Switchable multiwavelength erbium-doped fiber laser employing wavelength-dependent loss

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A R T I C L E   I N F O

Article history:
Received 6 September 2010
Revised 1 December 2010
Available online 12 February 2011

Keywords:
Erbium-doped fiber lasers (EDFLs)
Multiwavelength fiber lasers
Wavelength-dependent loss (WDL)

A B S T R A C T

A novel switchable multiwavelength erbium-doped fiber laser (EDFL) is proposed and demonstrated based on two comb filters. One comb filter is used to define the wavelength spacing, the other filter with a very narrow wavelength spacing is used to induce wavelength-dependent loss (WDL) effect to suppress the mode competition caused by homogeneous gain broadening of the erbium-doped fiber (EDF). As a result, triple-wavelength lasing operation with wavelength spacing of 0.8 nm has been achieved. Wavelength switching operation of the laser was also obtained by adjustment of a polarization controller (PC) in the cavity. The measured power fluctuation of each wavelength is less than 0.4 dB.

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1. Introduction

Multiwavelength erbium-doped fiber lasers (EDFLs) attract much interest due to their potential applications in fiber sensing, component testing, optical signal processing, and WDM optical communication systems. Since erbium-doped fiber (EDF) is a gain medium with homogeneous broadening, the gain saturation effect causes mode competition between different wavelengths making stable multiwavelength oscillations in EDFLs at room temperature difficult. A number of different techniques have been proposed to reduce gain saturation and suppress mode competition. These include the introduction of polarization hole burning (PHB) effect by using polarization-dependent elements in the laser cavities [1–5], and nonlinear optical approaches by inducing various nonlinear effects such as four-wave mixing [6–8], stimulated Brillouin scattering [9], nonlinear polarization rotation [10], and nonlinear loop mirror [11,12] in the laser cavity. Room temperature multiwavelength operation in an EDFL has been also reported in [13–15] by inserting a frequency shifter or phase modulator in the laser cavity to prevent steady-state oscillations. Other methods by incorporating in the laser cavity a length of multimode fiber [16] or a multimode fiber Bragg grating [17], employing specially designed erbium-doped fibers [18] or cavity structures [2,19] were also reported.

For an EDFL in which the laser cavity loss was the same for different wavelengths, it is difficult to balance cavity gains simultaneously for more than one wavelength, since homogeneous broadening mechanism is predominant. To satisfy the balance of gain and loss for more than one wavelength to obtain multiwavelength operations in EDFLs, one possible solution is to introduce wavelength-dependent loss (WDL) in the laser cavity. In [20], three-decibel couplers are used to incorporate four FBGs into the laser cavity, creating a tree topology. Each of those branches is composed of one FBG and a variable attenuator (VA), used to finely adjust the losses of the corresponding wavelength in order to achieve oscillation in all the four channels. Obviously, it is complicated to induce WDL by using many VAs, and the cost is also high.

In this paper, we propose a simple technique that exploits a narrow-wavelength spacing comb filter to induce WDL effect to suppress the mode competition caused by homogeneous gain broadening of the EDF. As a result, triple-wavelength lasing oscillations with wavelength spacing of 0.8 nm have been achieved. The laser can also be operated in wavelength switching mode by adjustment of a polarization controller (PC) in the cavity. The measured power fluctuation of each wavelength is less than 0.4 dB. The laser has the advantages of simple configuration and uniform output over wavelengths.

2. Experimental setup and operation principle

Fig. 1 shows the configuration of the proposed laser. It is composed of a commercial erbium-doped fiber amplifier (EDFA), a Fabry–Pérot (F–P) thin-film filter, an M–Z interferometer, a PC, and an output coupler. The EDFA provides the optical gain and
has a saturation output power of 500 mW. The F–P filter, which has a free spectral range of 0.8 nm, an extinction ratio of about 13 dB, and an insertion loss of less than 2 dB, is used to define the wavelength spacing of the EDFL output. The M–Z interferometer, which has a free spectral range of about 0.014 nm and a maximum extinction ratio of about 8 dB, was sealed in a box for stable operation. The M–Z interferometer is used as the second comb filter to induce wavelength-dependent loss. The PC was inserted before the M–Z comb filter for best output performance. The laser output was taken via the 10% output port of the output coupler and was measured using an optical spectrum analyzer (OSA) with 0.01 nm resolution.

Fig. 2 shows the transmission spectrum of the combined structure of the F–P comb filter and the M–Z interferometer. As can be seen from Fig. 2, there are more than five periods of the M–Z interferometer in the 3-dB bandwidth of one passband of the F–P comb filter. Then in this case, one transmission peak of the F–P filter may coincide with the transmission valley of the M–Z interferometer, while the next transmission peak of the F–P filter may coincide with the transmission peak of the M–Z interferometer. So, the losses for the different wavelengths defined by the F–P comb filter can be different. That is, the 0.014 nm comb filter could induce WDL for the wavelengths defined by the 0.8 nm comb filter. Obviously, such a WDL is inhomogeneous. Each laser line has its own cavity loss, so this mechanism can alleviate the mode competition. As a result, the balance between the inhomogeneous WDL and the homogeneous gain of the EDF can lead to multiwavelength oscillations at room temperature. So, the F–P comb filter was used to define the wavelength spacing, while the M–Z interferometer with very narrow wavelength spacing is used to induce WDL effect to suppress the mode competition caused by homogeneous gain broadening of the EDF.

On the other hand, the extinction ratio of the M–Z interferometer can be changed by adjustment of the PC, and accordingly, the magnitude of the WDL effect can be adjusted. When the loss difference is not sufficient to satisfy the balance of gain and loss for more than one wavelength by adjustment of the PC, only switchable single-wavelength operation could be obtained.

3. Experimental results and discussions

Using the mechanism described above and to confirm the existence of multiwavelength operation of the laser, we conducted experiment using the laser configuration shown in Fig. 1. The laser system can be easily set to the multiwavelength operation by monitoring its output spectra when we adjusted the PC. Fig. 3 shows the output spectrum of the laser emitting three wavelengths spaced at 0.8 nm. Power distribution over wavelengths is very uniform and the amplitude difference among the three wavelengths is less than 1 dB.

Through carefully adjusting the state of the PC, switchable single-wavelength and dual-wavelength operations have also been obtained. Fig. 4 shows the typical output spectra of the laser under switchable dual-wavelength operation.

To study the long term stability of the laser multiwavelength output, the output power fluctuation of a single laser line was measured by filtering out one channel with a bandpass filter from the multiwavelength output. The signal power fluctuation was...
measured to be less than 0.4 dB in a period of thirty minutes, as shown in Fig. 5.

As can be analyzed from the operation principle, the wavelength spacing of the output would have minor difference. Output performance, such as higher uniformity of wavelength separation and larger wavelength number, could possibly be achieved by using a comb filter with much narrower wavelength spacing or using other element to induce WDL.

In fact, multiwavelength operation with more wavelengths can be achieved if the differences in emission and absorption cross-sections of the different wavelengths can be equalized by wavelength-dependent cavity loss. That is, if the WDL profile is optimized and properly related to the shapes of emission and absorption cross-sections of the erbium ions, then wideband multiwavelength operation of the EDFL could be expected.

4. Conclusion

In conclusion, we have proposed and successfully demonstrated a novel and simple technique, based on two comb filters, to generate stable multiwavelength oscillations in an erbium-doped fiber ring laser. The wavelength-dependent loss induced by the comb filter with very narrow wavelength spacing can effectively suppress the mode competition caused by homogeneous gain broadening of the EDF. As a result, triple-wavelength lasing operation with wavelength spacing of 0.8 nm has been achieved. The power fluctuation in each wavelength is smaller than 0.4 dB when measured over 30 min. It is expected that wideband multiwavelength operation in erbium-doped fiber ring lasers could be obtained by using proper element to induce WDL.

Acknowledgments

This work was supported in part by the Program for New Century Excellent Talents in University (NCET-08-0078) in China, NSFC (No. 61077030), the Key Project of Chinese Ministry of Education (No. 210256), and the Fundamental Research Funds for the Central Universities (Nos. 21610411, 21609102) in china.

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