Switchable single-longitudinal-mode dual-wavelength erbium-doped fiber ring laser incorporating a semiconductor optical amplifier

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We propose and demonstrate a novel single-longitudinal-mode (SLM) dual-wavelength erbium-doped fiber ring laser incorporating a semiconductor optical amplifier. The SOA biased in its low-gain regime greatly reduces the gain competition of the two wavelengths. The stable SLM operation is guaranteed by a passive triple-ring cavity and a fiber Fabry–Perot filter. The dual-wavelength output with a 40 GHz wavelength spacing is switchable in the range of 1533–1565.4 nm. © 2008 Optical Society of America

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Multiwavelength fiber lasers are of great interest for their potential applications in wavelength-division-multiplexing communications, fiber-optic sensors, optical instrumentation, and microwave photonic systems. Previously, many multiwavelength fiber ring lasers have been proposed and demonstrated [1–4]. However, these multiwavelength fiber ring lasers inevitably suffer from an enormous number of densely spaced longitudinal modes around the central lasing wavelength owing to the long lasing cavity and the mechanism for suppressing gain competition, which limits their practical applications owing to multimode oscillation, mode hopping, and relatively large linewidth. Therefore, single-longitudinal-mode (SLM) multiwavelength fiber lasers are highly desirable. Sharma *et al.* [5] and Sun *et al.* [6] presented SLM dual-wavelength fiber ring lasers using Sagnac filters and a saturable absorber. However, the problem of gain competition was not overcome. Liu *et al.* [7] also achieved an SLM multiwavelength operation of a fiber ring laser using a fiber loop mirror with a saturable absorber. Nevertheless, they cooled the erbium-doped fiber (EDF) to 77 K by liquid nitrogen to suppress the gain competition, which made this technique impractical in many applications. Lu and Grover [8] demonstrated a widely tunable SLM triple-wavelength EDF ring laser, but they utilized three erbium-doped fiber amplifiers (EDFAs) to supply the gain for each lasing wavelength. As an alternate method, Chen *et al.* [9] proposed a semiconductor optical amplifier (SOA) based fiber ring laser incorporating an ultranarrow bandpass filter with two transmission peaks. However, SOA biased in a large-gain regime has the disadvantages of a high noise figure, low saturated power, and undesirable nonlinear effects. Moreover, wavelength tuning in a large range is unavailable.

In this Letter, a novel SLM dual-wavelength fiber ring laser is proposed and demonstrated. An SOA biased in its low-gain regime is incorporated to introduce inhomogeneous gain and reduce gain competition. Meanwhile, an EDFA is inserted to increase the gain level and maintain a good signal-to-noise ratio. Besides, a mode-restricting mechanism by a passive triple-ring cavity and a fiber Fabry–Perot filter (FFPF) is engaged to facilitate the SLM operation. The performance of the laser output, the important role of the three fiber rings, and the influence of the SOA's driven current are studied, respectively.

A schematic of our experimental setup is shown in Fig. 1. Ring-1 is composed of an EDFA, an SOA, a 90:10 optical coupler, two polarization controllers (PCs), an optical bandpass filter (OBPF), and an FFPF. The EDFA consists of two polarization independent isolators, a section of EDF, and two 980 nm laser diodes. The saturation power of the EDFA is 16.6 dBm. The SOA is driven by a current source with a maximum current of 250 mA, which offers a small signal gain of 21.1 dB and saturation output power of 6.1 dBm. Ring-2 and Ring-3 are composed of a 2×2 and 50:50 optical coupler with a different cavity length. The free spectrum ranges (FSRs) of the three rings are 3.1, 34, and 238 MHz, respectively. Owing to the Vernier effect, the value of the effect FSR becomes the least common multiple number of the three FSRs. Thus, mode suppression can be achieved by the three rings [10]. The FFPF with an

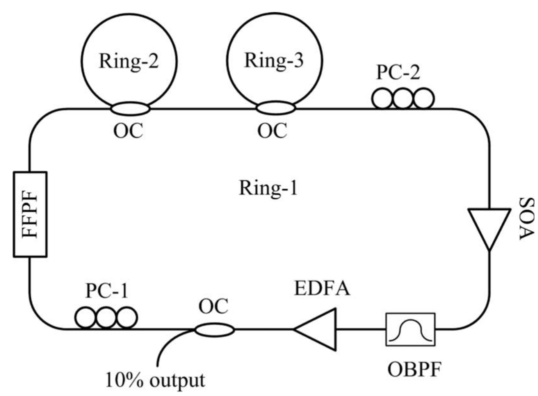

Fig. 1. Schematic of the proposed SLM dual-wavelength fiber ring laser. OC, optical coupler; PC, polarization controller; EDFA, erbium-doped fiber amplifier; SOA, semiconductor optical amplifier; OBPF, optical bandpass filter; FFPF, fiber Fabry–Perot filter.

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FSR of 40 GHz and 3 dB bandwidth of 1 GHz is another mode-restricting component. A combination of the FFPF and the triple-ring cavity ensures the SLM selection. A tunable OBPF with a 3 dB bandwidth of 0.8 nm is used to select the desired wavelengths. An optical spectrum analyzer (ANDO AQ6315B, resolution 0.05 nm) and a 20 GHz photodetector connected to an electrical spectrum analyzer (Agilent 8593E) are engaged to observe the laser output.

Figure 2(a) shows the optical spectrum of the dual-wavelength lasing of the fiber laser. The measurement is performed when the driven current of the SOA is 80 mA, 10 mA above the transparency current. The two peaks are 1559.93 and 1560.26 nm. The 3 dB linewidth is measured to be 0.05 nm for both wavelengths, limited by the resolution of our optical spectrum analyzer. The output power is ~4.4 mW. The side-mode suppression ratios (SMSRs) are 30.9 and 31.5 dB. This output spectrum is scanned every 2 min for more than 20 min. No significant spectral fluctuation is observed. The wavelengths shift within 0.02 nm, and the relative change of amplitudes is smaller than 0.2 dB. The SLM operation is verified by two methods. First, we apply the laser output to the 20 GHz photodetector and monitor the electrical signal with the electrical spectrum analyzer. As shown in Fig. 2(b), no beating noise appears. Second, we filter out the 1559.93 nm component and inject it into an $LiNbO_3$ modulator driven by a 10 GHz microwave generator. The output 10 GHz optical clock observed by a sampling oscilloscope has no visible amplitude fluctuation, as shown in the inset of Fig. 2(b). These results indicate that SLM performance is obtained in

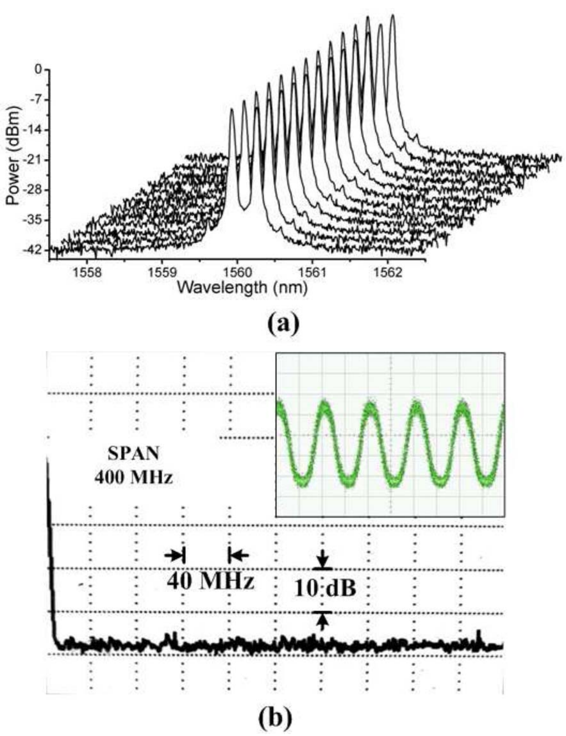

Fig. 2. (Color online) (a) Repeated scanning spectrum with a time interval of 2 min. (b) Electrical spectrum of the beating signals. Inset, 10 GHz optical clock generated by externally modulating one wavelength of the laser.

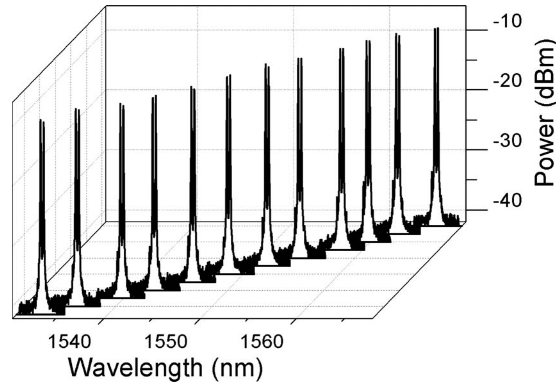

Fig. 3. Optical spectra while OBPF was tuned from 1533 to 1565.4 nm.

the dual-wavelength fiber laser. Wavelength switching is easily accomplished by tuning the OBPF. Figure 3 shows that the output lasing light is switchable in the range of 1533–1565.4 nm with 40 GHz of spacing. This range can be further extended by using another OBPF. The power variation is <3 dB. It should be noted that the two PCs should be accordingly adjusted to guarantee the SLM oscillation during tuning.

To testify the mode suppression by the triple rings, we measure the electrical spectrum, and the 10 GHz optical clocks generated by externally modulating one wavelength of the laser when Ring-2 and Ring-3 are disconnected. As shown in Fig. 4(a), a large number of beating tones appear in the electrical spectrum. Any adjustment of the two PCs will not reduce the large fluctuations. Accordingly, the 10 GHz optical clock is full of noise [Fig. 4(b)]. The performance of the laser is seriously degraded by multimode oscillation and mode hopping, which cannot meet the requirements of many applications. Then, we enable Ring-2. A marked reduction in the modal noise is obtained, indicating that the number of longitudinal modes is significantly reduced, as depicted in Fig. 4(c). Also, the noise in the optical clock is evidently

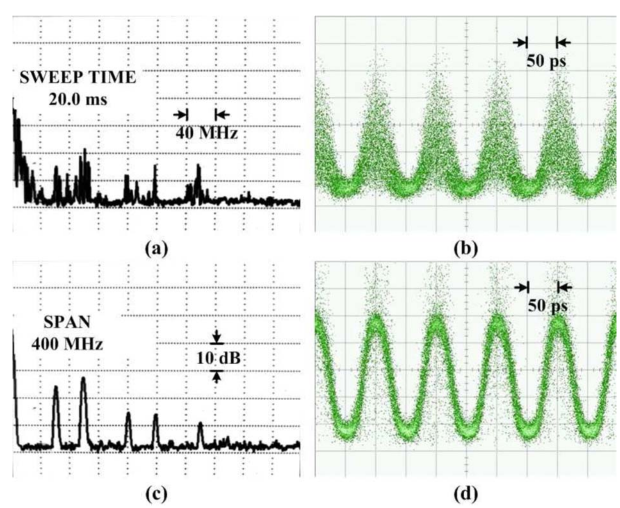

Fig. 4. (Color online) Electrical spectra and 10 GHz optical clocks generated by externally modulating one wavelength of the laser. (a), (b) Ring-2 and Ring-3 are disconnected; (c), (d) only Ring-3 is disconnected.

alleviated [Fig. 4(d)]. At last, both Ring-2 and Ring-3 are enabled. A stable SLM operation is achieved, which was previously shown in Fig. 2.

The driven current of SOA is very important for the performance of the dual-wavelength SLM laser. If it is too low, the SOA cannot offer sufficient inhomogeneous gain. Then, gain competition would dominate the dual-wavelength laser and make it unstable. Otherwise, if the SOA supplies too much gain, high noise and undesirable nonlinear effects would further degrade the performance of the laser. Therefore, the driven current of SOA must be properly selected. Figure 5(a) is the electrical spectrum when the driven current is 60 mA, 10 mA below the transparency current. Although a dual-wavelength operation is possible by carefully adjusting the two PCs, the laser is unstable and large beating noise exists because the gain competition of the two wavelengths is very serious in the cavity. When we increase the current to 8 mA, as shown in Fig. 5(b), a stable SLM operation is obtained. Further increase of the driven current would significantly enhance the noise level in the low frequency regime [Fig. 5(c)]. Figure 5(d) is the case when the current is 150 mA. Besides the high noise level, multimode oscillation presents again. It may be caused by the nonlinear effects in the SOA that depress the mode-restricting effect in the cavity.

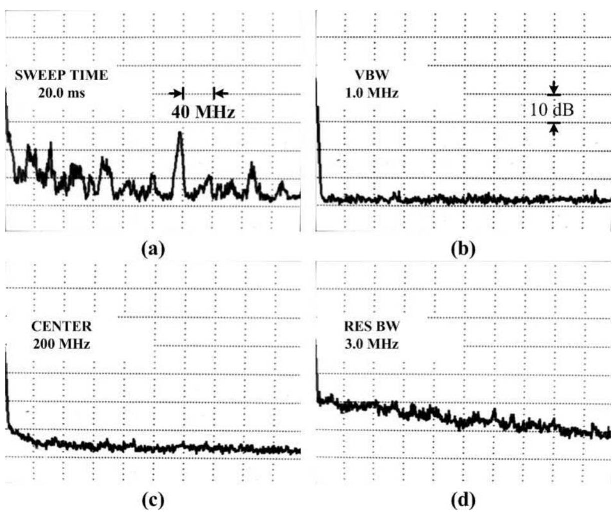

Fig. 5. Electrical spectra under different driven currents of SOA; (a) 60, (b) 80, (c) 110, and (d) 150 mA.

A triple-wavelength operation is tried by replacing the 0.8 nm OBPF with a 1.2 nm OBPF. To effectively suppress the gain competition, the driven current of SOA must be larger than 100 mA. After carefully adjusting the two PCs, beating noise in the electrical spectrum can be effectively suppressed, but it is very difficult to reduce the noise in the low frequency regime. Replacing the SOA with a low-noise SOA may solve this problem.

In summary, we have proposed and demonstrated a switchable SLM dual-wavelength EDF ring laser incorporating an SOA. Reduction of wavelength competition is obtained by inserting an SOA in the cavity. The SOA is biased in its low-gain regime to prevent excessive noise. Suppression of a multimode operation is achieved by a passive triple-ring cavity and an FFPF. The dual-wavelength output is switchable in the range of 1533–1565.4 nm.

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References

1. H. X. Chen, Opt. Lett. **30**, 619 (2005).
2. G. J. Cowle and D. Y. Stepanov, IEEE Photon. Technol. Lett. **8**, 1465 (1996).
3. J. Yao, J. P. Yao, Z. Deng, and R. Liu, J. Lightwave Technol. **23**, 2484 (2005).
4. D. Chen, H. Ou, H. Fu, S. Qin, and S. Gao, Laser Phys. Lett. **4**, 287 (2007).
5. U. Sharma, C. S. Kim, and J. U. Kang, IEEE Photon. Technol. Lett. **17**, 1277 (2004).
6. J. Sun, X. Yuan, X. Zhang, and D. Huang, Opt. Commun. **273**, 231 (2007).
7. J. Liu, J. P. Yao, J. Yao, and T. H. Yeap, IEEE Photon. Technol. Lett. **16**, 1020 (2004).
8. Z. Lu and C. P. Grover, IEEE Photon. Technol. Lett. **17**, 22 (2005).
9. X. Chen, J. Yao, and Z. Deng, Opt. Lett. **30**, 2068 (2005).
10. C. H. Yeh, T. T. Huang, H. C. Chien, C. H. Ko, and S. Chi, Opt. Express **15**, 382 (2007).