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# Stable Wavelength-Tuning Laser in Single-Frequency by Optical-Injected Fabry–Perot Laser Diode and RSOA for Long Fiber Distance Propagation[1]

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**Abstract**—In this demonstration, we propose and experimentally investigate a stable wavelength-tuning laser configuration by using self-seeded Fabry–Perot laser diode (FP-LD) and external-injected reflective semiconductor optical amplifier (RSOA). Here, this proposed laser can be tuned in the wavelength range of 1534.05 to 1553.00 nm with a 1.1 nm tuning-step. And the output powers and side-mode suppression ratios (SMSRs) are measured at –5.3 to 4.6 dBm and 31.2 to 50.1 dB/0.05 nm, respectively. And, the proposed laser also can be directly modulated at 2.5 Gb/s on-off keying (OOK) modulation format and propagates 75 km single-mode fiber (SMF) with no optical amplifier and dispersion compensation.

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## 1. INTRODUCTION

Recently, erbium-doped fiber (EDF) ring lasers with stable wavelength-tuning output have considerable interest in the wavelength division multiplexing (WDM) communications, optical testing, and fiber sensor applications [1–3]. Generally, the fiber laser consisted of laser cavity for frequency selection and gain medium for population inversion [4, 5]. In past few years, the various resonator designs of fiber lasers have been proposed, such as including the linear cavities [6–10], ring cavities [11–13] ring cavities with Fabry–Perot etalon [14], and compound fiber ring cavities [15, 16]. In general, using wavelength-selection components inside the cavities could achieve and perform the tunability of fiber laser [17]. Moreover, the erbium doped fiber amplifier (EDFA), semiconductor optical amplifier (SOA) and other optical amplifiers were used to serve as the gain medium for fiber ring lasers [18–25]. And, to achieve multi-wavelength lasing, a Sagnac loop design, a $LiNbO_3$ multifunction chip and a abrupt-tapered Mach–Zehnder block filter were used and reported [26–28]. To remove the optical amplifier and reduce the cost, using external- or self-injection semiconductor lasers have also been investigated and performed for wavelength-tuning [29–32].

In this work, we propose and experimentally investigate a stable wavelength-tuning laser configuration by using self-seeded Fabry–Perot laser diode (FP-LD) and external-injected reflective semiconductor optical amplifier (RSOA). Here, this proposed laser can be tuned in the wavelength range of 1534.05 to 1553.00 nm with a 1.1 nm tuning-step. And the output powers and side-mode suppression ratios (SMSRs) are between –5.3 and 4.6 dBm and 31.2 and 50.1 dB/0.05 nm, respectively. And, the proposed laser also can be directly modulated at 2.5 Gb/s on-off keying (OOK) modulation format and propagates 75 km single-mode fiber (SMF) without using optical amplifier and dispersion compensation. Moreover, the output stabilities of wavelength and power for the wavelength-tuning laser have been also performed and analyzed.

## 2. EXPERIMENT AND RESULTS

The experimental setup of the proposed stable wavelength-tuning semiconductor laser configuration was illustrated in Fig. 1. The proposed laser scheme was constructed by a FP-LD, a RSOA, a tunable bandpass filter (TBF), an optical circulator (OC), a polarization controller (PC), a $1 \times 2$ and 50 : 50 optical coupler (CP), and a reflected mirror (RM). The wavelength tuning range and insertion loss of TBF were 30 nm (1530 to 1560 nm) and 6 dB. And the total reflection of RM was 99.5% in C-band operating window. In this measurement, the output wavelength and output power of the proposed laser could be measured by using an optical spectrum analyzer (OSA) with a resolution of 0.05 nm and a power meter (PM).

First, we experimented the self-seeding FP-LD operation, as seen in Fig. 1. Here, the mode-spacing and threshold current of multi-longitudinal-mode (MLM) FP-LD were 1.1 nm and 9.5 mA, respectively.

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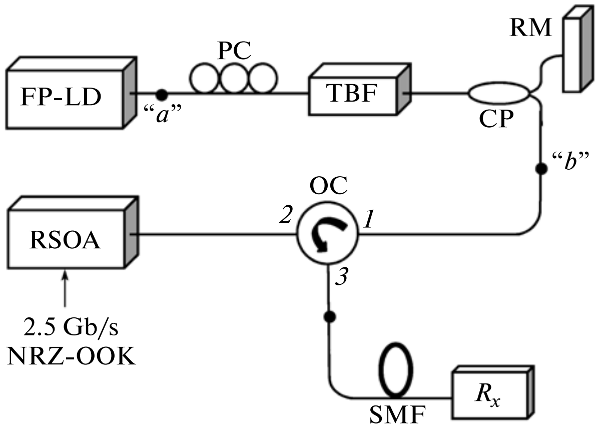


**Fig. 1.** Experimental setup of proposed wavelength-tuning laser configuration.

And the operating current of FP-LD was 30 mA at the temperature of 20°C in the experiment. Thus, the output spectrum of FP-LD in free-run status, measuring at the "*a*" point in Fig. 1, is illustrated of gray line in Fig. 2. Besides, we observe that the larger output level is located around 1544.00 to 1548.64 nm. As shown in Fig. 1, we could adjust the TBF to match the each corresponding mode of MLM FL-LD for filtering and mode selecting. So the filtered output mode transmitted through the 1 × 2 CP and RM to produce the self-seeding operation. And the PC was employed to obtain maximum output power and maintain the polarization status. In this measurement, we adjusted the central wavelength of TBF at 1546.20 nm for wavelength lasing. Due to the optical-injected operation, the injected mode of FP-LD would obtain larger gain to suppress the side-modes to generate a single-frequency output. Hance the lasing wavelength of 1546.25 nm with –7.0 dBm output power could be measured at "*b*" point (in Fig. 1), as drawn in red line of Fig. 2. Then, the lasing wavelength could be tuned by adjusting the TBF to match the each longitudinal-mode of FL-LD in its effectively amplification range. Furthermore, each lasing wavelength would inject into RSOA via an OC for wavelength amplifying and modulating. So, the output spectrum of RSOA can be measured at 1546.25 nm with 3.8 dBm output power, as also illustrated in blue line of Fig. 2, when the RSOA is operated at 50 mA operating current.

Next, we would investigate and analyze the performance of modulated signal versus different operating currents of RSOA. Hence, Fig. 3 shows the output powers of RSOA versus different operating currents, when the injected wavelength is selected at 1546.25 nm initially. In the experiment, the RSOA could be directly modulated at 2.5 Gb/s non-return-to-zero (NRZ) pseudorandom binary sequence (PRBS) format with pattern length of $2^{31}-1$. Here, we observe that the threshold current of RSOA is nearly 10 mA, as shown in Fig. 3. The obtained output powers are between –11.0 and 7.8 dBm in the operating currents of 20 to 80 mA. The inserts of Fig. 3 are the corresponding eye diagrams under different operating currents at the bit error rate (BER) of $10^{-9}$ under 2.5 Gb/s OOK modulation rate. The measured eye diagram is closer and not clear at 30 mA. With the increase of current gradually, the eye will also become widely open

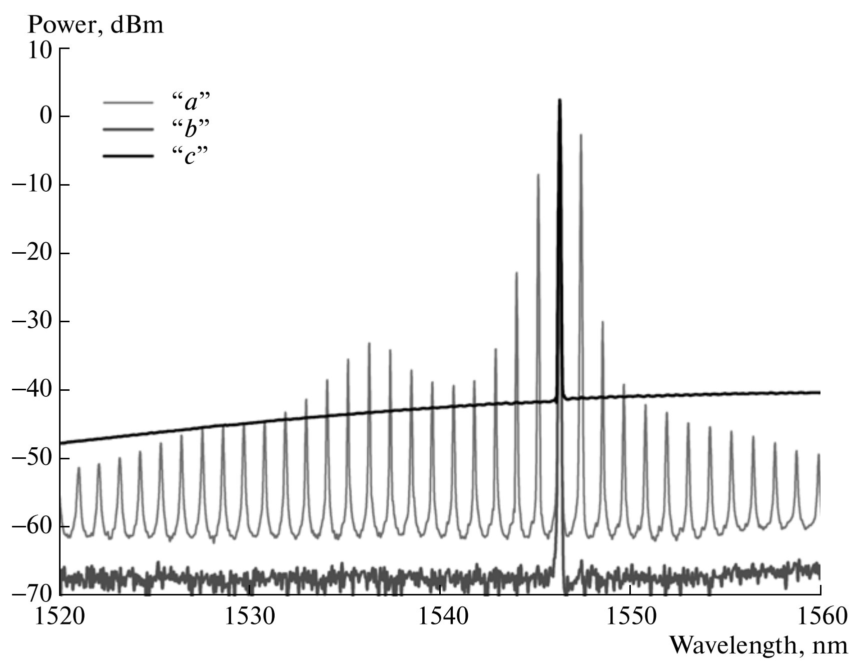


**Fig. 2.** Output spectra of the proposed laser measured at "*a*", "*b*," and "*c*" point, respectively, in Fig. 1.

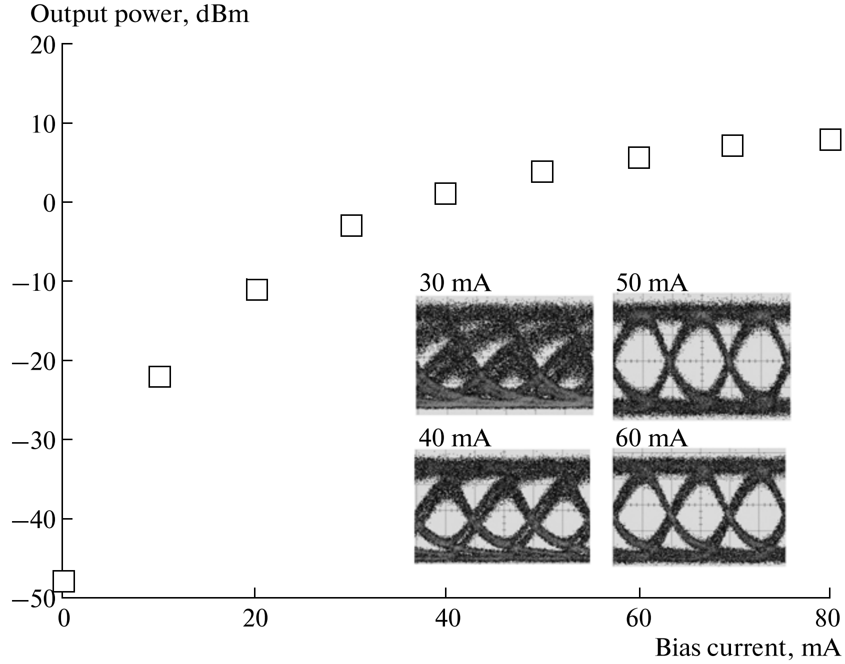


**Fig. 3.** Measured output powers of RSOA versus different operating currents, when the injected wavelength is selected at 1546.25 nm initially. Inserts are the corresponding eye diagrams.

and clear. However, the larger output power of RSOA could also produce the nonlinear effect when the bias current is larger than 70 mA. As a result, we can set the operating current of RSOA at 50 mA for optimal operation in the proposed laser configuration.

Figure 4 presents the output power and side-mode suppression ratio (SMSR) at the different lasing wavelength in the operating range of 1534.05 to 1553.00 nm with 1.1 nm tuning step according to the effectively output of MLM FP-LD (as also seen in Fig. 2). Here, the output powers and SMSRs can be observed between −5.3 and 4.6 dBm and 31.2 and 50.1 dB/0.05 nm. Besides, the maximum SMSR of 50.1 dB/0.05 nm is measured at the lasing wavelength of 1548.50 nm with 4.6 dBm output power.

To realize the output characteristic of lasing wavelength in the proposed laser, the BER measurements are performed and analyzed. In the experiment, the RSOA was operated at 50 mA and directly modulated at 2.5 Gb/s OOK data rate. And we selected a lasing wavelength at 1546.25 nm with 3.8 dBm output power for signal testing. Therefore, Fig. 5 shows the BER performance of the proposed laser source at the back-to-back (B2B), 25, 50, and 75 km single-mode fiber (SMF) transmissions, respectively. As shown in Fig. 5, the optical power penalties of 0.4, 0.5, and 1.5 dB are observed after 25, 50, and 75 km SMF transmissions, respectively, at the BER of $10^{-9}$ without dispersion compensation. Moreover, the inserts of Fig. 5 are the corresponding eye diagrams at the B2B, 25, 50, and 75 km single-mode fiber (SMF) transmissions, respectively, at the BER of $10^{-9}$. And these measured eyes are wide open and clear. Though transmitting 75 km SMF long, the output wavelength of proposed wavelength-tuning laser still has the better output performance.

Finally, in order to realize and investigate the output stabilities of power and wavelength for the proposed wavelength-tuning laser scheme, a short-term observation time was performed in the experiment, as

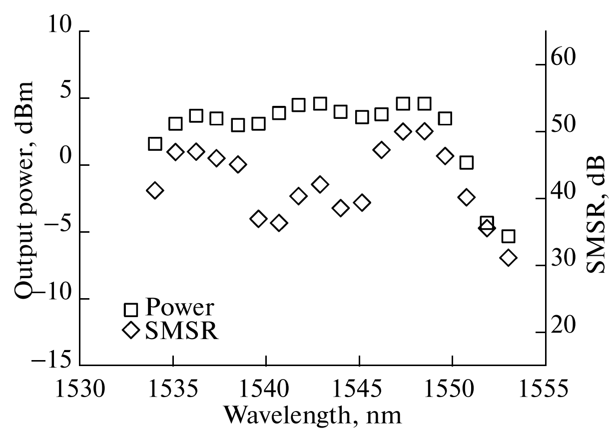


**Fig. 4.** Measured output power and side-mode suppression ratio (SMSR) at the different lasing wavelength in the operating range of 1534.05 to 1553.00 nm with 1.1 nm tuning step according to the effectively output of MLM FP-LD.

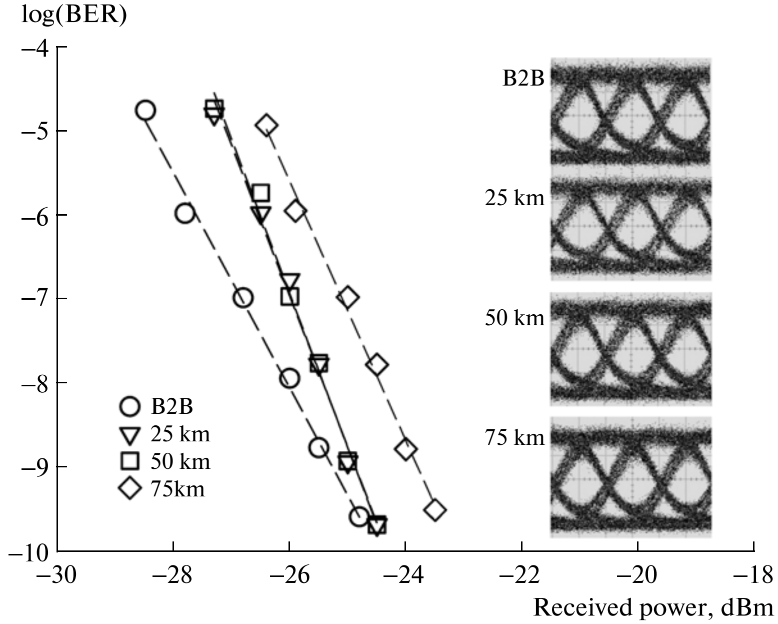


**Fig. 5.** BER performance of the proposed laser source at the back-to-back (B2B), 25, 50, and 75 km single-mode fiber (SMF) transmissions, respectively. Inserts are the corresponding eye diagrams.

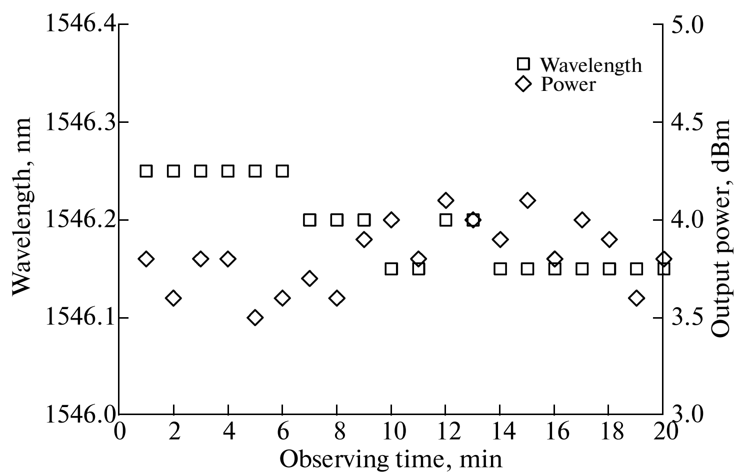


**Fig. 6.** Output stabilities of power and wavelength for the proposed quadruple-wavelength laser scheme over 20 min observing-time.

illustrated in Fig. 6, when the lasing signal was selected at 1546.25 nm with 3.8 dBm output power initially. During 20 min observing-time, the observing power and wavelength variations of the laser are 0.5 dB and 0.1 nm respectively, as also shown in Fig. 6. Moreover, after two hours observation time, the output performances of the proposed laser are still maintained.

## 3. CONCLUSIONS

In summary, we have first proposed and experimentally investigated a stable wavelength-tuning laser configuration by using self-seeded FP-LD and external-injected RSOA. Here, this proposed laser can be tuned in the wavelength range of 1534.05 to 1553.00 nm with a 1.1 nm tuning-step. And the output powers and SMSRs are between −5.3 and 4.6 dBm and 31.2 and 50.1 dB/0.05 nm, respectively. And, the proposed laser also can be directly modulated at 2.5 Gb/s OOK modulation format and propagates 75 km SMF with no optical amplifier and dispersion compensation. Moreover, the output stabilities of wavelength and power for the wavelength-tuning laser have been also performed and analyzed.

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