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Demonstration of a self-injected Fabry–Perot laser for dual-wavelength tuning together with different mode-spacing

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Abstract
In this demonstration, we experimentally investigate a dual-ring fiber laser architecture to achieve dual-wavelength-tunable by utilizing the self-injected Fabry–Perot laser diode (FP-LD) mechanism. Here, two tunable bandpass filters (TBFs) are utilized in the proposed laser structure to obtain the dual-wavelength with single-longitudinal-mode (SLM). The different mode-spacing of the proposed dual-wavelength fiber laser can also be tuned between 20.8 and 1.3 nm, due to the effective gain amplification of FP-LD. Moreover, we can employ the different FP-LDs with various gain distributions to achieve wide wavelength range tuning.

Keywords: fiber lasers, fiber optics, communication optical

(Some figures may appear in colour only in the online journal)

1. Introduction

The wavelength-tunable fiber laser is a potential component for applications of the wavelength division multiplexed (WDM) system, optical fiber sensing, optical instrument testing, and optical signal processing etc [1–4]. Furthermore, to achieve tunable dual-wavelength output, an erbium-doped fiber (EDF)-based laser architecture has been proposed and studied [5–7]. However, due to the homogeneous gain broadening of EDF, it would result in wavelength competition. Hence, many studies have focused on the technique of using the optical filter in the laser loop cavity for single- or multi-wavelength oscillations [4–7]. Recently, utilization of the self-seeding Fabry–Perot laser diode (FP-LD) or distributed feedback laser diode (DFB-LD) with fiber Bragg grating (FBG) or optical filter to generate single-wavelength, dual-wavelength or multi-wavelength short pulses has also been analyzed [8–11]. Furthermore, using self-seeded FP-LD schemes required an erbium-doped fiber amplifier (EDFA) to be combined to enhance the gain amplification range and achieve dual-wavelength lasing in the whole C-band window [10–12].

In this study, we propose and experimentally investigate a new and simple architecture to achieve a tunable dual-wavelength fiber laser using a self-injected FP-LD without EDFA or other optical amplifiers. The continuous-wave (CW) single-longitudinal-mode (SLM) dual-wavelength can be accomplished via self-injected FP-LD design. By adjusting two tunable bandpass filters (TBFs), which are placed inside the cavity loop, to match the corresponding output mode of FP-LD, the different mode-spacing of dual-wavelength also can be retrieved. Therefore, the proposed dual-wavelength laser scheme is easy to construct and cost-effective.

2. Experiment setup

The experimental setup of the proposed tunable dual-wavelength fiber laser scheme is illustrated in figure 1. The proposed laser scheme consists of an FP-LD, a 1 × 2 optical

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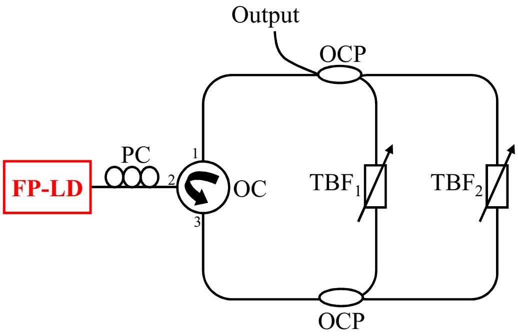

Figure 1. Experimental setup of the proposed tunable dual-wavelength fiber laser scheme.

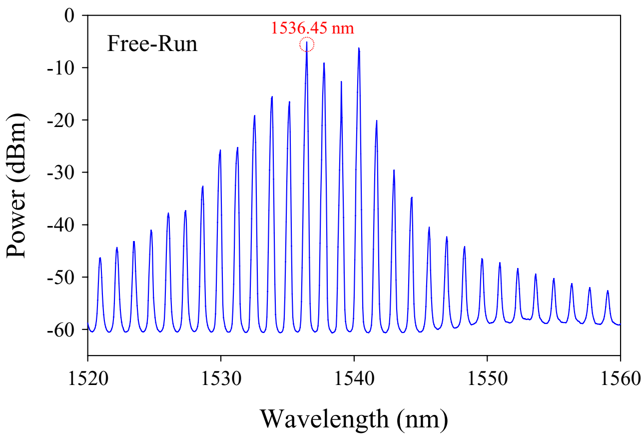

Figure 2. The wavelength spectrum of the free-run multi-mode FP-LD, which is operated at the bias current and temperature of 30 mA and 25 °C, respectively.

coupler (OCP), a 2 × 2 OCP, a 3-port optical circulator (OC), a polarization controller (PC) and two TBFs (TBF_1 and TBF_2). As shown in figure 1, two OCPs could produce a dual-ring fiber configuration, and two TBFs are used inside the dual-ring scheme to match the corresponding output mode of the FP-LD for dual-wavelength selection. In figure 1, the OC would result in the wavelength propagation in the counter-clockwise direction. Moreover, the PC is utilized to adjust the polarization status and maintain maximum output power. The wavelength-tunable range and 3 dB bandwidth of the two TBFs used are around 35 nm (1525–1560 nm) and 0.4 nm, respectively, and the output spectrum of the proposed laser scheme is observed by an optical spectrum analyzer (OSA) with a 0.01 nm resolution.

Figure 2 shows the wavelength spectrum of a free-run multi-mode FP-LD, which is operated at the bias current and temperature of 30 mA and 25 °C, respectively. Here, the central wavelength of the FP-LD is measured at 1536.45 nm and the mode-spacing of the FP-LD is 1.30 nm. In this measurement, we first fix the central wavelength of TBF_1 at 1536.45 nm to match the central output mode of the FP-LD. Then we adjust the central wavelength of TBF_2 from shorter to longer wavelengths for dual-wavelength output with various mode-spacing. Hence, figure 3 presents the output dual-wavelength spectra of the proposed self-injected FP-LD, when TBF_1 (λ_1) is fixed at 1536.45 nm. As shown in figure 3,

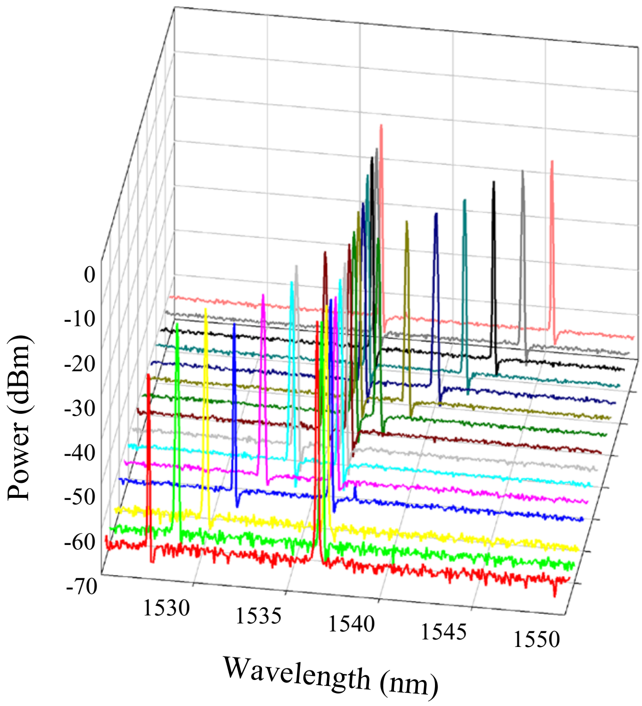

Figure 3. The output dual-wavelength spectra of the proposed self-injected FP-LD, when TBF_1 is fixed at 1536.45 nm and TBF_2 is adjustable.

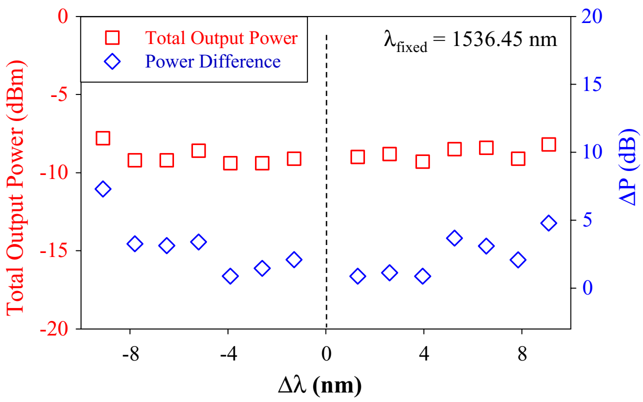

Figure 4. The total output power and power difference (ΔP) of dual-wavelength under different mode-spacing ($\Delta\lambda$), when the central wavelengths of TBF_1 and TBF_2 are tuned.

when we gradually adjust the central wavelength of TBF_2 (λ_2) to shorter wavelength, the maximum mode-spacing of dual-wavelength of 9.1 nm (1527.35–1536.45 nm) can be obtained. While the central wavelength of TBF_2 is less than 1527.35 nm, the proposed laser can only generate a 1536.45 nm wavelength due to the gain competition of the FP-LD. Similarly, we can also achieve a 9.1 nm maximum mode-spacing (1536.45–1545.55 nm), when the central wavelength of TBF_2 is tuned to the shorter wavelength gradually.

In the measurement, figure 4 shows the total output power and power difference (ΔP) of dual-wavelength under different mode-spacing ($\Delta\lambda$), when the central wavelengths of TBF_1 and TBF_2 are tuned. Here, we employ a power meter (PM) to measure the total output power of the proposed dual-wavelength laser. The central wavelength of TBF_1 is

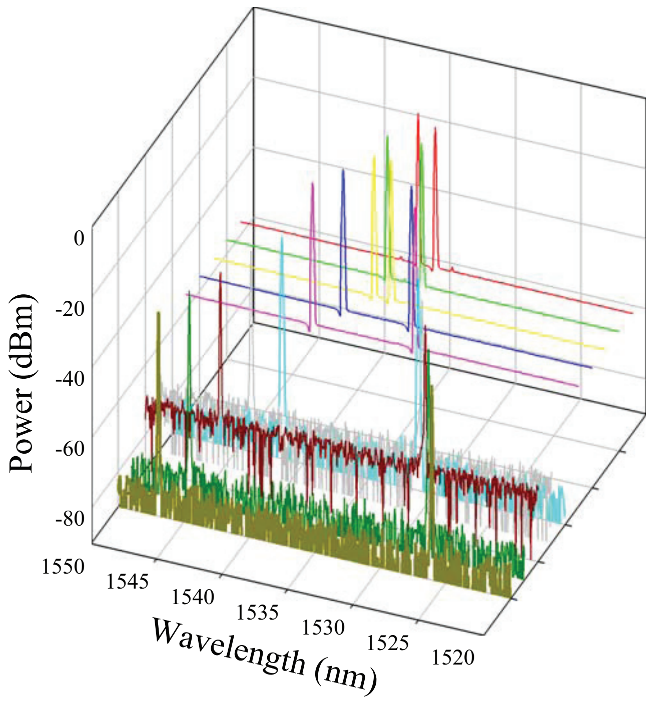

Figure 5. Output wavelength spectra of the proposed dual-wavelength laser with different mode-spacing outwards from the middle.

fixed at 1536.45 nm, and the central wavelength of TBF_2, with a 1.3 nm tuning step, could be tuned to the shorter and longer wavelengths for dual-wavelength output. The obtained mode-spacing of dual-wavelength is from 1.3 to 9.1 nm, as illustrated in figure 3. Hence, figure 3 shows that the corresponding obtained total output power and power difference (ΔP) of dual-wavelength is between –9.4 and –7.8 dBm and 0.87 and 7.31 dB, respectively. As shown in figure 3, the smaller mode-spacing would lead to smaller power difference ΔP in the proposed laser scheme.

Next, we experiment with the maximum and minimum mode-spacing of the proposed dual-wavelength laser configuration. Because the central wavelength of the FP-LD is 1536.35 nm in free-run, we would first select the two wavelengths at 1536.45 and 1535.15 nm for the minimum mode-spacing of dual-wavelength output. Then, we increase the mode-spacing of the proposed dual-wavelength laser gradually by adjusting the two TBFs with the tuning step of 1.3 nm for wavelength tuning. Therefore, figure 5 shows the output wavelength spectra of the proposed dual-wavelength laser with the different mode-spacing outwards from the middle. Here, the maximum mode-spacing of 20.8 nm is also obtained, and the two corresponding wavelengths are 1526.05 and 1546.85 nm. When the mode-spacing increases over 20.8 nm, only one wavelength can be generated, due to the gain competition of the FP-LD. However, as the mode-spacing increases gradually, the observed wavelength peak power decreases.

And so, figure 6 shows the total output power and power difference ΔP of the proposed dual-wavelength laser under various mode-spacings with a multiple of 1.3 nm. The minimum and maximum mode-spacing and total output powers of 1.3 and 20.8 nm and –14.4 and –8.8 dBm, respectively,

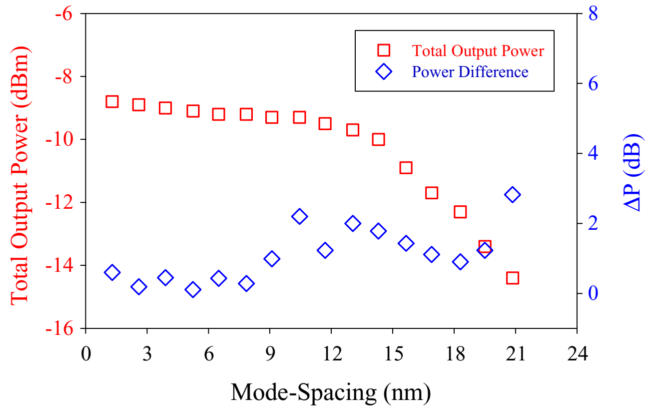

Figure 6. The total output power and power difference ΔP of the proposed dual-wavelength laser under various mode-spacings with a multiple of 1.3 nm.

are observed, and the measured peak power difference ΔP is between 0.1 and 2.8 dB, as shown in figure 6. The minimum ΔP is observed at a mode-spacing of 5.2 nm. Due to the effective gain distribution of 20.8 nm in the FP-LD, the dual-wavelength output can only be around this range. As seen in figure 6, with the gradual increase of mode-spacing, the retrieved output powers decrease. In a previous study [11], we integrated the EDFA and FP-LD in the fiber laser scheme to achieve the gain amplification of 39.49 nm for wide dual-wavelength output. Compared with the new proposed dual-wavelength laser scheme, the lasing wavelength bandwidth of the past work was doubled. Here, the new proposed laser does not require use of EDFA for dual-wavelength lasing, and its dual-wavelength bandwidth is around 20.8 nm according to the effective amplification range. In addition, if we want to obtain the broad tuning range based on the proposed fiber laser scheme, we can select a different central wavelength output of the FP-LD to extend the amplification range.

3. Conclusion

In summary, we proposed and experimentally investigated a dual-ring fiber laser architecture to accomplish dual-wavelength lasing and tuning simultaneously by utilizing the self-injected FP-LD mechanism. Here, two TBFs are utilized in the proposed laser structure to obtain the dual-wavelength output with SLM. The different mode-spacing of the proposed dual-wavelength fiber laser could also be achieved between 20.8 and 1.3 nm, due to the effective amplification of the FP-LD. In addition, we employed the different FP-LDs with various gain distributions to achieve wide wavelength range tuning.

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