

Multiwavelength narrow linewidth erbium-doped fiber laser based on FP-LDs

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Abstract: In this paper, we propose and demonstrate a technique to realize multiwavelength operation in erbium-doped fiber lasers (EDFLs) by inserting two Fabry P rot laser diodes (FP-LDs) in the laser cavity respectively in cascaded and parallel way. The FP-LDs not only act as wavelength selection elements, but also offer optical gain or loss for the operation wavelengths in the laser cavity. The gains or losses for the oscillation wavelengths obtained from FP-LDs differ with adjustment of the driving current of the FP-LDs. Thus, the utilization of the FP-LDs in the laser cavity can introduce wavelength dependent gain or loss which can effectively suppress the competition caused by the homogeneous gain broadening of the erbium-doped fiber (EDF). As a result, 16-wavelength and 20-wavelength operation with a wavelength-spacing of 1.25 nm has been achieved respectively in the cascaded and parallel FP-LDs based EDFL schemes. The measured power fluctuation of each wavelength is smaller than 0.4dB for both EDFLs. Furthermore, the injection locking of the FP-LDs ensures a narrow linewidth of the EDFL output and the linewidth is estimated to be narrower than 100 MHz for the cascaded scheme based EDFL.

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1. Introduction

Multiwavelength erbium-doped fiber laser (EDFL) has attracted much interest due to its potential applications in fiber sensing, component testing, optical signal processing, and wavelength-division-multiplexed (WDM) optical communication systems. However, it is difficult to achieve multiwavelength operation in erbium-doped fiber lasers at room temperature, due to the mode competition induced by the homogeneous gain broadening of the erbium-doped fiber (EDF). In order to reduce the gain saturation and suppress the mode competition, different approaches have been proposed to realize multiwavelength oscillation at room temperature in EDFLs. These include the introduction of polarization hole burning (PHB) effect [1–3], frequency shifters [4,5], wavelength or intensity dependent loss [6,7], and various nonlinear effects such as four-wave mixing [8,9] or stimulated Brillouin scattering [10,11] in the laser cavities. Other methods by incorporating in the laser cavity a length of multimode fiber or a multimode fiber Bragg grating [12,13], employing specially designed erbium-doped fibers [14] or cavity structures [15] were also reported.

C. H. YeH et al. ever reported a multiwavelength EDFL using a Sagnac loop and Fabry-Perot laser diode (FP-LD) [16]. They mainly use the polarization dependent characteristic of the Sagnac loop to obtain multiwavelength operation. Since the outputs have different polarization states, the output wavelength numbers are limited and the flatness among wavelengths was not so good.

In this paper, we propose and demonstrate a technique to realize multiwavelength operation in EDFL by cascading or paralleling two FP-LDs in the laser cavity. Here, the FP-LDs not only act as multichannel filters, but also can effectively suppress the mode competition induced by the homogeneous gain broadening of the EDF. Consequently, multiwavelength oscillation in EDFL can be achieved by proper adjustment of the drive current of the FP-LDs. Furthermore, the injection locking of the FP-LDs ensures a narrow linewidth of the EDFL output. As a result, 16-wavelength and 20-wavelength lasing operation with wavelength spacing of 1.25 nm has been respectively achieved in cascaded and parallel FP-LDs based EDFLs. The measured power fluctuation of each wavelength is smaller than 0.4 dB and the linewidth is estimated to be narrower than 100 MHz for the cascaded scheme based EDFL.

2. Experimental setup and operation principle

Figure 1(a) and 1(b) respectively show the schematic configurations of the proposed multiwavelength EDFL based on cascaded and parallel FP-LDs schemes. Both lasers are composed of a commercial erbium-doped fiber amplifier (EDFA), two circulators (CIRs), two FP-LDs, two polarization controllers (PCs) and an output coupler with a splitting ratio of 7:3. In the cascaded scheme as shown in Fig. 1(a), the output of FP-LD1 is directly input into FP-LD2. However, for the parallel scheme as shown in Fig. 1(b), the FP-LD1 and FP-LD2 are respectively located at the two arms of a Mach-Zehnder interferometer (MZI) formed by two 50/50 couplers. The PCs are inserted to vary the polarization state of the light inputting into the FP-LDs for best operation performance. The longitudinal mode spacing of the FP-LD is

1.25 nm and the threshold and maximum driving current are respectively 10 mA and 100 mA. The EDFA can provide a saturate power of 500 mW. The laser output was taken via the 30% output port of the output coupler and was measured using an optical spectrum analyzer (OSA) with 0.02 nm resolution.

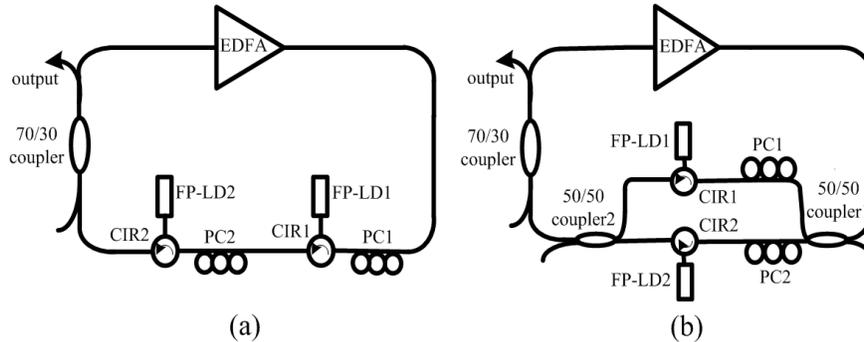


Fig. 1. Schematics of the proposed multiwavelength EDFLs based on (a) cascaded FP-LDs scheme and (b) parallel FP-LDs scheme.

The operation principle of multiwavelength operation of the proposed lasers can be explained as following. The oscillating wavelengths in the laser cavity are defined by the longitudinal modes of the two FP-LDs. These wavelengths would experience different optical gain or loss depending on the power and polarization state of the injection light, and the drive current of the FP-LDs [17]. Thus, the utilization of the FP-LDs in the laser cavity can introduce wavelength dependent gain or loss which can effectively suppress the competition caused by the homogeneous gain broadening of the EDF. Therefore, multiwavelength operation can be possibly achieved in the EDFLs by adjusting the driving current of the FP-LD and the polarization state of the light inputting the FP-LDs. Furthermore, the injection locking of the FP-LDs ensures a narrow linewidth of the EDFL output, and multiwavelength oscillation with narrow linewidth is expected to be obtained in the proposed EDFLs.

3. Results and discussions

Using the mechanism described above, and to confirm the existence of multiwavelength operation in the laser, we conducted experiment with the ring laser cavity configurations shown in Fig. 1. First, we investigate the cascaded FP-LDs scheme based EDFL. A 16-wavelength within 3-dB bandwidth has been achieved as shown in Fig. 2(a), when the driving currents of the two FP-LDs are respectively 10 mA and 90 mA. As can be seen from the Fig. that power distribution over the 16 wavelengths is comparatively uniform and the extinction ratios of the wavelengths are greater than 40 dB. The spectra have a wavelength spacing of about 1.25 nm, which is determined by the longitudinal mode spacing of the FP-LDs. The corresponding output spectra of the two FP-LDs under free-running condition are shown in Fig. 2(b) (the upside) and the spectrum by cascading FP-LD1 and FP-LD2 is shown in Fig. 2(b) (the underside). Compared Fig. 2(a) with 2(b), we can see that the flatness among the lasing wavelengths has been greatly improved by using the proposed technique.

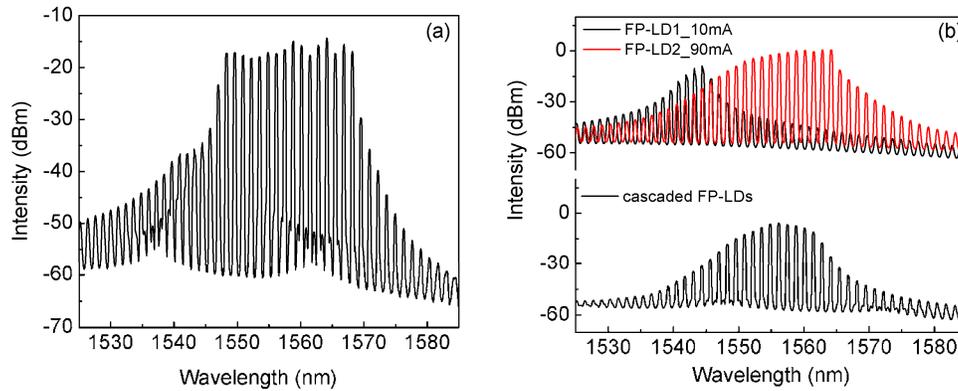


Fig. 2. Output spectrum of (a) EDFL based on cascading two FP-LDs, (b) the two FP-LDs under free-running condition (the upside) and the cascaded FP-LDs (the underside).

To further investigate the performance of the EDFL, one wavelength is filtered out by a bandpass filter to be studied about the linewidth and the output power stability of the laser. The RF spectrum of the single channel is shown in Fig. 3(a), which was measured by a 13 GHz electronic spectrum analyzer (ESA) with a resolution of 1 kHz. As can be seen from Fig. 3(a), there are longitudinal mode beating signals only within about 350 MHz, indicating a 3-dB linewidth of much narrower than 100 MHz of the single wavelength. The power variation as a function of time is shown in Fig. 3(b). The fluctuation of the signal power of the wavelength is less than 0.4 dB over a period of 20 minutes, which was measured using a power meter without averaging.

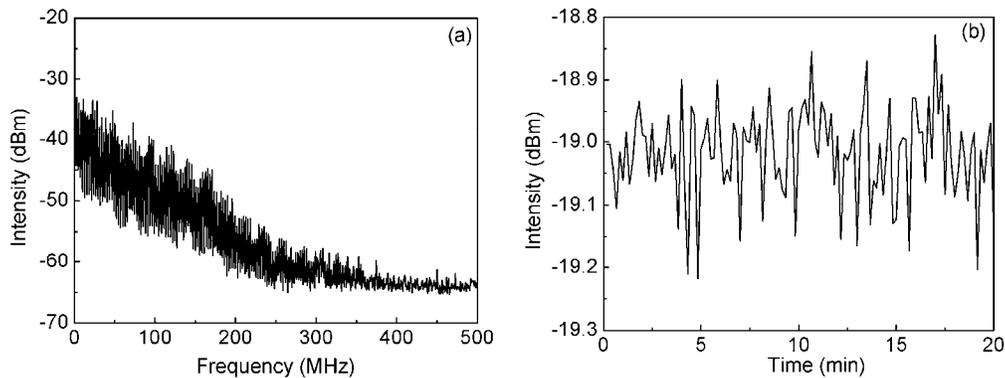


Fig. 3. (a) RF spectrum of single wavelength, (b) Output power fluctuation versus time for the cascaded FP-LDs based EDFL.

Afterwards, we studied the parallel FP-LDs scheme based multiwavelength EDFL. 20-wavelength oscillation within 3 dB bandwidth has been obtained as shown in Fig. 4(a), when the driving current of FP-LD1 and FP-LD2 are respectively 35 mA and 75 mA. The power distribution over the 18 wavelengths is uniform and the extinction ratios of the wavelengths are also greater than 40 dB. The spectra have a same wavelength spacing of about 1.25 nm, which is defined by the longitudinal mode spacing of the FP-LDs. The corresponding output spectra of the two FP-LDs under free-running and the spectrum by paralleling the two FP-LDs are shown in Fig. 4(b). Compared Fig. 4(a) with 4(b), we can see that the flatness among the lasing wavelengths has also been greatly improved by using the proposed technique.

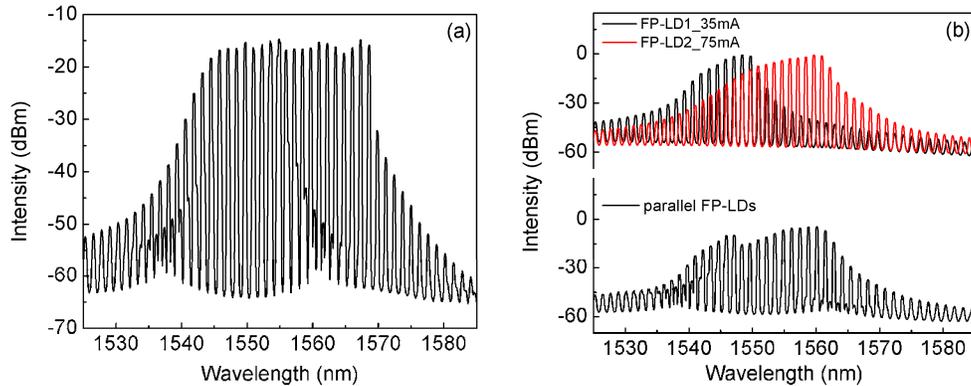


Fig. 4. Output spectrum of (a) EDFL based on paralleling two FP-LDs, (b) two FP-LDs under free-running condition (the upside) and the parallel scheme of the two FP-LDs (the underside).

The linewidth and power stability of the EDFL output were also investigated. Figure 5(a) shows the RF spectrum of the filtered single wavelength, which was measured by an ESA with a resolution of 300 kHz. From the Fig. 5(a), we can see that the longitudinal modes beating signals exist only within about 1GHz, indicating a 3-dB linewidth of much narrower than 500 MHz. The power fluctuation as a function of time is shown in Fig. 5(b). The variation of the signal power of the wavelength is also less than 0.4 dB over a period of 20 minutes.

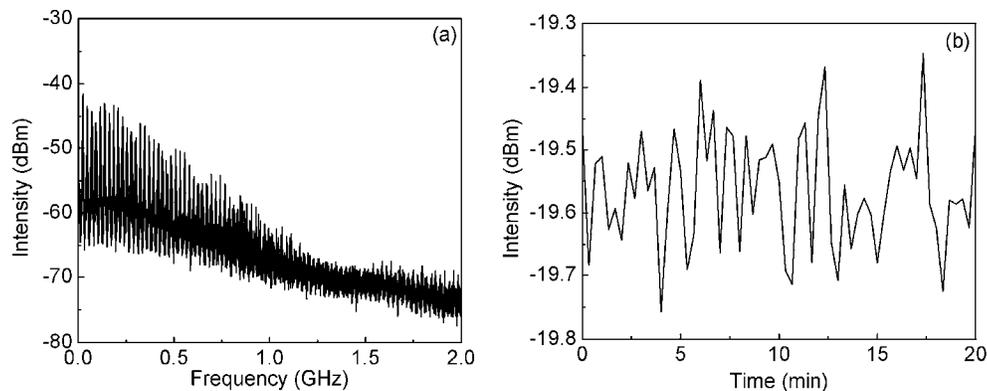


Fig. 5. (a) RF spectrum, (b) power fluctuation of a single wavelength of the proposed parallel FP-LDs scheme based EDFL.

From the experimental results of the cascaded and parallel FP-LDs scheme based multiwavelength EDFLs, we can see that more wavelengths operation can be achieved in the EDFL based on the parallel FP-LDs scheme. However, the linewidth is somewhat narrower for the cascaded FP-LDs based scheme than that of the parallel FP-LDs scheme based EDFL. This can be simply explained as the following: The oscillation wavelengths pass through the FP-LD twice at each roundtrip in the cascaded FP-LDs based cavity, and the narrowing effect would be more effective than the parallel FP-LDs scheme. However, somewhat less wavelengths would satisfy the oscillation state for this cascading effect. On the other hand, the parallel FP-LDs scheme in the MZI configuration would broaden the longitudinal mode spacing of the laser oscillation [18], which can be clearly seen from Fig. 3(a) and Fig. 5(a).

Another point we have to note is that the proposed multiwavelength EDFLs can be easily reconfigured by cascading or paralleling more FP-LDs with different wavelengths. Consequently, broadband multiwavelength oscillation with large amount wavelength number and narrower linewidth can be possibly achieved.

4. Conclusion

In conclusion, we have proposed and experimentally demonstrated a novel way to realize multiwavelength operation in EDFL by cascading or paralleling two FP-LDs. The FP-LDs not only act as wavelength selection devices, but also can effectively alleviate the mode competition induced by the homogeneous gain broadening in the EDF. Furthermore, the injection locking of the FP-LDs can narrow the bandwidth of the output. As a result, 16-wavelength and 20-wavelength narrow bandwidth oscillation with a wavelength-spacing of about 1.25 nm have been respectively obtained in the cascaded and parallel FP-LDs based multiwavelength EDFLs. The power fluctuation of each wavelength for both of the proposed EDFL is less than 0.4 dB.

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