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Wavelength-tunable erbium fiber ring laser in single-frequency operation utilizing Fabry–Perot laser with Sagnac cavity

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Abstract

We propose and demonstrate experimentally a stabilized and wavelength-selective erbium-doped fiber ring laser in single-longitudinal-mode operation with Fabry–Perot laser diode (FP-LD) and using a tunable bandpass filter (TBF) inside and outside a Sagnac ring cavity. The side-mode suppression ratios of 21 dB and 36.5 dB and the output power of –3.6 dB m and –8.7 dB m in the wavelengths of 1524.45–1562.35 nm and 1531.07–1562.35 nm with the tuning step of 1.4 nm can be achieved when the TBF outside and inside Sagnac loop, respectively. The output wavelength variation of zero and the output power fluctuation of <0.1 dB are also obtained. Moreover, the transmission efficiency of the ring laser has also been performed experimentally under a 1.25, 2.5 and 10 Gb/s external modulation, respectively.

Keywords: Fiber laser; Single-mode; Fabry–Perot

1. Introduction

Stable and wavelength-tunable single-frequency is needed in the fiber ring lasers applied on wavelength-division-multiplexing (WDM) communications and optical sensor systems. Conventionally, fiber Fabry–Perot tunable filters (FFP-TF) can be used to provide wavelength tuning in the fiber ring lasers. However, it is insufficient to stabilize the lasing wavelength and power of a fiber ring laser due to the mode hopping effect. To overcome the unstable optical output, several techniques are used to retrieve a single-longitudinal-mode (SLM) operation, such as integrating two cascaded FFP-TF of widely different free spectral ranges (FSRs) into cavity [1,2], using a compound ring resonator composed of a dual-coupler fiber ring and a tunable bandpass filer [3], adding an extra ITU-grid periodic filter in the optical loop [4], and using a unpumped erbium-doped fiber (EDF) in fiber loop to serve as a saturable-absorbor-based filter [5], have been reported, recently.

In this paper, a proposed technique using a Fabry–Perot laser diode (FP-LD) and a tunable bandpass filter (TBF) for the stabilized and wavelength-tunable erbium-doped fiber (EDF) Sagnac ring laser has been proposed and experimentally investigated. The performances of the tunable range, wavelength and power stabilities, and side-mode suppression ratio (SMSR have been studied. Moreover, the transmission performance of the ring laser has also been performed experimentally under a 1.25, 2.5 and 10 Gb/s external modulation, respectively.

2. Experiments and results

An experimental setup for the stable and wavelength-tunable fiber laser is illustrated in Fig. 1. The proposed

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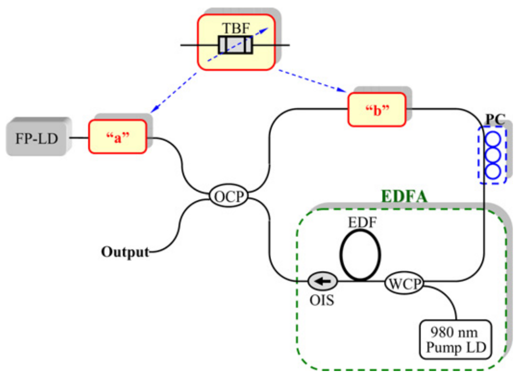

Fig. 1. Stable and wavelength-tunable fiber ring laser scheme.

EDF ring laser consists of an erbium-doped fiber amplifier (EDFA), a 1×2 and 50:50 optical coupler (OCP), a Fabry–Perot laser diode (FP-LD), a polarization controller (PC), and a tunable bandwidth filter (TBF). The TBF, with the 0.4 nm of 3 dB bandwidth, 30 nm wavelength tuning range and 5 dB insertion loss, will be placed on "a" and "b" positions (inside and outside Sagnac loop) into the intercavity for tuning wavelength, respectively. The EDFA constructs by an EDF with 10 m long, a 980/1550 nm WDM coupler, an optical isolator (OIS) and a 980 nm pumping laser with 80 mW.

To provide the stable and tunable SLM operation, the central wavelength of the TBF is tuned to align and the longitudinal-mode FP-LD for wavelength lasing. And, by rotating the PC to align the maximum output power of eigenstate of the polarization can always be retrieved. Therefore, 1.4 nm tuning step is determined by the longitudinal-mode spacing of the FP-LD. This way, the side-modes of the FP-LD are suppressed and the optical output amplified. Fig. 2 shows the output spectrum of FP-LD when the bias current and temperature are 20 mA and 25 °C. The output spectra and powers are observed by using an optical spectrum analyzer (OSA) with a 0.05 nm resolution.

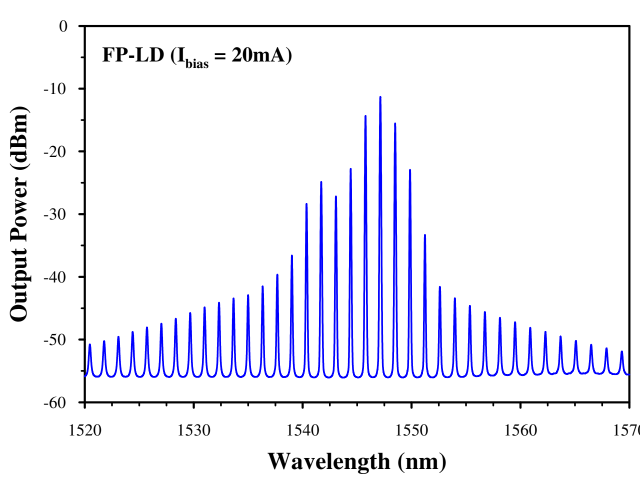

Fig. 2. Output spectrum of FP-LD when the bias current and temperature are 20 mA and 25 °C.

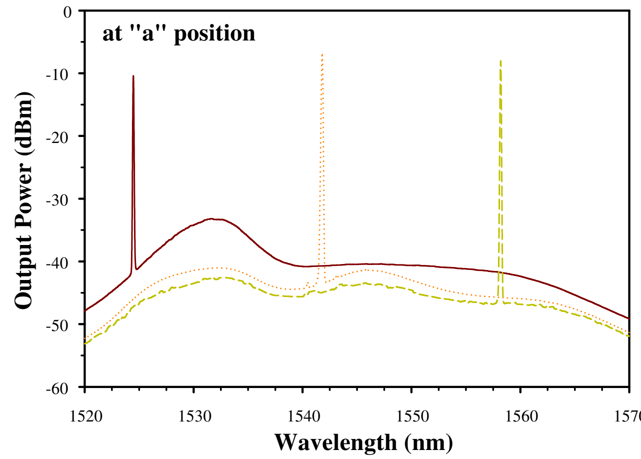

Fig. 3. Output spectra of the proposed fiber laser over the wavelengths of 1524.45–1562.35 nm while the TBF is placed on "a" position (outside Sagnac cavity) to tune the lasing wavelength.

First, Fig. 3 shows the output spectra of the proposed fiber laser over the wavelengths of 1524.45–1562.35 nm while the TBF is placed on "a" position (outside the Sagnac loop) to tune the lasing wavelength. From Fig. 3, the

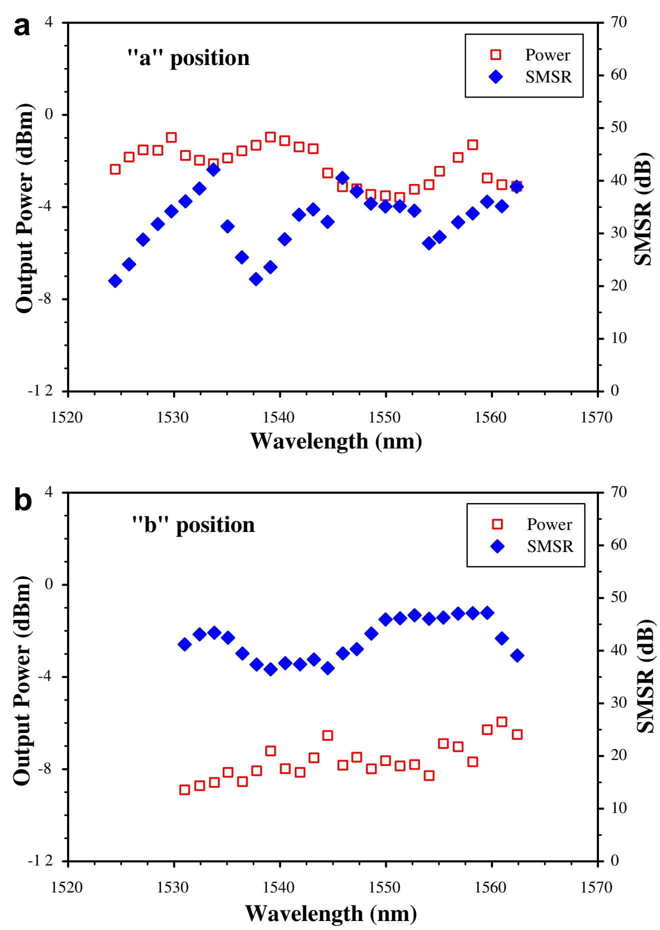

Fig. 4. Output power and side-mode suppression ratio (SMSR) versus the different lasing wavelength with a 1.4 nm tuning step when the TBF is placed on (a) "a" and (b) "b" positions, respectively.

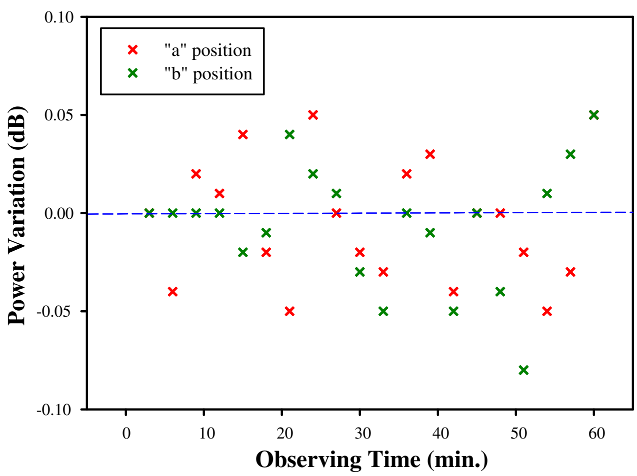

Fig. 5. Observing short-term stability of the output power for the proposed laser under the observing time of 60 min when the TBF is on "a" and "b" positions, respectively, at 1547.24 nm initially.

ring laser has lower amplified spontaneous emission around 1540 nm. Next, we also can put the TBF on "b" position (inside the Sagnac loop) to tune the lasing wavelength. Therefore, Fig. 4a and b show the output power

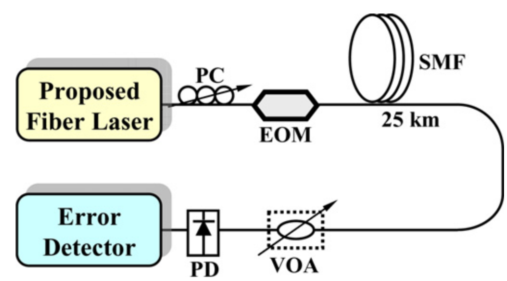

Fig. 6. Experimental setup for a testing transmission with a 25 km long SMF span.

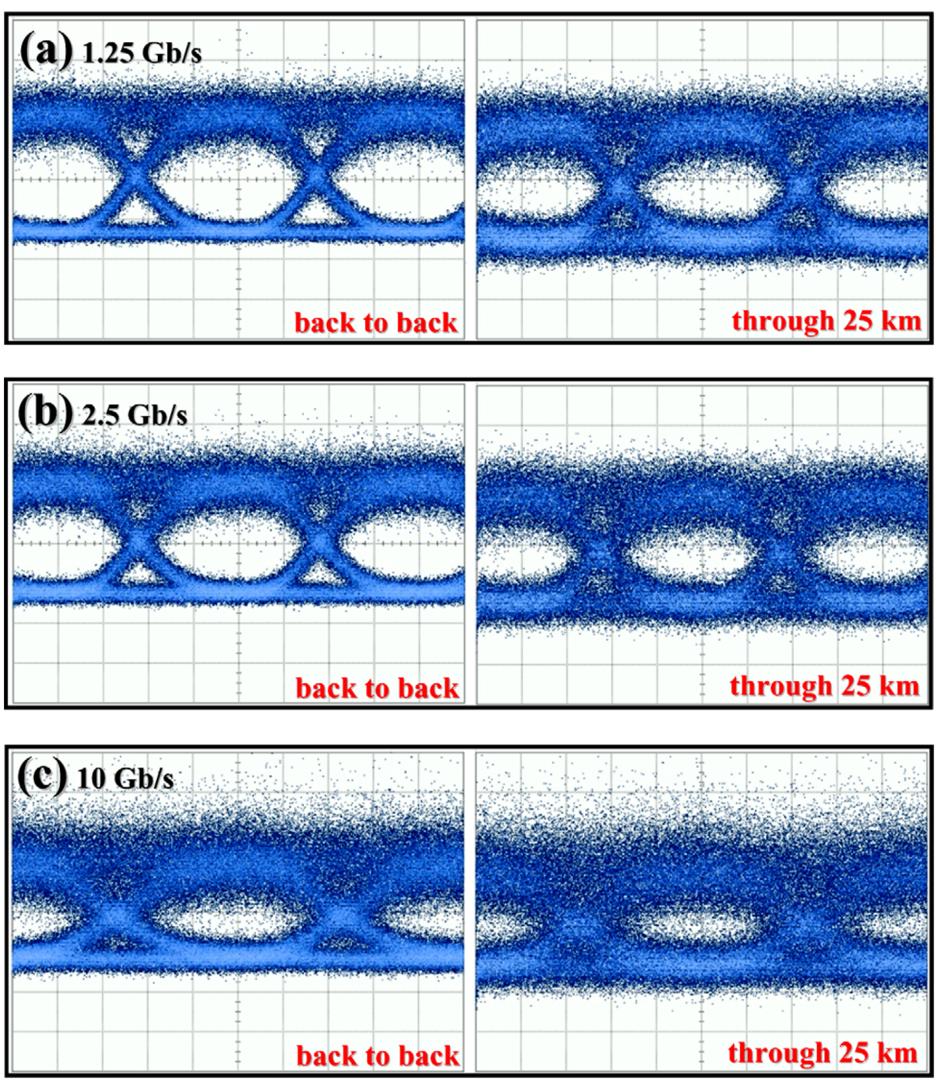

Fig. 7. Eye diagrams under back to back and through 25 km transmission span when the EOM is modulated at (a) 1.25, (b) 2.5, and (c) 10 Gb/s, respectively, when the TBF is on "a" position at 1547.24 nm initially.

and side-mode suppression ratio (SMSR) versus the different lasing wavelength with a 1.4 nm tuning step when the TBF is placed on "a" and "b" positions. As seen in Fig. 4a, the SMSR and output power are larger than 21 dB and 3.6 dB m, respectively, in the tuning range over 37.7 nm from 1524.45 nm to 1562.35 nm. The maximum output power is 1 dB m at 1529.74 nm and its SMSR is 34.2 dB. When a lasing wavelength operated at 1533.72 nm, the SMSR is up to 42 dB. From Fig. 4b, the SMSR and output power are larger than 36.5 dB and 8.7 dB m, respectively, in the tuning range over 31.28 nm from 1531.07 nm to 1562.35 nm. The maximum output power is 5.9 dB m at 1560.94 nm and its SMSR is 42.3 dB. When a lasing wavelength operated at 1559.56 nm, the SMSR is up to 47.2 dB. According to above results, Fig. 4a indicates a better output power efficiency and a widely tuning bandwidth but with the worse SMSR. However, Fig. 4b shows the opposite results. Besides, a different temperature will cause the central wavelength of the LD to slightly shift. Therefore, the lasing wavelength, by controlling the temperature of the LD, could be continued tunable. In accordance with the nonlinear Sagnac fiber loop design, the fiber laser not only can obtain larger output power, but increase the tuning wavelength range of TBF (nonlinear effect).

To investigate the performances of output power and wavelength stabilities, the short-term stability of the proposed structure is measured when the TBF is located at "a" and "b" positions, respectively. The lasing wavelength is 1547.24 nm initially and the observing time is over 60 min when the TBF is on different location. The proposed ring laser can dramatically reduce the wavelength variation to zero. The power fluctuation is observed <0.1 dB when the TBF is placed on "a" or "b" positions, respectively, as shown in Fig. 5. During an 8 h observation, the stabilized output of the proposed ring laser is still maintained. The external injection into FP-LD can lock mode for stabilized single-frequency output. Compared with a conventional fiber ring laser, this laser has more stable output.

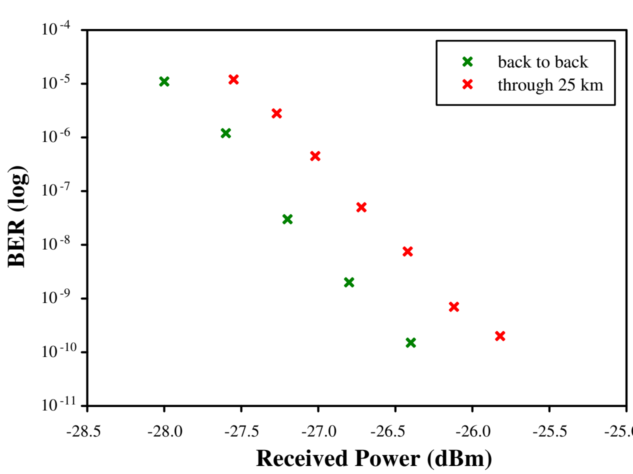

Fig. 8. BER performance under back to back and through 25 km transmission span when the EOM is modulated at 2.5 Gb/s, respectively, when the TBF is on "a" position at 1547.24 nm initially.

To verify the transmission efficiency of the proposed tunable laser, a simply testing transmission will use the proposed fiber laser to act as an optical source, illustrated in Fig. 6. We tune the lasing wavelength at 1547.24 nm with –4.3 dB m output power when the TBF is located at "a" position. A testing transmission distance is 25 km long. The 1547.24 nm wavelength will through PC and an electro-optical modulator (EOM). The PC and EOM will cause ~7.5 dB insertion loss. The EOM can emit a 10 Gb/s signal under non-return-to-zero (NRZ) pseudo random binary sequence (PRBS) with a pattern length of 2^{31}–1. Therefore, Fig. 7 show the eye diagrams under back to back and through 25 km SMF transmission span when the EOM is modulated at (a) 1.25, (b) 2.5 and (c) 10 Gb/s, respectively. However, the major contributing factor is observed jitter mainly in the back to back measurement due to the group velocity dispersion of fiber amplifier. The proposed not only can be tuned for different wavelength lasing, but also can be operated at SLM and modulated for optical fiber transmissions.

In this experiment, we also measure the bit error rate (BER) when the lasing wavelength (1547.24 nm) is modulated at 2.5 Gb/s passing through 25 km SMF and the TBF is on "a" position. Fig. 8 shows the BER measurements under back-to-back (BTB) and through 25 km SMF state. Fig. 8 also shows the power penalty of <0.6 dB while the BER = 10^9.

3. Conclusion

In summary, we have proposed and demonstrated a stabilized and wavelength-selective erbium-doped fiber ring laser with single-longitudinal-mode operation using the FP-LD and a TBF inside and outside the Sagnac cavity. The side-mode suppression ratios of 21 dB and 36.5 dB and the output power of 3.6 dB m and 8.7 dB m can be achieved while the two proposed ring lasers are tuned from 1524.45 nm to 1562.35 nm and 1531.07–1562.35 nm with the step of 1.4 nm, respectively. Moreover, the output wavelength variation of zero and the output power fluctuation of <0.1 dB are obtained. The transmission efficiency of the ring laser has also been performed experimentally under a 1.25, 2.5 and 10 Gb/s external modulation, respectively.

References

[1] K.J. Vahala, P. Namkyoo, J. Dawson, S. Sanders, Tunable, single frequency, erbium fiber ring lasers, in: IEEE LEOS '93 Conf. Proc., 1993, p. 708.
[2] K.K. Chow, C. Shu, M.W.K. Mak, H.K. Tsang, IEEE Photon. Technol. Lett. 14 (2002) 1445.
[3] R.M. Sova, K. Chang-Seok, J.U. Kang, J.B. Khurgin, Tunable dual-/spl lambda/fiber ring laser based on 2/sup nd/order Sagnac-

Lyot fiber filter, in: IEEE CLEO 2002 Tech. Dig., vol. 1, 2002, p. 444.

[4] A. Bellemare, J.-F. Lemieux, M. Tetu, S. LaRochelle, Erbiumdoped fiber ring lasers step-tunable to exact multiples of 100 GHz (ITUgrid) using periodic filters, in: Proc. Eur. Conf. Opt. Commun. (EOCC'98), vol. 1, 1998, p. 153.

[5] H.Y. Ryu, W.-K. Lee, H.S. Moon, S.K. Kim, H.S. Suh, D. Lee, IEEE Photon. Technol. Lett. 17 (2005) 1824.