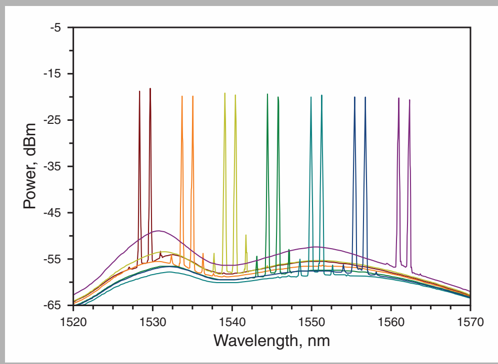
Tunable and stable single-longitudinal-mode dual-wavelength erbium fiber laser with 1.3 nm mode spacing output

2008 Laser Phys. Lett. 5 821

(http://iopscience.iop.org/1612-202X/5/11/008)

Abstract: In this investigation, we propose and investigate a stable and tunable dual-wavelength erbium-doped fiber (EDF) ring laser with self-injected Fabry-Perot laser diode (FP-LD) scheme. By using an FP-LD incorporated with a tunable bandpass filter (TBF) within the gain cavity, the fiber laser can lase at two single-longitudinal-mode (SLM) wavelengths simultaneously due to the self-injected operation. The proposed dual-wavelength laser has a good performance of the output power and optical side-mode suppression ratio (SMSR). The laser also shows a wide tuning range from 1523.08 to 1562.26 nm. Besides, the output stabilities of the fiber laser are also discussed.



Output wavelength spectra of the proposed dual-wavelength fiber laser with 100 mW pumping power and 18 mA bias current, in the operating wavelengths of 1523.08 to 1562.26 nm

Tunable and stable single-longitudinal-mode dual-wavelength erbium fiber laser with 1.3 nm mode spacing output

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Received: 11 July 2008, Revised: 17 July 2008, Accepted: 19 July 2008
Published online: 29 July 2008

Key words: erbium-doped, dual-wavelength, Fabry-Perot

PACS: 42.60.Da, 42.81.-i, 42.81.Wg

1. Introduction

Tunable and stable multiwavelength fiber lasers are important and attractive in recent years because of their potential applications in wavelength-division-multiplexed (WDM) technique, optical code-division multiple-access (OCDMA) technique, fiber sensor system, and optical instrument measuring and testing [1–10]. Different techniques for the reduction of wavelength competition have been used to achieve stable multiwavelength oscillations. However, homogeneous gain broadening of erbium-doped fibers (EDFs) will lead to the wavelength competition [2]. Many reports have been focused on the technique by inserting the optical filter, such as the tunable bandpass filter, Fabry-Perot tunable filter and fiber Bragg grating, into the EDF laser cavity for single or multiwavelength oscillations [2–10]. In such configurations, the cavity losses corresponding to the different wavelengths have to be balanced with the cavity gains simultaneously. Therefore, it is difficult to control the lasing wavelength output.

Recently, the self-injection Fabry-Perot laser diodes (FP-LDs) and distributed feedback laser diode (DFB-LD) with mode-locked operation using Bragg grating or op-

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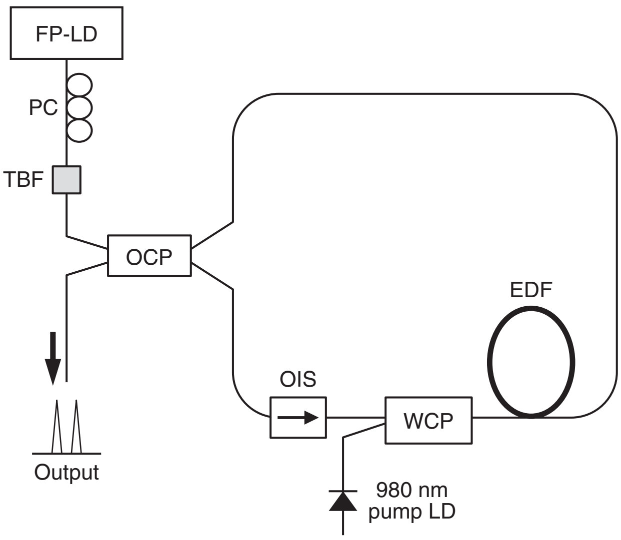

Figure 1 Experimental setup of the proposed tunable and stable dual-wavelength fiber laser

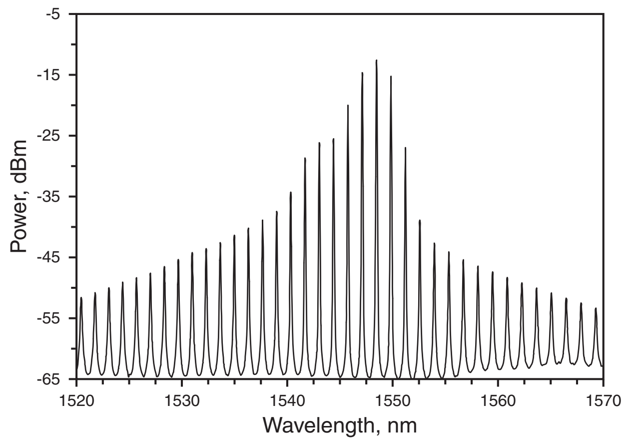

Figure 2 Output wavelength spectrum of the FP-LD without self-seeding operation in the wavelengths of 1520 to 1570 nm when the LD operates at 18 mA and 25°C

tical filter to generate tunable single-wavelength, dual-wavelength or multiwavelength short pulses have been proposed [9–15]. Mode-spacing and wavelength tuning laser using bismuth-oxide fiber or photonics crystal fiber with nonlinear effect have been studied and reported [15–18], however, by comparing with our proposed scheme, we only need commercially available and standard components to achieve the two-mode lasing and has cost-effective.

In this study, a new and simple architecture of a stable and tunable dual-wavelength fiber ring laser using a self-injected FP-LD is proposed and demonstrated. The lasing of continuous-wave (CW) single-longitudinal-mode (SLM) dual-wavelength is performed via the self feedback injection of the FP-LD. By adjusting the tunable band-pass filter (TBF) inside the cavity, the dual-wavelength output can be retrieved. Furthermore, the proposed laser scheme is easy to be constructed and cost-effective. The output performance of the tunable dual- wavelength fiber ring laser, operated at optimal operating condition, is also investigated experimentally.

2. Experiments and results

In this experiment, Fig. 1 shows the proposed structure of tunable dual-wavelength EDF ring laser. The proposed fiber laser is consisted of an erbium-doped fiber amplifier (EDFA), a 2×2 and 50:50 optical coupler (OCP), a FP-LD and a polarization controller (PC). In Fig. 1, the EDFA constructed by a 10 m long EDF (Fibercore DC1500F), a 980/1550 nm WDM coupler, an optical isolator (OIS) and a 980 nm pumping laser. In this proposed laser scheme, when the pumping power exceeds 100 mW, it would saturate the lasing output. Thus, the 980 nm pump LD is set at 100 mW. The 3 dB bandwidth and average insertion loss of TBF used are nearly 0.4 nm and 3.5 dB respectively. The TBF also has a 40 nm tuning range from 1520 to 1560 nm.

The PC between FP-LD and OCP is used to control the polarization state of the feedback injection light into the FP-LD. According to the past self-injected report [9], only one polarized direction being parallel to the TE-mode of FP-LD of feedback wavelength leads to the maximum self-injected efficiency. In the experiment, the mode spacing ($\Delta\lambda$) and threshold current of FP-LD are 1.3 nm and 10 mA, respectively. In the measurement, the threshold pumping power in this experiment is around 20 mW while the FP-LD is operated at 18 mA and 25°C. Therefore, we set the bias current of the FP-LD at 18 mA at the temperature of 25°C. To measure and analyze the output power and wavelength of the proposed dual-wavelength laser, an optical spectrum analyzer (OSA) with a 0.05 nm resolution is used for the measurement. Fig. 2 presents the output wavelength spectrum of the FP-LD without self-seeding operation in the wavelength range of 1520 to 1570 nm. Fig. 2 also shows that the output power level of FP-LD is above –20 dBm around the wavelengths between 1545 and 1550 nm.

Then, by using the proposed self-injected structure, Fig. 3 displays the output wavelength spectra of the proposed dual-wavelength fiber laser when the 980 nm pump LD power and bias current of the FP-LD are 60 mW and 18 mA, respectively, in the operating wavelengths of 1523.08 to 1562.26 nm with 1.3 nm tuning step. In Fig. 3, the mode spacing of the dual-wavelength laser is measured at nearly 1.3 nm. The minimum side-mode suppression ratio (SMSR) is larger than 36.5 dB over the operating range. The maximum and minimum output powers of −9 and −14.5 dBm are also observed in the tuning range.

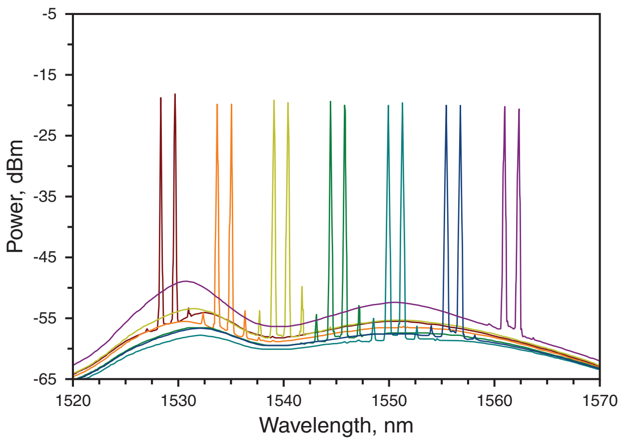

Figure 3 (online color at www.lphys.org) Output wavelength spectra of the proposed dual-wavelength fiber laser with 100 mW pumping power and 18 mA bias current, in the operating wavelengths of 1523.08 to 1562.26 nm

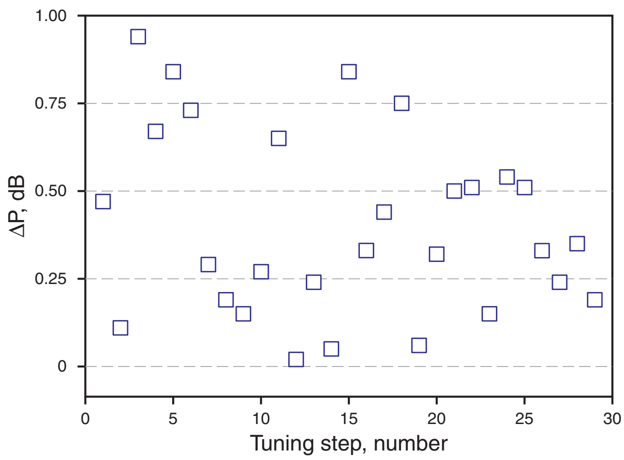

Figure 4 (online color at www.lphys.org) Power difference (ΔP) of the lasing dual-wavelength in the operating range with ∼ 1.3 nm tuning step

Besides, the dual-wavelength can be slightly tuned by adjusting the temperature of the FP-LD. While the temperature difference (ΔT) of the FP-LD is ±5°C, the central wavelength variation also shifts at ±0.2 nm. Therefore, the dual-wavelength can be tuned continuously by controlling the temperature. Based on the proposed laser architecture, the fiber laser not only can lase dual-wavelength but also enhance the tuning wavelength range to 39.18 nm. As a result, Fig. 2 is a free-run FP-LD, with very small output powers at shorter wavelength (< 1545 nm) and longer wavelength (> 1555 nm). However, in our proposed scheme, we simultaneously achieve two-mode laser with even and high output power across the wavelength range of 39.18 nm. The significantly improvement can be seen in Fig. 3. We have tried several coupling ratios (such as 90/10, 80/20, 70/30, 60/40, and 50/50) and we found that the 50/50 is the optimum case.

Fig. 4 shows the output power difference (ΔP) of the lasing dual-wavelength in the operating range with ∼ 1.3 nm tuning step. The output power difference is defined to $\Delta P = |P_1 - P_2|$. The maximum and minimum ΔP of 0.9 and 0.1 dB are measured in Fig. 4. As a result, the dual-wavelength also presents a good equalizing output power over the tuning range.

Fig. 5 shows the average output power and SMSR of the lasing dual-wavelength with 1.3 nm tuning step in the wavelengths of 1523.08 to 1562.26 nm. In the tuning step 7 to 28 (from 1530.88 to 1558.18 nm), the average output power and SMSR could be larger than –10 dBm and 40.1 dB, respectively. For the whole tuning range, in the wavelengths of 1523.08 to 1562.26 nm (step 1 to 29), the minimum average output power and SMSR of –14.6 dBm and 36.4 dB can still be achieved. Fig. 5 also shows a flat average output power in the tuning range in the tuning step 4 to 27 ($\Delta P_{max} = 0.9$ dB). Moreover, the average SMSR

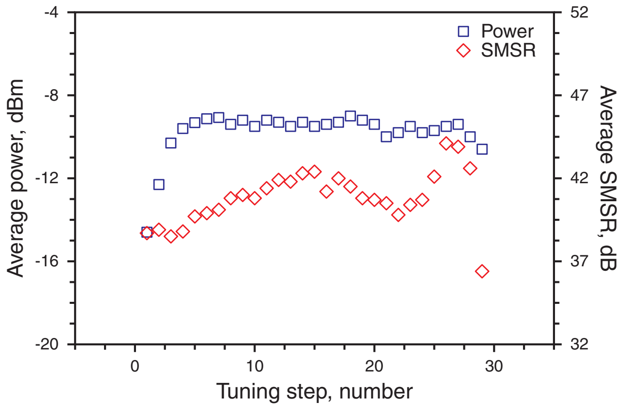

Figure 5 (online color at www.lphys.org) The average output power and SMSR of the lasing dual-wavelength with 1.3 nm tuning step in the wavelengths of 1523.08 to 1562.26 nm

spectrum in Fig. 5 presents two peaks at the step 15 and 26, respectively. And the maximum difference of average SMSR is ∼ 5.4 dB in the tuning range.

In order to investigate the output stabilities of the proposed dual-wavelength laser, a short-term stability of output power and wavelength is measured and observed. In the measurement, the lasing two wavelengths are 1528.36 and 1529.67 nm with output power of –9.0 and –8.4 dBm initially over 20 minutes observation time. The output wavelength variations of the two wavelengths are zero and the maximum power fluctuation of λ_1 and λ_2 are 0.5 and 0.4 dB, respectively, as shown in Fig. 6. Then, in one hour observing time, the output stability is also maintained as mentioned before.

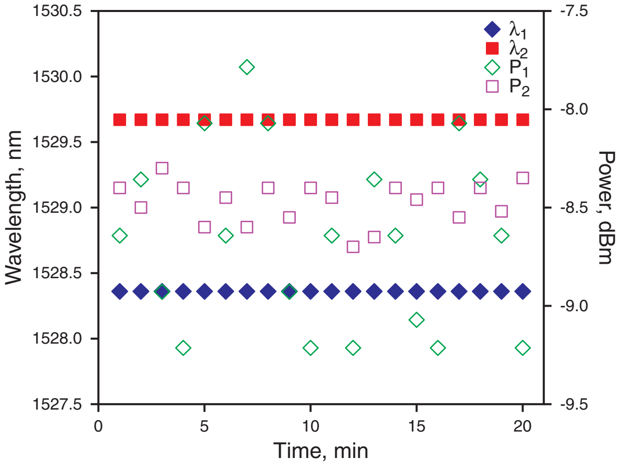

Figure 6 (online color at www.lphys.org) The average output power and SMSR of the lasing two wavelengths with 1.3 nm tuning step from 1523.08 to 1562.26 nm

3. Conclusion

We have proposed and investigated a stable and tunable dual-wavelength erbium-doped fiber ring laser employing a self-injected FP-LD. By adding an FP-LD incorporated with a tunable bandpass filter within a gain cavity, the fiber laser can lase two wavelengths simultaneously due to the self-injected operation. The proposed dual-wavelength laser shows a good performance of output power and optical side-mode suppression ratio. The laser also presents a 39.18 nm wide tuning range from 1523.08 to 1562.26 nm. When compared with the previously proposed schemes [11–13] (they showed only a few nm tuning range for dual-wavelength operating), our proposed dual-wavelength fiber laser not only has the better optical output efficiency, but also has a wide tuning range of 39.18 nm. Besides, it has the advantage of simply architecture, low cost and better output efficiency.

Acknowledgements This work was supported in part by the National Science Council of ROC (Taiwan) under Contracts NSC-96-2221-E-155-038-MY2-1, NSC-96-2221-E-155-039-MY3-1, and NSC 96-2218-E-009-025-MY2.

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