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Multiwavelength erbium-doped fiber ring laser employing Fabry–Perot etalon inside cavity operating in room temperature

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ABSTRACT

In this investigation, we propose and demonstrate a simple and cost-effective erbium-doped fiber (EDF) ring laser using a Fabry–Perot etalon inside a linear cavity and employing the accurate fiber cavity length to satisfy the least common multiple number for generating multiwavelength in C-band at room temperature. Furthermore, the center wavelength of the lasing wavelength bands can be adjusted to 1541.02, 1551.32, and 1562.03 nm, respectively. The wavelength separation in each wavelength band is 0.34 nm. Moreover, the output stability of the multiwavelength laser has also been discussed and analyzed.

1. Introduction

Recently, tunable and stable multiwavelength erbium-doped fiber (EDF) laser source has considerable interest due to its important applications in wavelength-division-multiplexed (WDM) communication system, optical device testing, fiber sensing, and precise spectroscopy. For the multiwavelength EDF lasers, because of the homogeneous broadening effect of erbium at room temperature, gain competition among different lasing modes is the main issue for stable multiwavelength operation. The EDF could be cooled by liquid nitrogen at 77 K to reduce the homogeneous behavior [1,2]. However, this method is not practical due to its high cost and poor system durability. In order to realize the multiwavelength fiber lasers, various techniques have been proposed, such as the ring cavity with a semiconductor modulator [3], with a spectral polarization-dependent loss element [4], with cascaded fiber Bragg grating (FBG) [5–7], with multi-ring cavity design [8], and with a Sagnac loop reflector [9]. Most of these techniques employ the FBG, which is used to select lasing single wavelength or multiwavelength. Furthermore, the room-temperature multiwavelength EDF ring laser using phase-modulation method with Sagnac loop in linear cavity has been also investigated [10]. This approach is particularly interesting but needs to adjust the phase modulator and polarization status in optimal operating condition. Besides, using an acousto-optical frequency shifter to decrease homogeneous line broadening at room temperature is also proposed [11,12].

In this paper, we propose and demonstrate a simple EDF laser scheme using a Fabry–Perot etalon inside linear cavity with optimal fiber length. When the free spectral ranges (FSRs) of Fabry–Perot etalon and fiber cavity length satisfy the least common multiple number, then the proposed fiber laser could generate multiwavelength in C-band window. Furthermore, based on proper control of the polarization state in the proposed laser, three lasing wavelength bands of center wavelengths located in 1541.02, 1551.30, and 1562.03 nm, respectively, are observed. The wavelength separation in each wavelength band is 0.34 nm. Moreover, the output stability of the multiwavelength laser has also been discussed and analyzed.

2. Experiments and results

Fig. 1 illustrates the experimental setup of multiwavelength EDF ring laser. The proposed laser scheme is consisted of an erbium-doped fiber amplifier (EDFA), a 1 × 2 and 10/90 optical coupler (CP), a polarization control (PC), and a Fabry–Perot etalon. The PC is used to control and adjust the polarization status and maintain the maximum output power. The EDFA used is gain-flattened. Hence, Fig. 2 shows the output amplified spontaneous emission (ASE) spectrum and gain profile of the EDFA without the ring structure at different wavelengths when the 980 nm pumping power operates at 215 mW. The power difference of ASE spectrum is nearly 5 dB between 1528 and 1562 nm as also shown in Fig. 2. Moreover, the total output power of ASE is measured at -3.6 dBm. Fig. 2 also presents the flattened gain spectrum and the maximum gain is 23.5 dB at 1528 nm for the -20 dBm input

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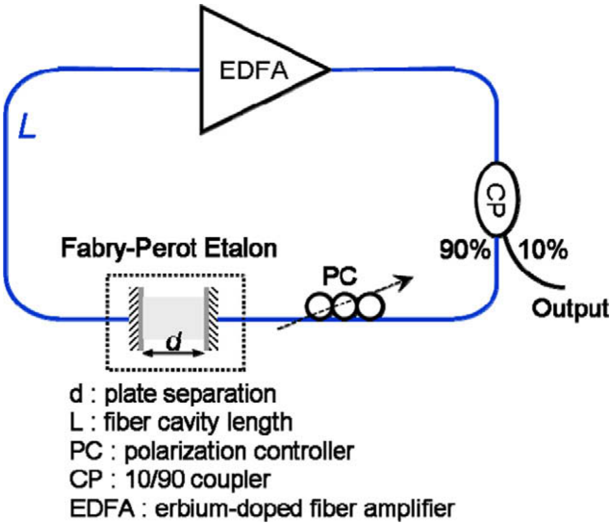

Fig. 1. Experimental setup of the proposed multiwavelength EDF ring laser architecture.

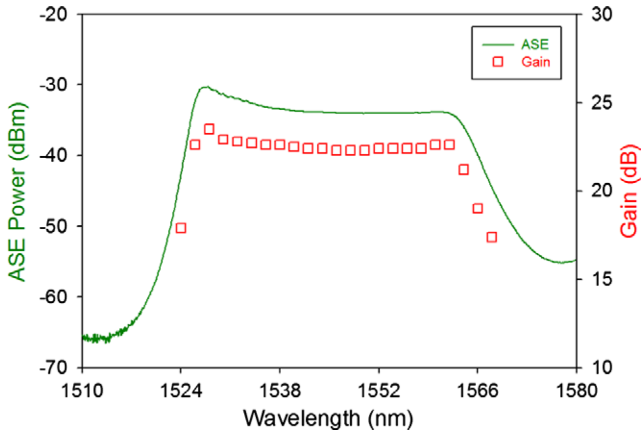

Fig. 2. Output ASE spectrum and gain profile of the commercially gain-flattened EDFA used under different wavelength.

signal power. The gain value is between 21.2 and 23.5 dB with 2.3 dB gain variation at the wavelengths of 1526 to 1564 nm. And the saturated output power of the EDFA is ∼15 dBm. Furthermore, the FSR1 ($FSR1 = c/2d$, where c is light speed in vacuum and d is cavity length between two reflected plates) of Fabry–Perot etalon is 0.34 nm (∼42.5 GHz). Thus, Fig. 3 shows the output spectrum when the gain-flattened ASE light source has passed through the Fabry–Perot etalon filter. It is also worth to note that the output power is very low (∼−60 dBm) in this case.

In this experiment, the total fiber cavity length (L) of the proposed laser scheme is nearly 24 m long. Hence, the FSR2 of the laser, $FSR2 = c/nL$, 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, is nearly 8.5 MHz. Therefore, when the value of effective FSRs of etalon and fiber ring cavity become the least common multiple number for both FSR1 and FSR2, the multi-mode laser could be oscillated that satisfies the resonant conditions of the etalon cavity length and the fiber ring cavity simultaneously.

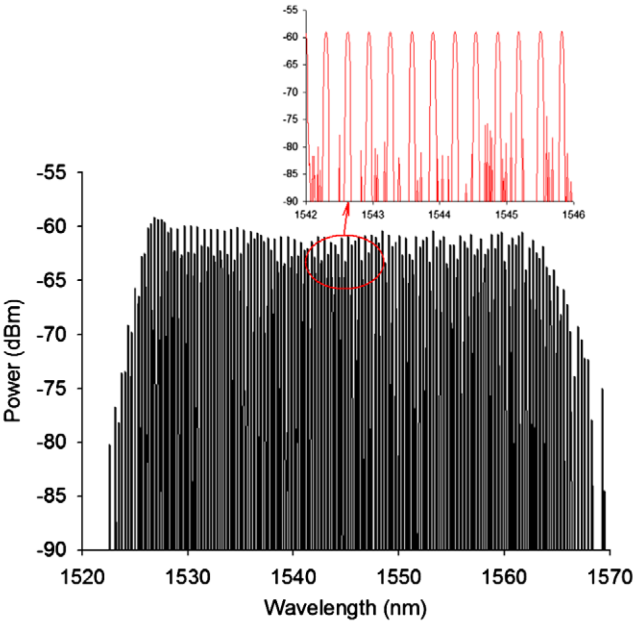

Fig. 3. Received output spectrum when the ASE source of EDFA injects into the Fabry–Perot etalon filter. The insert is the FPEF output spectrum between 1542 and 1546 nm.

Compared with the past studies, our proposed EDF laser does not need to cool the EDF at 77 K [1,2] or use the fiber frequency shifter [11,12] inside fiber ring cavity to reduce the homogeneous broadening effect and maintain the multiwavelength lasing. In the proposed laser, while the FSR1 and FSR2 satisfy the least common multiple number and the proper polarization control is adjusted, the multiwavelength can be retrieved easily. Therefore, Fig. 4 shows the output spectra of the proposed multiwavelength EDF ring laser under different and proper polarization status in the effective operating range of 1520–1570 nm. When the PC is adjusted in a proper position, there are three multiwavelength lasing bands observed as shown in Fig. 4. However, when a cavity length is changed to 20 m, then the proposed fiber laser scheme could not generate multiwavelength lasing and also has unstable output wavelength due to the homogeneous broadening and gain competition, as shown in Fig. 5.

When the operating conditions for the proposed laser are achieved, three lasing wavelength bands are obtained at center wavelength of 1541.02, 1551.32, and 1562.03 nm, respectively, having 0.34 nm mode spacing, as shown in Fig. 6(a)–(c). As illustrated in Fig. 6(a)–(c), with the lasing wavelength increases, the

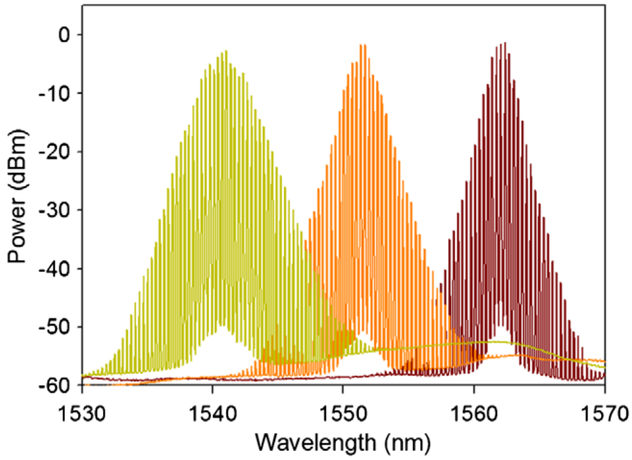

Fig. 4. Output spectra of the proposed multiwavelength EDF ring laser with 24 m fiber cavity length in the effective operating range of 1530–1570 nm under different polarization status.

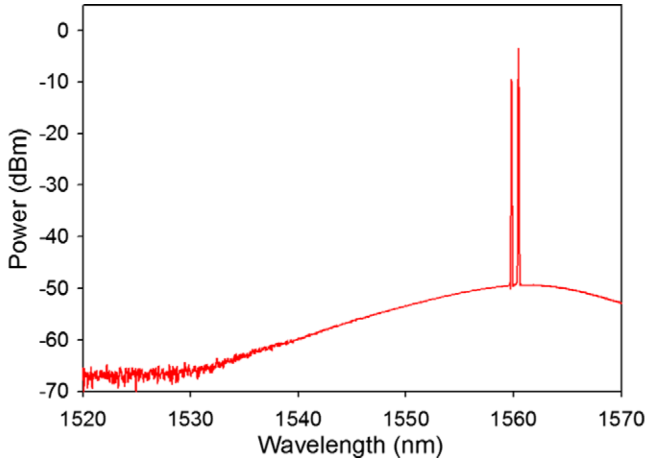

Fig. 5. Output spectrum of the proposed multiwavelength EDF ring laser scheme with 20 m fiber cavity length.

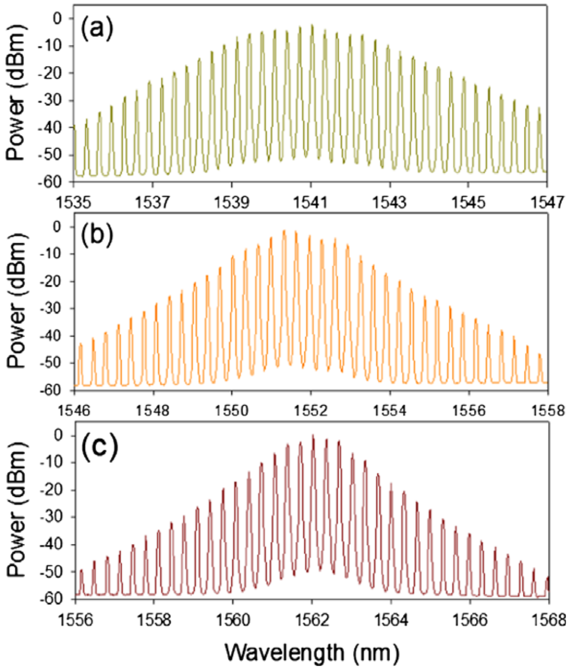

Fig. 6. Three lasing central wavelengths are obtained at (a) 1541.02, (b) 1551.30, and (c) 1562.03 nm, respectively, having nearly 10 nm multiwavelength bandwidth with 0.34 nm mode spacing.

lasing multiwavelength distribution would change from flat to sharp gradually. Fig. 6(a)–(c) shows that the maximum peak powers and optical signal to noise ratios (OSNRs) are −1.9, −1.3, and 0.3 dBm and 48.2, 49.0. and 48.4 dB/0.1 nm at the wavelength of 1541.02, 1551.32, and 1562.03 nm, respectively. We can see that the output power is greatly enhanced when compared with the non-lasing case (Fig. 3). Besides, Fig. 6(a)–(c) also presents the lasing multiwavelength of 29-line, 22-line, and 18-line while the OSNR is larger than 30 dB between 1536.58 and 1545.50 nm ($\Delta\lambda = 8.92$ nm), 1548.42 and 1555.18 nm ($\Delta\lambda = 6.76$ nm), and 1559.09 and 1564.65 nm ($\Delta\lambda = 5.56$ nm), respectively. And the perk powers are larger than −26.6, −26.9, and −26.0 dBm, respectively, in the same wavelength bandwidth as mentioned.

In order to realize and investigate the performance of output stability, the short-term stability measurement of the proposed laser is performed, as shown in Fig. 7. The maximum output peak power and output wavelength are 0.3 dBm and 1562.03 nm initially and the observing time is over 60 min for the stability observation. We observed that the output wavelength variations and the output power fluctuations of the lasing central lightwave are smaller than 0.7 nm and 1.1 dB, respectively, as also shown in Fig. 7. During 4 h measurement and observation, the stable output of the proposed fiber laser is still maintained. Besides, Fig. 8 shows the output spectra under 60 min observation time. And the output profiles are nearly the same. The power and wavelength fluctuation could be due to the optical feedback produced by the back-reflection of fiber connectors of the Fabry–Perot etalon and the pump instability of the EDFA [13]. As a result, the proposed fiber laser not only can generate multiwavelength output, but also has good output stability in a long-term observing time. In addition, the proposed laser has the advantages of simply architecture and cost-effective for stable multiwavelength operation.

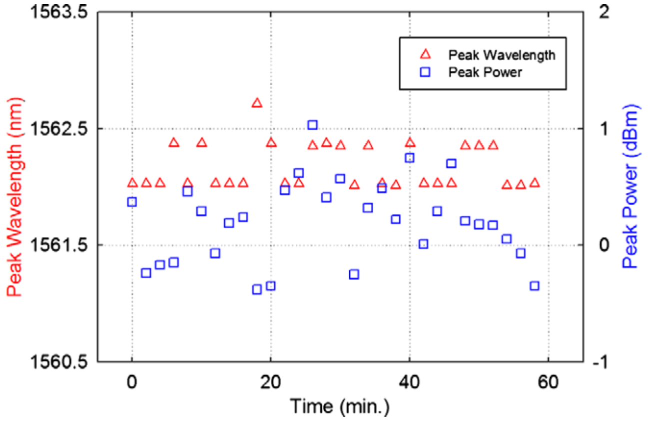

Fig. 7. Observing short-term stability of the proposed laser when the maximum output peak power and output wavelength are 0.3 dBm and 1562.03 nm initially and the observing time is over 60 min.

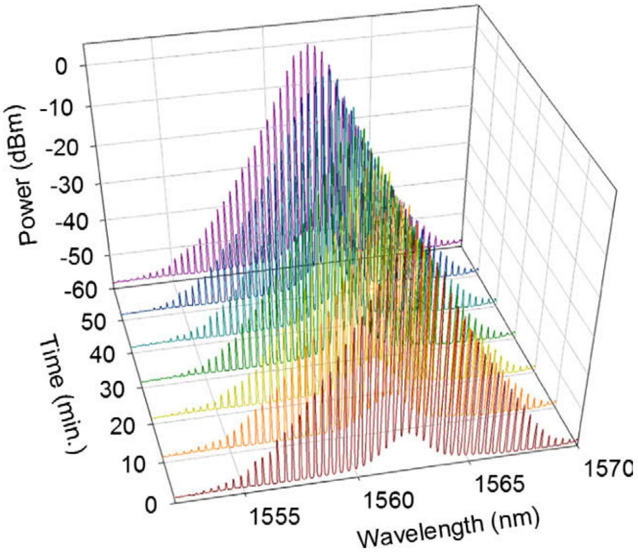

Fig. 8. Observing output spectra of the proposed multiwavelength fiber laser at 60 min observation time when the central wavelength locates at 1562.03 nm.

3. Conclusion

We have proposed and experimentally investigated a simple and cost-effective EDF ring laser configuration using a Fabry–Perot etalon with fixed cavity length [FSR is 0.34 nm (∼42.5 GHz)] inside a linear cavity and employing a accurate fiber cavity length to satisfy the least common multiple number, for generating multiwavelength in C-band at room temperature. Furthermore, based on properly control of polarization status in the fiber laser, the lasing wavelength bands located at 1541.02, 1551.32, and 1562.03 nm, respectively, are observed, having the total wavelength bandwidth of 8.92, 6.76, and 5.56 nm in each band and 0.34 nm mode spacing. The OSNR is above 30 dB/0.1 nm in each band. Moreover, the output stability of the multiwavelength laser has also been discussed and analyzed.

Acknowledgments

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