Cost-effective wavelength-tunable fiber laser using self-seeding Fabry-Perot laser diode

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Abstract: We propose and experimentally demonstrate a continuous wave (CW) tunable-wavelength fiber laser using self-seeding Fabry-Perot laser diode (FP-LD) without optical amplifier inside gain cavity. By employing a tunable bandpass filter (TBF) and a fiber reflected mirror (FRM) within a gain cavity, the fiber laser can lase a single-longitudinal wavelength due to the self-seeding operation. The proposed tunable wavelength laser has a good performance of the output power (> −15 dBm) and optical side-mode suppression ratio (> 40 dB) in the wavelength tuning range of 1533.75 to 1560.95 nm. In addition, the output stabilities of the fiber laser are also investigated.

OCIS codes: (060.0060) Fiber optics and optical communications; (060.2320) Fiber optics amplifiers and oscillators

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1. Introduction

Recently, optical fiber communication is operated around the wavelength region of C-band (1530 to 1560 nm). Optical amplifier technology at this wavelength region is dominated by using erbium-doped fiber amplifiers (EDFAs). However, the ever-increasing demand for data bandwidth has led to saturation of the C-band in wavelength division multiplexed (WDM) systems [l]. The limited gain bandwidth of erbium demands that new amplifier components are developed to allow transmission over other regions of the optical spectrum, providing greater capacity for WDM systems, such as using tunable Raman pump source to cover the 1470 to 1560 nm region [2], or employing erbium fiber for S-band (1470 to 1520 nm) [3] and L-band (1560 to 1620 nm) operations [4]. Based on these optical amplifiers, the tunable continuous wave (CW) fiber lasers were also proposed and experimented in different operating ranges [2-5]. These CW fiber lasers, for examples, the erbium-doped fiber (EDF) and Raman fiber lasers, have potential applications in optical communications, fiber sensors, and spectroscopy. Fiber laser using Fabry-Perot laser diode (FP-LD) is also a potential

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candidate, and past study using FP-LD and optical filter inside ring cavity can retrieve a stable and tunable single-wavelength output [5]. However, these fiber lasers are relatively costly since fiber amplifiers inside the gain cavities are required [2-5].

In this paper, we propose and experimentally demonstrate a continuous wave (CW) tunable-wavelength fiber laser using self-seeding Fabry-Perot laser diode (FP-LD) in C-band operating region without fiber amplifier inside gain cavity. By employing a tunable bandpass filter (TBF) and a fiber reflected mirror (FRM) within the gain cavity, the fiber laser can lase at a single wavelength with high side-mode suppression ratio (SMSR) ≧ 40 dB. Besides, we can also use the S- and L-band FP-LD to extend the tuning range in other operating region by the same proposed laser scheme.

2. Experimental Results

A simple scheme for the CW tunable-wavelength fiber laser is illustrated in Fig. 1. The proposed fiber laser is consisted of a C-band FP-LD, a 1×2 and 50:50 optical coupler (OC), a tunable bandpass filter (TBF), a polarization controller (PC) and a fiber reflected mirror (FRM). The multi-longitudinal-mode FP-LD has 1.38 nm mode spacing ($\Delta\lambda$). The 3 dB bandwidth and average insertion loss of TBF was nearly 0.4 nm and 3.5 dB, respectively, and the tuning wavelength range is from 1530 to 1560 nm. The PC is placed inside the ring cavity in order to control the polarization state properly and obtain the maximum output power and maintain the wavelength stabilization. The FRM has a ~99.8 % reflection in C- to L-bands. To provide a stable frequency operation, the central wavelength of the TBF is tuned to align to the corresponding longitudinal-mode of the FP-LD for single wavelength lasing. Therefore, 1.38 nm tuning step is determined by the longitudinal-mode spacing of the FP-LD. The side-modes of the FP-LD are suppressed and the optical output amplified when the bias current is adjusted at proper operating conditions by self-seeding. The output spectra and powers are observed by using an optical spectrum analyzer (OSA) with a 0.05 nm resolution and a power meter, respectively.

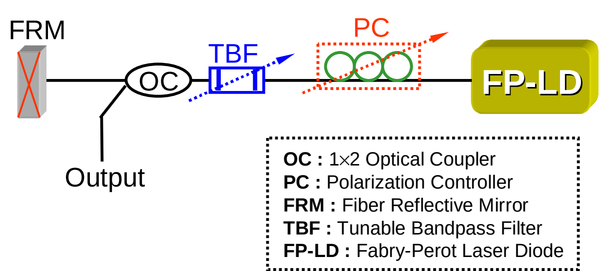

Fig. 1. A simple scheme for the CW tunable-wavelength fiber laser.

The operating mechanism of the proposed self-seeding laser is as follows. When the lasing light from the multi-mode FP-LD passes through the PC, TBF and OCP initially, the observed lasing wavelength is only filtered by corresponding TBF from FP-LD without self-seeding. Therefore, the feedback light is selected by the TBF and transmits through the following fiber path: FP-LD → PC → TBF → OC → FRM → OC →TBF → PC → FP-LD → PC → TBF → OC → Output. Figure 2(a) shows the original output spectrum of multi-mode FP-LD without self-seeding when the bias current and temperature are 25 mA and 25 ^{o}C respectively. The threshold current of the FP-LD is 10 mA without self-seeding. When the proposed self-seeding FP-LD is used, the single-longitudinal-mode wavelength output are observed in the proposed fiber laser scheme, as shown in Fig. 2(b), while the TBF is set at 1547.2 nm. Therefore, Fig. 3 presents the output power spectra of the proposed laser in the tuning range of 1533.75 to 1560.95 nm with tuning step of ~1.38 nm, and the SMSR is distributed from 40

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to 55.2 dB. Figure 4 shows the output power and SMSR versus the different lasing wavelengths with ~1.38 nm tuning step. The maximum and minimum output power is –6.9 and −15.3 dBm (ΔP_{max} = 8.4 dB) at the wavelength of 1547.20 and 1533.75 nm, respectively, as illustrated in Fig. 4. When the lasing wavelength is operated at 1555.40 nm, the SMSR can be up to 55.2 dB. In the operating range of 1540.45 to 1552.65 nm, the output power and SMSR are larger than −9.8 dBm and 40 dB, respectively. Between 1545.85 to 1560.95 nm, the SMSR can be larger than 50.6 dB ($\Delta SMSR_{max}$ = 4.6 dB), as also shown in Fig. 4. The output power of the laser is determined by the gain profile of the FP-LD, hence it is lower at both ends of the spectrum. To investigate the output performances of power and wavelength stabilities, a short-term stability of the proposed structure is measured, as shown in Fig. 5. The lasing wavelength is 1552.65 nm initially and the observing time is over 30 minutes. In Fig. 5, the wavelength variation and the power fluctuation for the proposed fiber laser are 0.02 nm (readout resolution = 0.01 nm) and 0.77 dB, respectively. After two hours of observing, the stabilized output of the proposed fiber laser is still maintained. Besides, the cavity length of proposed fiber laser would influence the output stability due to the environmental temperature. To obtain and maintain the great output stability of the fiber laser, it is better than that the cavity length is shorter.

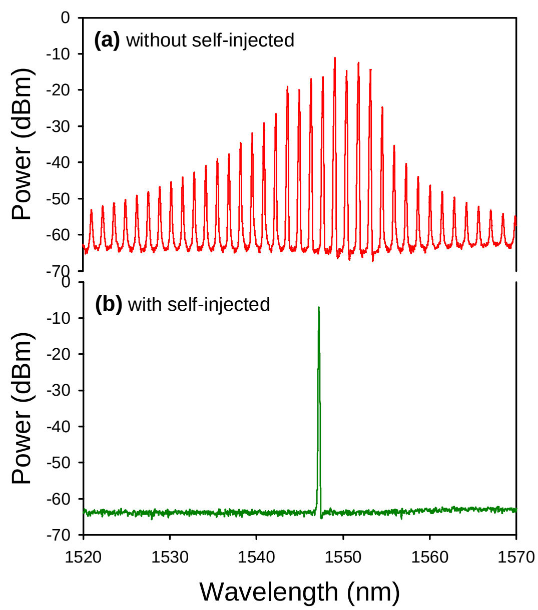

Fig. 2. (a). Original output spectrum of multi-mode FP-LD without self-seeding when the bias current and temperature are 25 mA and 25 °C, respectively. (b) When the proposed self-seeding FP-LD is used, the single-longitudinal-mode wavelength output is observed while the TBF is set at 1547.2 nm.

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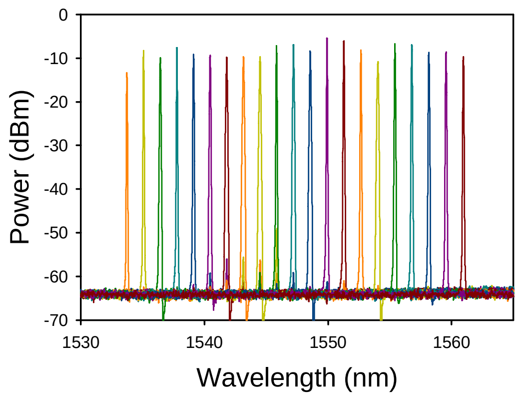

Fig. 3. Output wavelength spectra of the proposed laser in the tuning range of 1533.75 to 1560.95 nm with tuning step of ~1.38 nm.

In addition, Fig. 6 show the (a) output power, (b) SMSR and (c) lasing wavelength versus different bias current of FP-LD (12 to 30 mA) in the proposed wavelength-tunable laser. The lasing wavelength is initially 1547.2 nm at 30 mA. When the bias current is below 12 mA, the self-seeding laser cannot lase. According to the experimental results of Figs. 6, with the increase of operating current gradually, the output power, SMSR and lasing central wavelength will also increase too. In the operating current of 12 to 30 mA, the output power, SMSR and central wavelength are between –21.4 to –6 dBm, 35.4 to 51.4 dB and 1546.84 to 1547.2nm, respectively. Different temperature could cause the central wavelength of the FP-LD to shift slightly. Thus, the lasing wavelength, by controlling the temperature of the LD, could be continuously tunable, and this can cover the wavelength ranges between the longitudinal mode of FP-LD. As a result, the proposed tunable fiber laser has the advantage of simple scheme, low cost, better output efficiency and wide wavelength tuning range.

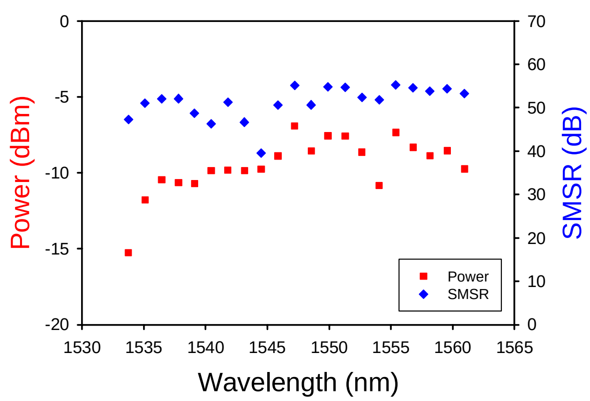

Fig. 4. Output power and SMSR versus the different lasing wavelength with ~1.38 nm tuning step.

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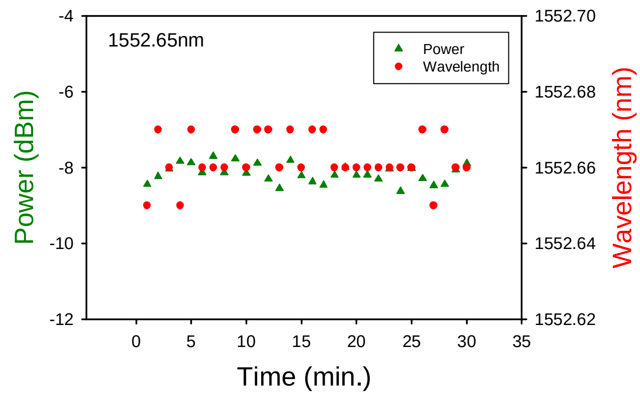

Fig. 5. Lasing wavelength is 1552.65 nm initially and the observing time is over 30 minutes for stability measurement.

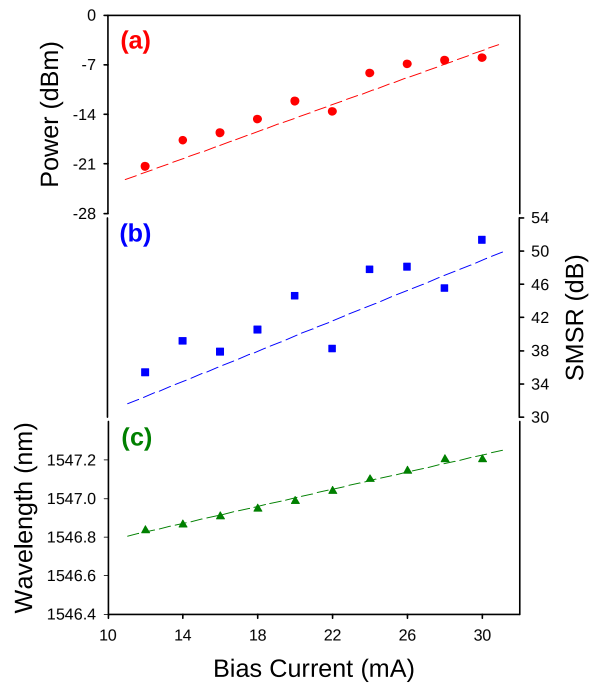

Fig. 6. (a). Output power, (b) SMSR and (c) lasing wavelength versus different bias current of FP-LD (12 to 30 mA) in the proposed wavelength-tunable laser.

3. Conclusion

In summary, we have proposed and investigated a CW tunable-wavelength fiber laser using self-seeding FP-LD. By employing a TBF and a FRM within a gain cavity, the fiber laser can lase a single wavelength because of the self-seeding operation. The proposed tunable wavelength laser has a good performance of the output power (> –15 dBm) and optical SMSR (> 40 dB) in the wavelength tuning range of 1533.75 to 1560.95 nm. In addition, the output stabilities of the fiber laser are also investigated. Therefore, the laser is expected to benefit the applications of fiber sensor and WDM communications.

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