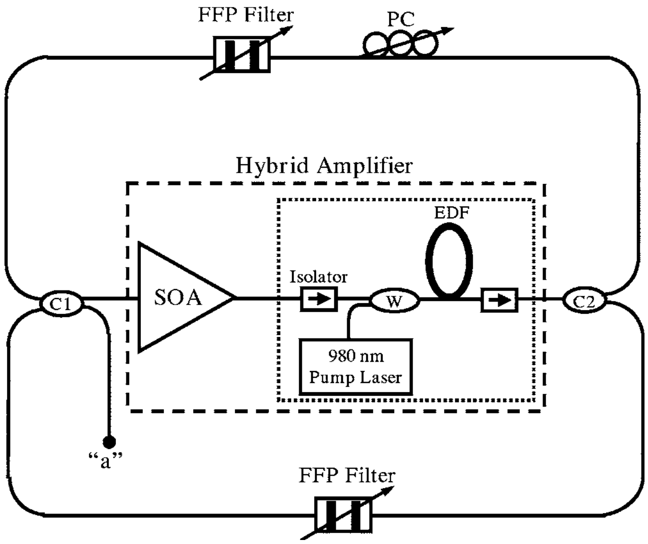

Fig. 1 Experimental setup of the proposed fiber double-ring laser.

2 Experiments

Figure 1 shows the experimental setup for the widely stable and wavelength-tunable C- plus L-band fiber double-ring laser. This proposed apparatus consists of two 2×2 and 50:50 optical couplers (C_1 and C_2), a polarization controller (PC), two FFP filters, and a two-stage hybrid amplifier module. In the hybrid amplifier module, the first (SOA) stage has 250-mA bias current, and the second (EDFA) stage is composed of a high-concentration 18-m-long EDF (High Wave 742), a 1550 to 980-nm WDM coupler (W), two optical isolators, and a 980-nm pump laser, as shown in Fig. 1. According to the proposed structure, we only employ an SOA and a shorter EDF length to achieve a wide operation range of 1540 to 1620 nm. Actually, the optical output of the SOA can be used to pump the second stage (EDFA module) for extending the bandwidth from C to L band. The two FFP filters are all-fiber devices having a wide tuning range, a low insertion loss of <0.5 dB, and polarization-dependent loss (PDL) of ~ 0.1 dB. Two FFP filters having a free spectral range (FSR) of 80 nm and a finesse of 200 can provide wavelength selection in the ring laser cavity by applying an external voltage of 0 to 12 V to the piezoelectric transducer (PZT) of the two FFP filters. Due to the remaining PDL of the passive components (optical filters, isolators, etc.) and the polarization-dependent gain (PDG) in the EDF, proper adjustment of the PC is necessary. In addition, an optical spectrum analyzer (OSA) and a power meter (PM) are used to measure the output spectra and powers for this proposed fiber ring laser at point "a" in Fig. 1.

3 Results and Discussion

The double-ring configuration can serve as a mode filter so that only the particular resonant mode that coincides with the central frequencies of the two filters can oscillate. The double-ring configuration can be viewed as the combination of the main and subsidiary ring cavities, which have free spectral ranges (FSRs) of FSR_m and FSR_s, respectively. Owing to the vernier effect of the double-ring cavity,[4] the value of the effective FSR becomes the least common multiple of FSR_m and FSR_s, and mode suppression can be achieved. Besides, the two lasing spectra from FFP filters 1 and 2 are nearly overlapped to provide further restriction on possible laser modes. As a result, only the mode f_s is selected for oscillation and mode stability can be guaranteed. Thus, the two beams from the two ring cavities can interfere mutually to produce a stabilized single-frequency output when the PC is properly controlled.

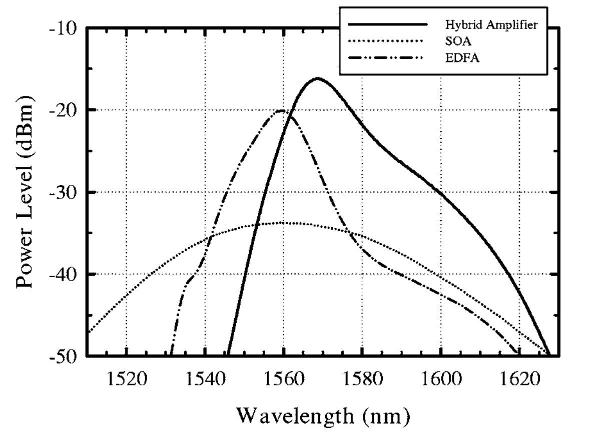

Fig. 2 Optical spectra of the ASE for the hybrid amplifier, the first (SOA) stage, and the second (EDFA) stage.

Figure 2 shows the amplified spontaneous emission (ASE) spectra of the first (SOA) stage, the second (EDFA) stage, and the hybrid amplifier when the EDFA and SOA were operated at 100-mW pump power and 250-mA bias current, respectively. In Fig. 2, the maximum peak power levels of ASE for the EDFA and SOA are −20.1 and −33.2 dBm at near 1559 and 1561 nm, respectively. In addition, when a hybrid amplifier consisting of an SOA and an EDFA is used, the medium gain will be enhanced at the longer wavelength. Therefore, an 80-nm ASE bandwidth of 1540 to 1620 nm can be achieved, and the −18.7-dBm peak power level occurs at 1566 nm, as shown in Fig. 2.

Figure 3 shows the optical spectra of the proposed fiber double-ring laser over the operating region of

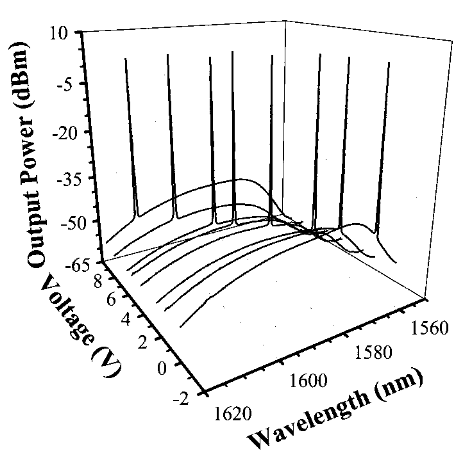

Fig. 3 The output wavelength spectra of the proposed double-ring laser over the wavelength range of 1540 to 1620 nm.

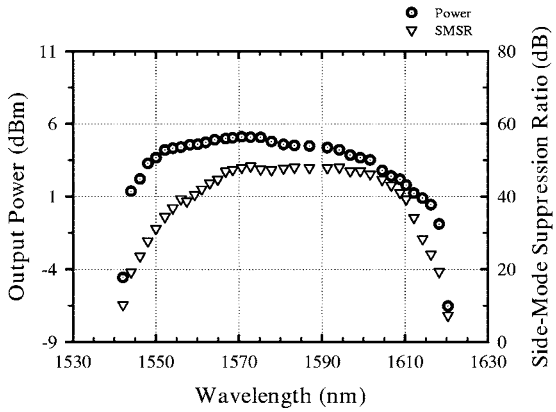

Fig. 4 The output power and SMSR versus the tuning wavelength for the proposed ring laser over the tuning range from 1540 to 1620 nm.

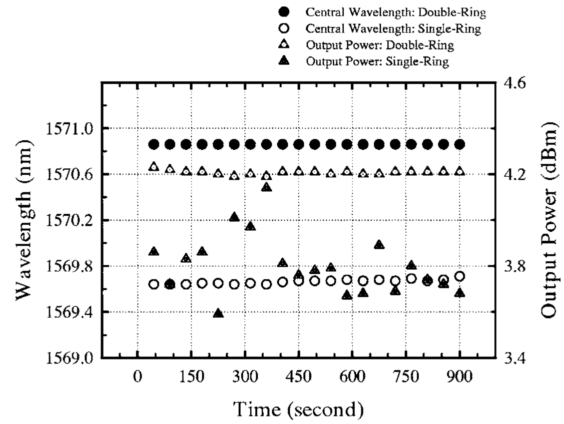

Fig. 5 The output power fluctuation and the wavelength variation of the proposed (double-ring) and traditional (single-ring) configurations when the wavelength is set at 1570.1 nm.

1540 to 1620 nm when voltages of 0 to 12 V are applied to the PZTs of the two FFP filters. Figure 4 shows the output power and SMSR versus the tuning wavelength for this double-ring laser over the bandwidth from 1540 to 1620 nm. As seen in Fig. 4, the maximum output power of 5.1 dBm is obtained at around 1570 nm, and the output power drops to 3.8 and 1.1 dBm at 1596 and 1614 nm, respectively. The output power level can be kept above 2.0 dBm over the tuning range of 1546 to 1608 nm. Owing to the ASE compression and gain competition, the maximum SMSR value can be up to 48.3 dB at 0.05 nm near 1572 nm. The SMSR can be kept larger than 31.2 dB at 0.05 nm over a tuning range of 62 nm from 1550 to 1612 nm.

The threshold current of the SOA is 50 mA in the proposed configuration. The measured slop efficiencies are 2.13% and 1.25% for the double-ring and the traditional single-ring cavity.[7] When the pumping current of an SOA is above about 200 mA, then the output power will be saturated.

To investigate the behavior of the output power and the wavelength stability, the short-term stability of the proposed configuration (in Fig. 1) was measured and compared with the traditional architecture,[7] as shown in Fig. 5. The lasing wavelength is 1570.1 nm initially, and the observation time is more than 900 s. In Fig. 5, the output power fluctuations for the proposed (double-ring) and traditional (single-ring) configuration are 0.02 and 0.42 dB, respectively. Figure 5 also shows that the wavelength variations of two configurations are 0 and 0.1 nm (readout resolution=0.01 nm), respectively. During 4-h observation, the stable output of the proposed double-ring laser is still maintained. Therefore, compared with the traditional fiber single-ring laser, this proposed laser has better stability.

4 Conclusion

In conclusion, we have proposed and experimentally demonstrated a stable and wavelength-tunable C- plus L-band fiber double-ring laser, which uses a hybrid amplifier with an SOA and an EDFA. Because of the double-ring configuration, the proposed fiber ring laser exhibits stability of output wavelength and power over a broader band than does the single-ring laser. We have achieved a wide tuning range of 1540 to 1620 nm, a maximum SMSR of 48.3 dB at 0.05 nm near 1572 nm, an SMSR of 31.2 dB at 0.05 nm over a tuning range of 62 nm (1550 to 1612 nm), and an output power of >2 dBm over the operation range of 1546 to 1608 nm.

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