Tunable Dual-Wavelength Fiber Laser Using Optical-Injection Fabry–Pérot Laser

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***Abstract*—In this investigation, we propose and experimentally demonstrate a dual-wavelength fiber laser based on a self-injected Fabry–Pérot laser diode and an erbium-doped fiber. The dual-wavelength tuning range is 39.49 nm, from 1526.27 to 1565.76 nm. And the mode spacing of the dual-wavelength can be tuned from 1.32 to 39.49 nm. In addition, the output power difference of the dual-wavelength can be controlled and smaller than 1 dB.**

***Index Terms*—Self-injected, Fabry–Pérot (FP), dual-wavelength.**

I. Introduction

Recently, multiwavelength fiber lasers have high potential for different applications, such as wavelength-division-multiplexed (WDM) communications, fiber sensing systems, optical instrument testing, and optical signal processing [1]–[4]. In addition, the operation mechanism of a dual-wavelength fiber laser has been reported, such as an erbium-doped fiber (EDF) ring laser with two cavities, a coupled dual-cavity fiber laser with four fiber gratings, a fiber laser with a twin-peak reflection grating, etc. [5]–[7]. However, the homogeneous gain broadening of the EDF would result in wavelength competition. Many studies have been focused on the techniques by using optical filters into the laser loop cavity for single or multiwavelength emissions [4]–[7]. In addition, utilizing a self-injected Fabry–Pérot laser diode (FP-LD) or distributed feedback laser diode (DFB-LD) with a fiber Bragg grating (FBG) or optical filter to generate single or multiple wavelengths have also been analyzed [8]–[10].

In this study, we propose and demonstrate a laser scheme using self-injected FP-LD and EDF. It is a ring architecture. Dual-wavelength tuning is also achieved. The tuning range of the dual-wavelength laser is 39.49 nm. The maximum and minimum mode spacing is 39.49 and 1.32 nm, respectively. The proposed laser has the following advantages: 1) two wavelengths can be tuned separately using the two tunable bandpass filters (TBFs); 2) the mode spacing can also be tuned by the TBFs; 3) the laser has a broadly tuning range; and 4) the laser structure is relatively simple.

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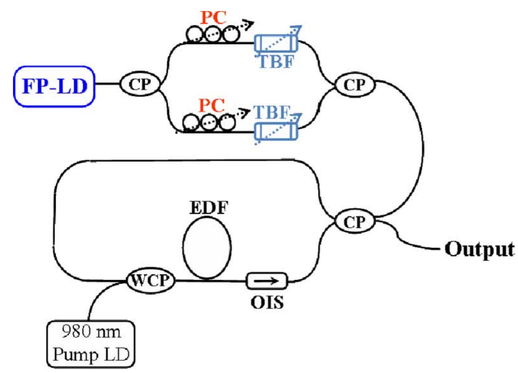

Fig. 1. Experimental setup for the tunable dual-wavelength fiber ring laser scheme.

II. Experiment and Discussion

Fig. 1 shows the experimental setup for the tunable dual-wavelength fiber ring laser. The proposed fiber laser consisted of one 2×2 3-dB coupler (CP), two 1×2 3-dB CPs, two TBFs, two polarization controllers (PCs), an FP-LD, and an erbium-doped fiber amplifier (EDFA). The EDFA was constructed by a 980/1550-nm WDM coupler (WCP), 980-nm pump laser diode (LD), an optical isolator (OIS), and a 10-m EDF.

When the pumping power exceeds 100 mW in the proposed laser, the output power will be saturated. Thus, the 980-nm pump LD was set at 100 mW in the experiment. The 3-dB bandwidth and insertion loss of the TBF used was 0.4 nm and 4 dB, respectively. The tuning range of the TBF was 40 nm (1520–1560 nm). The PCs were used to adjust the polarization states of the feedback lightwave into the FP-LD. According to the past study [11], an injected optical signal at transverse-electric-mode of FP-LD can result in maximum injection locking efficiency.

The threshold pumping power in this experiment was around 14 mW while the FP-LD was operated at 22 mA and 25 °C. To measure the output power and wavelength of the proposed dual-wavelength laser, an optical spectrum analyzer (OSA) with 0.05-nm resolution was used in the measurement. Fig. 2 shows the original output spectrum of the free-run FP-LD

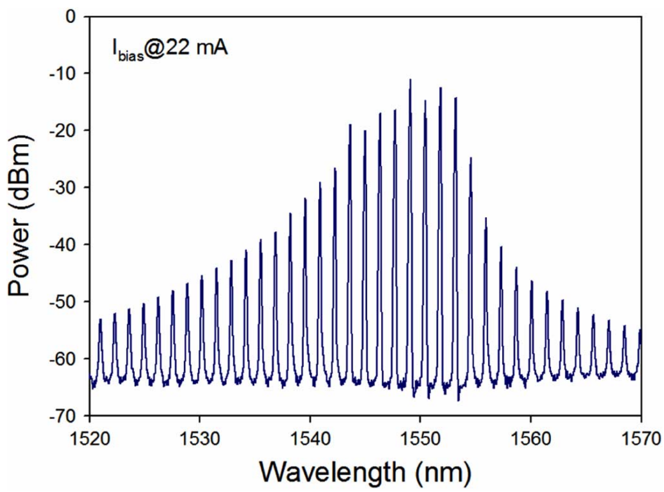

Fig. 2. Original output spectrum of FP-LD operates at 22 mA on 25 °C without self-seeding.

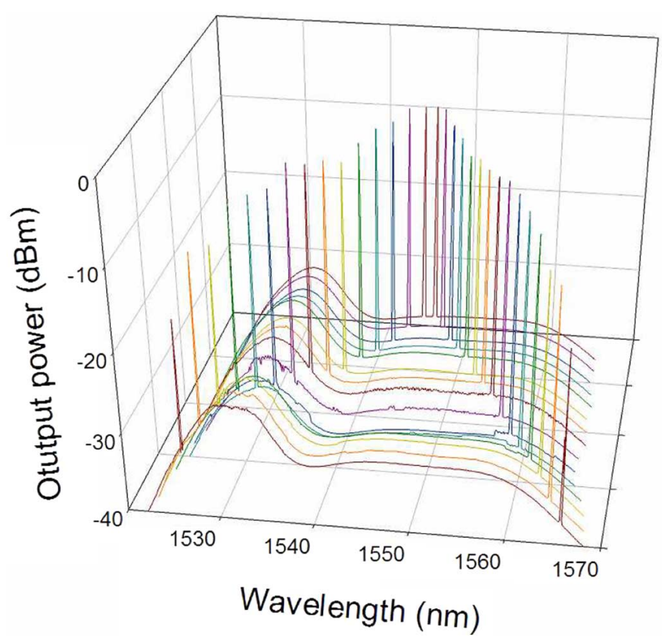

Fig. 3. Output wavelength spectra of the proposed tunable dual-wavelength fiber laser while the pumping power of 980-nm LD and bias current of the FP-LD are 110 mW and 22 mA, respectively, in the wavelength range of 1526.3–1565.8 nm with different mode spacing.

without self-injection. The mode spacing $(\Delta\lambda)$ and threshold current of FP-LD are 1.38 nm and 9.5 mA, respectively.

The two TBFs inside the ring cavity were used to align and filter the corresponding modes for two wavelengths lasing simultaneously. Fig. 3 shows the output spectra (wavelength range from 1526.27 to 1565.76 nm with different mode spacing) of the proposed tunable dual-wavelength fiber laser at the pumping power $=$ 100 mW and bias current of the FP-LD $=$ 22 mA. The mode spacing can also be determined by adjusting the two TBFs to properly align and match the filtering mode of the FL-LD. In Fig. 3, the maximum and minimum mode spacing of the dual-wavelength laser was 39.49 and 1.32 nm, respectively. Over the tuning range, the maximum and minimum power variation $(\Delta P_{\max}$ and $\Delta P_{\min})$ was equal to 0.98 and 0.01 dB when the mode spacing is 36.69 and 17.65 nm, respectively. The proposed laser is limited to step tuning (in this case, it is 1.32 nm). We can also retrieve the continuous wavelength tuning by adjusting the temperature of the FP-LD. While the temperature difference (ΔT) of the FP-LD was ± 5 °C, the central wavelength variation was ± 0.2 nm. Thus, the dual-wavelength can be tuned continuously by controlling the temperature.

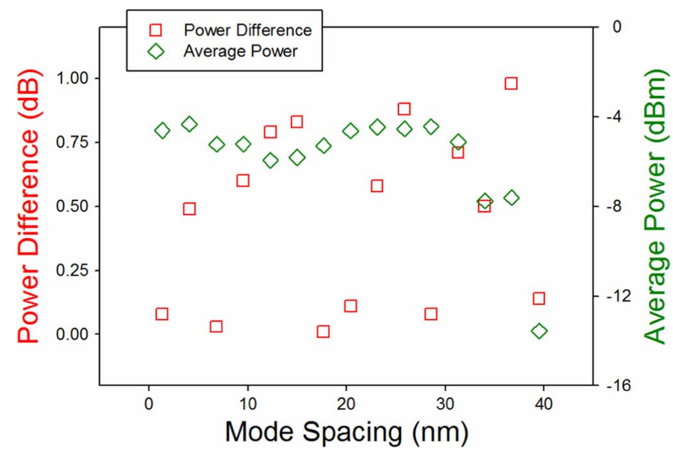

Fig. 4. Output power difference and average output power under various mode spacing for the tunable dual-wavelength fiber laser.

Fig. 4 shows the output power differences and the average output powers under various mode spacing of the fiber laser. The average output power is between -13.56 and -4.33 dBm, as shown in Fig. 4. By increasing of the mode spacing gradually, the average output power is decreasing, as illustrated in Fig. 4. Thus, when the mode spacing is 39.49 nm, the output power will drop to -13.56 dBm due to the smaller gain in both shorter and longer wavelength sides of the FP-LD (in Fig. 2). In addition, the output power differences of the dual-wavelength can be less than 1 dB due to the proper adjusting of the PCs. The nonlinear filter function of the self-injected FP-LD can also improve the noise performance of the proposed laser [12], [13]. We also studied the stability of the proposed laser, and the power variation during a 30-min observation time was negligible. We believe that the inhomogenously broadened FP-LD gain saturation plays a part in suppressing the erbium gain competition. The stability of the proposed laser can be further enhanced by using all polarization-maintaining (PM) components inside the laser cavity.

Fig. 5 shows the optical spectra of the dual-wavelength fiber laser lasing at wavelengths of 1545.08 and 1546.40 nm, when the pumping power was adjusted from 14 to 120 mW. The lasing output power will start to saturate at 100 mW, as shown in Fig. 5. The threshold pumping power of the proposed dual-wavelength laser was 28 mW, as also illustrated in Fig. 5.

III. Conclusion

We proposed and experimentally demonstrated a tunable dual-wavelength fiber laser based on a self-injected FP-LD and an EDF. The dual-wavelength output of the proposed fiber laser is widely tunable, and the mode spacing of the two lasing wavelengths can also be adjusted within the tuning range. Two TBFs were used inside the laser cavity to generate the

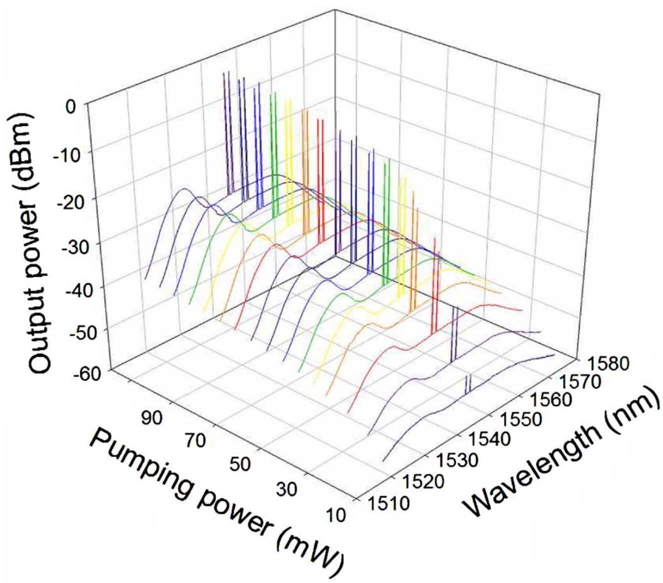

Fig. 5. Output wavelength spectra versus the different pumping power under 14 to 120 mW at the two wavelengths of 1545.08 and 46.40 nm initially.

dual-wavelength output. The dual-wavelength tuning range can be achieved up to 39.49 nm from 1526.27 to 1565.76 nm. The mode spacing of the dual-wavelength can be tuned by using the two TBFs to align the corresponding longitudinal-mode of the FP-LD. The maximum and minimum mode spacing of the laser is 39.49 and 1.32 nm, respectively. The proposed laser is limited to step tuning (in this case, it is 1.32 nm). Moreover, the threshold pumping power and saturated pumping power of the laser are 28 and 100 mW, respectively. The output power difference of dual-wavelength can be controlled to smaller than 1 dB.

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