Optical Engineering 44(4), 044204 (April 2005)

Stable and tunable fiber double-ring laser based on an erbium-doped waveguide amplifier

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Abstract. A stable and tunable fiber double-ring laser based on an erbium-doped waveguide amplifier (EDWA) is proposed and experimentally demonstrated. A widely tunable range from 1527 to 1567 nm, the side-mode suppression ratio (SMSR) of >45.6 dB/0.05 nm and the output power of >1.04 dBm in the operating range from 1535 to 1565 nm can be achieved for this ring laser. By applying the double-ring configuration, the ring laser is stabilized. The central wavelength variation of <0.02 nm and the power fluctuation of <0.03 dBm can therefore be retrieved.
[DOI: 10.1117/1.1886727]

Subject terms: erbium-doped waveguide amplifier; fiber laser; double ring.

Paper 040460 received Jul. 13, 2004; revised manuscript received Sep. 29, 2004; accepted for publication Oct. 21, 2004; published online Mar. 30, 2005.

1 Introduction

Fiber ring lasers based on erbium-doped fibers (EDFs) have been studied intensively because of their wide tuning range, high output power, and attractive applications to optical communications, spectroscopy, and fiber sensing. Wavelengths can be easily tuned by a fiber Fabry-Perot (FFP) filter inside the ring cavity. However, the out wavelength and power of conventional fiber ring lasers are slightly unstable. Recently, several approaches have been reported to improve the stability of fiber ring lasers, such as using two cascaded FFP filters of wide, different free spectral ranges (FSRs) in the cavity to provide single-longitudinal-mode (SLM) selection and full tenability,[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] In this work, a stable and wavelength-tunable fiber ring laser, which employs an erbium-doped waveguide amplifier (EDWA) and double-ring structure, has been proposed and demonstrated. This fiber double-ring laser features both good performance and compact size. Moreover, the characteristics of the output power and wavelength stabilities, tuning range, and side-mode suppression ratio (SMSR) have also been experimentally studied.

2 Experiments

The experimental setup of the stable and tunable fiber double-ring laser based on an EDWA is illustrated in Fig. 1. This apparatus comprises a polarization controller (PC), two 50:50 optical couplers, two fiber Fabry-Perot filters (FFP-TP), and an EDWA module (produced by *Teem Photonics*) with an uncooled laser pump. The EDWA, which is produced with a two-step ion exchange process in Er/Yb-doped phosphate glass, has the same advantages of the EDFA, such as low noise figure, low polarization dependence, and no cross talk between WDM channels. This EDWA module has the feature of a 4.5-dB noise figure over the entire C band, 15-dB small signal gain obtained in the gain medium of only 5 cm, 12-dBm output power when the double-pump scheme is used, and the pump current of 440 mA is applied at ambient temperature. In addition, optical isolators can reduce backward amplified spontaneous emission (ASE) and improve noise figure performance, and the pump kill filter is utilized to eliminate 980-nm pump power and keep 1550-nm signal pass. In view of both compactness and functionalities, fiber wavelength division multiplexers (FWDMs), pump kill filter, an uncooled laser pump, and optical isolators are all attached directly into the EDWA module. Therefore, the size of this packaged block is just about 40 cm^3 and is 1/5 the typical size of EDFA.

Also, two FFP filters are all-fiber devices with free spectral range (FSR) of 44.5 nm, the finesse of 200, low insertion loss of <0.5 dB, and low polarization-dependent loss of ~ 0.1 dB. As the external voltages on the piezoelectric transducer (PZT) of two FFP filters are properly adjusted, the stablized wavelength tuning in the double-ring configuration can be easily realized. Two FFP filters in the double-ring configuration 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 PC in the dual-ring cavity is properly adjusted. In addition, an

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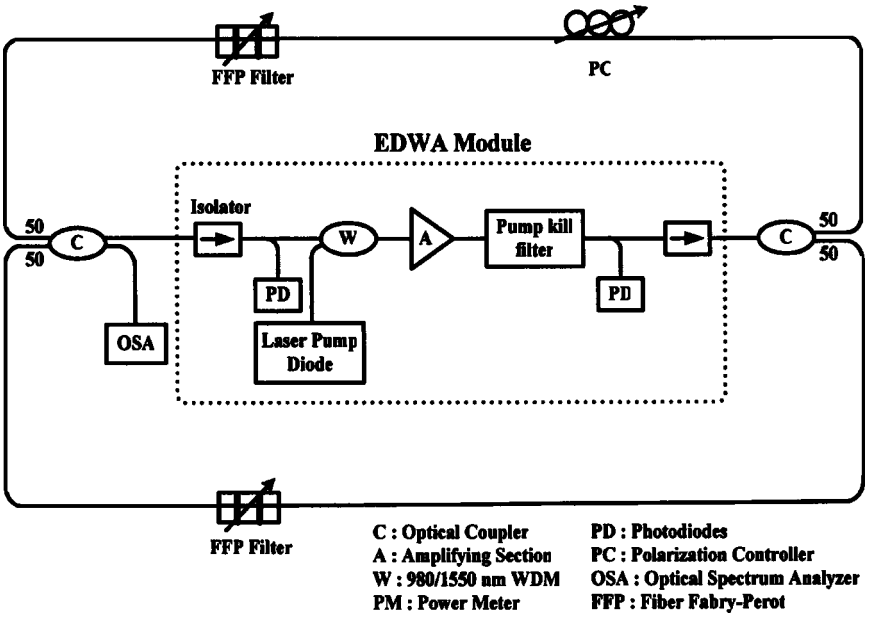

Fig. 1 Experiment setup of the stable EDWA-based fiber double-ring laser.

optical spectrum analyzer (OSA) with 0.05-nm resolution is used to measure the output wavelengths and powers of the proposed fiber laser.

3 Results and Discussions

Double-ring configuration, which is regarded as a mode filter, can retrieve the stabilized single wavelength output while the FFP filters and PC within the ring cavities are properly controlled. Therefore, Fig. 2 illustrates the optical spectra of this EDWA-based double-ring laser. When voltages from 0 to 12 V are properly applied on the PZTs of two FFP filters, lasing lights from 1527 to 1567 nm can be selected. The insert of Fig. 2 is the ASE spectrum of the EDWA module. Figure 3 shows the output power and SMSR versus the tuning wavelength from 1527 to 1567 nm. As indicated in Fig. 3, the maximum output power of 2.07 dBm is retrieved at around 1555 nm. However, the output powers reduce to −2.51 and −0.43 dBm with the operating wavelength at 1527 and 1567 nm, respectively. The output power is always kept larger than 1.04 dBm over the tuning range of 1535 to 1565 nm. On the other hand, the SMSR can be maintained and is larger than 45.6 dB/0.05 nm over the wide tuning range from 1535 to 1565 nm. According to the ASE compression and gain competition effect, the maximum SMSR value can be up to 55.8 dB/0.1 nm around 1537 nm.

The double-ring configuration consisting of the main and subring cavities can serve as a mode-restricting element.[4] Owing to the vernier effect, the effective FSR in this double-ring cavity is equivalent to the least common multiple number of FSRs in each cavity, and mode suppression can be initially achieved. Next, the main cavity, which is composed of a polarization controller, a Fabry-Perot filter, two 50:50 couplers, and an EDWA, has provided coarse wavelength selection and allows several longitudinal modes to exist in this cavity. The polarization controller is working to compensate the polarization state between vertical and

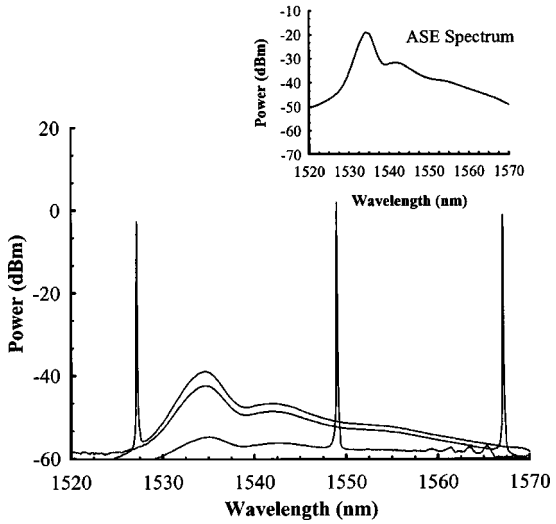

Fig. 2 The optical output spectra of the EDWA-based fiber double-ring laser.

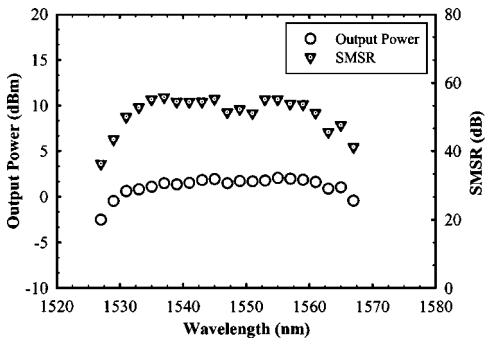

Fig. 3 The output power and SMSR at different wavelengths over the tuning range from 1527 to 1567 nm.

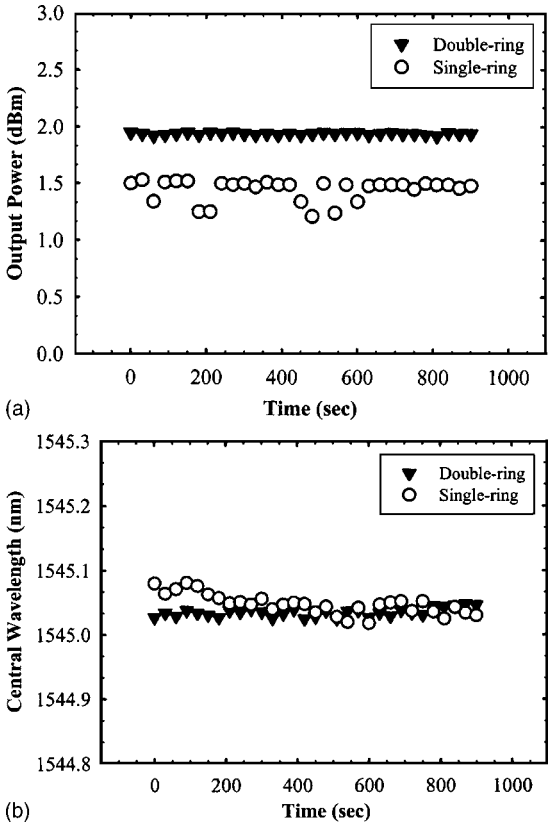

Fig. 4 (a) The output power fluctuation and (b) the wavelength variation of proposed and conventional configurations with the wavelength initially set at 1545 nm.

horizontal modes and stabilize the cavity. Finally, the subring cavity is used to provide fine mode selection by adjusting the passband windows of two FFP filters as close as possible, and a polarization controller is not required in the subring cavity. To investigate the behaviors of output power and wavelength stabilities, the stability of the proposed scheme (in Fig. 1) is measured and compared with that of the traditional case,[5] as indicated in Figs. 4(a) and 4(b). The initial lasing wavelength is set at 1545 nm and the total observing time is over 900 s. In Fig. 4(a), the output power fluctuations for the proposed (double-ring) and traditional (single-ring) configuration are 0.03 and 0.32 dBm, respectively. Figure 4(b) shows that the wavelength variations of the proposed and conventional configurations are 0.02 and 0.06 nm. During 3-h observation, the stable output of the proposed double-ring laser is still maintained. Therefore, when the double-ring structure used, the stabilities of output power and wavelength can be improved by as much as 90.63 and 66.67%, respectively.

4 Conclusion

In conclusion, we propose and experimentally demonstrate a stable and tunable double-ring laser based on EDWA. For the double-ring configuration, mode stability is guaranteed, and this fiber double-ring laser exhibits more stable output powers and wavelengths than that of the single ring. A widely tunable range of 1527 to 1567 nm, an SMSR of >45.6 dB/0.05 nm, and an output power of >1.04 dBm over the operation range of 1535 to 1565 nm are retrieved. Power fluctuation of <0.03 dBm and central wavelength variation of <0.02 nm can also be obtained. The EDWA-based fiber double-ring laser is well suited to WDM networking applications.

Acknowledgment

This work was supported in part by the National Science Council (NSC) of Taiwan under grants NSC 93-2752-E009-009-PAE, NSC 93-2215-E-115-004, and NSC 93-2215-E-115-005.

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