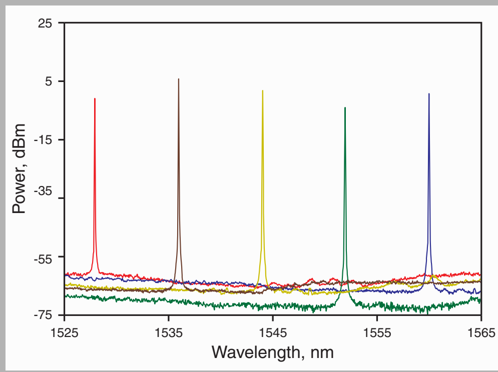
Unitizations of double-ring structure and Erbium-doped waveguide amplifier for stable and tunable fiber laser

2007 Laser Phys. Lett. 4 382

(http://iopscience.iop.org/1612-202X/4/5/011)

382 Laser Physics Letters Laser Phys. Lett. **4**, No. 5, 382–384 (2007) / **DOI** 10.1002/lapl.200610129

Abstract: We propose and demonstrate experimentally a single-longitudinal-mode (SLM) fiber double-ring laser using an Erbium-doped waveguide amplifier (EDWA), polarization controller (PC), and a fiber Fabry-Perot tunable filter (FFP-TF) into the ring cavity. In addition, the output power, side-mode suppression ratio (SMSR), and the stabilities of power and wavelength of the laser also are investigated.



Output wavelengths of the proposed fiber laser in an operating range of 1530 to 1560 nm

Unitizations of double-ring structure and Erbium-doped waveguide amplifier for stable and tunable fiber laser

S.-Y. Chou, [1] *C.-H. Yeh,* [2,*] *and S. Chi* [1,3]

[1] Department of Photonics and Institute of Electro-Optical Engineering, National Chiao Tung University, Hsinchu 30010, Taiwan
[2] Information and Communications Research Laboratories, Industrial Technology Research Institute, Chutung, Hsinchu 31040, Taiwan
[3] Department of Electrical Engineering, Yuan Ze University, Chungli 32003, Taiwan

Received: 25 December 2006, Revised: 2 January 2007, Accepted: 5 January 2007
Published online: 17 January 2007

Key words: Erbium-doped, ring laser, single-frequency

PACS: 42.60.Da, 42.81.-i

1. Introduction

Single-longitudinal-mode (SLM) Erbium-doped fiber (EDF) ring lasers have potential applications in optical communications, fiber sensors, and spectroscopy. In accordance with these Erbium fiber lasers, the unidirectional ring-cavity structure, which can potentially offer more output power with low relative intensity noise, has been extensively studied [1–4]. Due to the requirements of intracavity components and connecting fibers, a rather long cavity length of the fiber ring laser is unavoidable and brings out an enormous number of densely spaced longitudinal modes lying beneath the Erbium gain curve. To complete SLM operation, several SLM fiber lasers techniques have proposed, such as using two cascaded Fabry-Perot filters into the ring cavity [5], employing a compound ring resonator composed of a dual-coupler fiber ring and a tunable bandpass filter (TBF) [6], and utilizing twisted EDFs and fiber-type half-wave plate to control the cavity [7,8].

In this paper, we propose and investigate experimentally a sable and tunable fiber double-ring laser to achieve SLM operation, based on an Erbium-doped waveguide amplifier (EDWA), a fiber Fabry-Perot tunable filter (FFP-TF), and a polarization controller into the ring cavity. Moreover, the output power, side-mode suppression ratio (SMSR), and the stabilities of power and wavelength of the laser are also discussed.

* Corresponding author: e-mail: depew@itri.org.tw

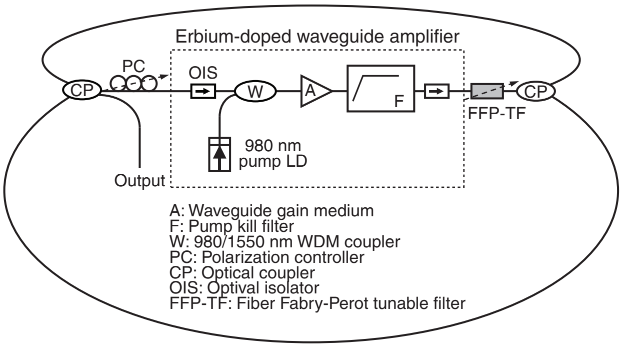


Figure 1 Proposed fiber double-ring laser architecture for SLM operation

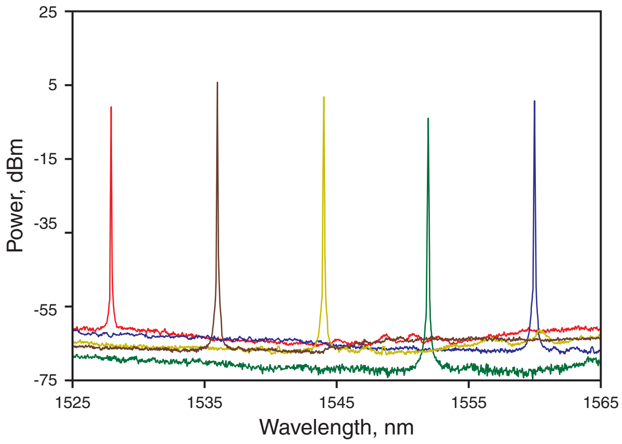


Figure 2 (online color at www.lphys.org) Output wavelengths of the proposed fiber laser in an operating range of 1530 to 1560 nm

2. Experiments and results

Fig. 1 illustrates the proposed SLM Erbium-doped fiber double-ring laser. The proposed architecture consists of an EDWA, two 3 dB optical couplers (OCPs), a fiber Fabry-Perot tunable filter (FFB-TF), and a polarization controller (PC). The EDWA, which is manufactured via two-step ion-exchange process, has the advantage of inheriting the known properties of the Erbium-doped fiber amplifier (EDFA), such as low noise figure, slight polarization dependence, and no crosstalk between wavelength-division-multiplexing (WDM) channels. All optical performances are measured when the laser pump diode current equals to 440 mA at ambient temperature. The PC is used to align the state of polarization of the ring cavity to guarantee a stable oscillation. The FFP-TF is an all-fiber device having a widely tunable range, low insertion loss of < 0.5 dB, and low polarization-dependent loss of ~ 0.1 dB. This FFP-TF having the free spectral range (FSR) of 44 nm can provide wavelength selection in the ring laser cavity by controlling the external voltage (0 to 12 V) on the piezoelectric transducer (PZT) of this filter. In addition, an optical spectrum analyzer (OSA) with a 0.05 nm resolution is used to measure the output spectra of ring laser.

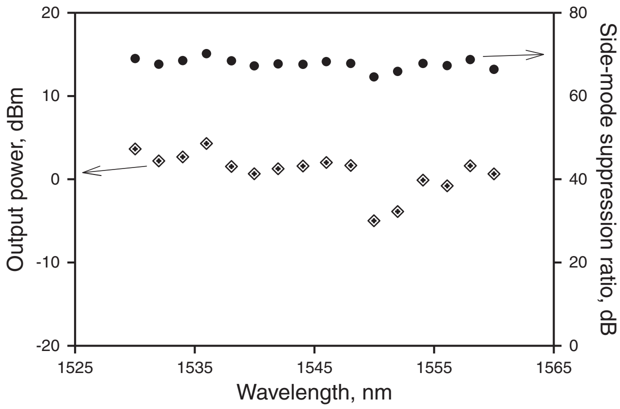


Figure 3 Output power and SMSR versus different wavelength for the proposed laser over the wavelengths of 1530 to 1560 nm

The FFP-TF not only determines a lasing wavelength but also serves as a mode-restricting component to provide the first restriction on the possible laser modes. Because of the combination of a FFP-TF and a double-ring cavity, a SLM operation in this fiber laser is achieved. The wavelength mode oscillates only at a single frequency, which satisfies the resonant conditions of the proposed structure.

The cavity of ring laser has a free spectral ranges (FSRs), $\mathrm{FSR} = \mathrm{c/nL}$, 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 ring laser has two ring cavities, as shown in Fig. 1. In this experiment, the two ring lengths of 11.96 and 13.04 m are the optimal choice for SLM operation. Therefore, the lengths of two ring loops are 11.96 and 13.04 m long, corresponding to the FSRs of nearly 17.1 and 15.7 MHz, respectively. Then, the single-frequency operation of the fiber laser and its influence can be verified by a self-homodyne detection method. An optical circuit for a measurement is composed of a photodetector with a 3 dB bandwidth of 12 GHz and a Mach-Zehnder interferometer with a 25 km long standard single-mode fiber (SMF).

Fig. 2 illustrates the output wavelengths of the proposed fiber laser in an operating range of 1530 to 1560 nm. Fig. 2 also shows that all the output SMSRs are above 64.6 dB. To realize the output behaviors of the laser, Fig. 3 shows the output power and SMSR versus different wavelength for the proposed laser over the wavelengths of 1530 to 1560 nm. Fig. 3 presents that the output power and SMSR of the laser are large than -5 dBm and 64.6 dB at 1550 nm in the effectively operating range. The maximum output power and SMSR of the laser are 4.3 dBm and 70.2 dB at 1536 nm, as also seen in Fig. 3. Compared with the past report [9], the proposed laser has the lower cost and simpler scheme. Moreover, the SMSR of the proposed

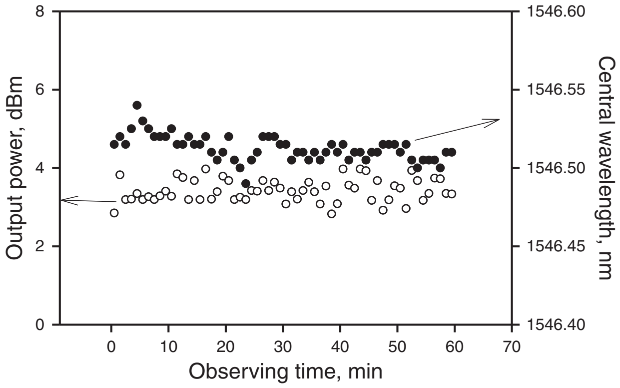


Figure 4 Output wavelength and power variations of the proposed laser for a lasing wavelength of 1546.5 nm initially and an observing time of 60 minutes

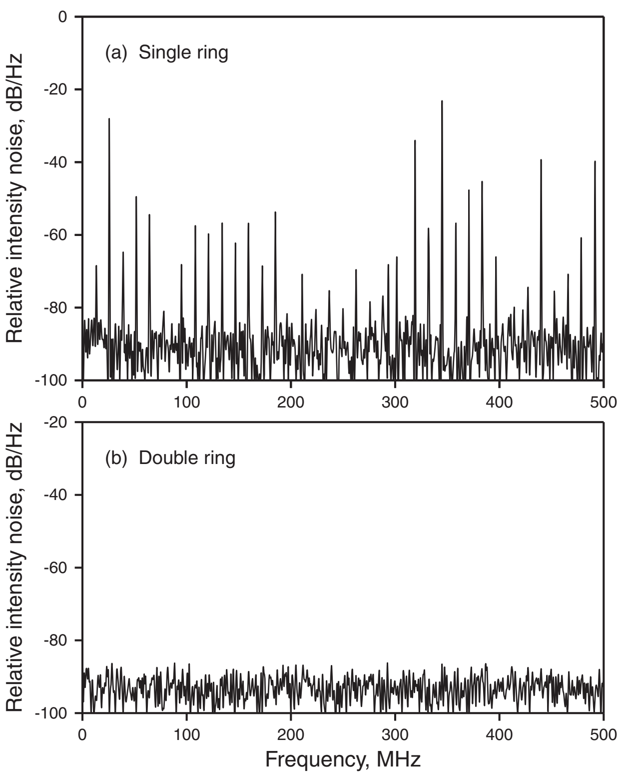


Figure 5 Self-homodyne spectra of the (a) single-ring and (b) double-ring laser at 1546.5 nm initially

laser is better (minimal SMSR of > 64.6 dB) than that of [9] (minimal SMSR of > 30 dB). Therefore, the proposed fiber laser not only has easily structure but also has better performance compared with the past.

In order to investigate the performance of output power and wavelength, a short-term stability of the laser is measured in Fig. 4. An initial lasing wavelength is set at 1546.5 nm and total observing time is over 60 minutes. The results show that our proposed fiber laser has an excellent performance. The output power and central wavelength variations are less than 1 dB and 0.04 nm, respectively.

To verify the single-frequency performance, the self-homodyne spectra of the fiber laser without and with double-ring structure (an operating wavelength is at 1546.5 nm) as shown in Fig. 5a and Fig. 5b, respectively. A noisy and unstable waveform with spikes is observed in the spectrum of single-ring laser as seen in Fig. 5a. When it is combined with a double-ring configuration, the proposed resonator can guarantee a SLM laser oscillation in Fig. 5b. Simultaneously, the fiber laser effectively suppresses side-mode frequencies of 500 MHz, also shown in Fig. 5b.

3. Conclusion

We have proposed and investigate experimentally a tunable and stable fiber laser with SLM output based on double-ring architecture. Double-ring structure provides a fine mode restriction and guarantees a SLM operation. The output power of larger than -5 dBm and the SMSR of larger than 64.6 dB over the operating range from 1530 to 1560 nm can be obtained. And the maximum output power and SMSR of the laser are 4.3 dBm and 70.2 dB at 1536 nm. In addition, the power fluctuation of less than 1 dB and the central wavelength variation of less than 0.04 nm also are observed for lasing wavelength in a short-term observing time.

Acknowledgements This work was supported in part by the National Science Council (NSC) of Taiwan (ROC) under grants NSC 94-2215-E-155-001 and NSC 94-2215-E-155-003. Authors would like to thank C.-T. Chen for help with the experiments.

References

[1] K.K. Chow, C. Shu, M.W.K. Mak, and H.K. Tsang, IEEE Photon. Technol. Lett. **14**, 1445 (2002).
[2] R.M. Sova, K. Chang-Seok, J.U. Kang, and J.B. Khurgin, in: IEEE CLEO 2002 Tech. Dig., USA 2002, vol. 1, p. 444.
[3] H. Ahmad, N.K. Saat, and S.W. Harun, Laser Phys. Lett. **2**, 369 (2005).
[4] F. Abdullah, A.S.M. Noor, M.A. Mahdi, H.A.A. Rashid, and M.K. Abdullah, Laser Phys. Lett. **2**, 535 (2005).
[5] K.J. Vahala, P. Namkyoo, J. Dawson, and S. Sanders, in: Proc. IEEE LEOS 1993 Conf., USA 1993, p. 708.
[6] G.A. Ball, W.W. Morey, and W.H. Glenn, IEEE Photon. Technol. Lett. **3**, 613 (1991).
[7] V. Mizrahi, D.J. Digiovanni, R.M. Atkins, S.G. Grubb, Y.K. Park, and J.M.P. Delavaux, J. Lightwave Technol. **11**, 2021 (1993).
[8] J. Zhang, C.Y. Yue, G.W. Schinn, W.R.L. Clements, and J.W.Y. Lit, J. Lightwave Technol. **14**, 104 (1996).
[9] H.C. Chien, C.H. Yeh, C.C. Lee, and S. Chi, Opt. Commun. **250**, 163 (2005).