Stable room-temperature multi-wavelength lasing realization in ordinary erbium-doped fiber loop lasers

Yan-ge Liu[1], Xinyong Dong[2], Ping Shum[2], Shuzhong Yuan[1], Guiyun Kai[1], Xiaoyi Dong[1]

[1]*Institute of Modern Optics, Nankai University, Tianjin 300071, China*

ygliu@nankai.edu.cn; liu_yan_ge@hotmail.com

[2] *Network Technology Research Center, School of Electrical and Electronics Engineering, Nanyang Technological University, Singapore 637553*

Abstract: A suppressant effect for mode competition of multi-wavelength lasing oscillations induced by deeply saturated effect in an ordinary erbium-doped fiber ring laser (EDFRL) was observed and experimentally investigated. Results show that the effect is helpful to obtain stable multi-wavelength lasing at room temperature in the EDFRL, which offers a new and simple approach to achieve stable multi-wavelength EDF lasing. Stable two- and three- wavelength lasing oscillations were achieved based on the effect in the ordinary EDFRL for the first time to our best knowledge. The multi-wavelength lasing oscillations were so stable integrated over smaller than 1 ms that the maximum power fluctuation over more than 30 minutes of observation was less than 0.1 dB and 0.5 dB for two-wavelength lasing with a spacing of 1.28 nm and 0.76 nm, respectively.

OCIS codes: (140.3500) Lasers, erbium; (060.2320) Fiber optics amplifiers and oscillators

References and links

1. N. Park and P. F. Wysocki, "24-Line Multiwavelength operation of erbium-doped fiber-ring laser," IEEE Photon. Technol. Lett. **8**, 1459-1461 (1996).
2. A. Bellemare, M. Karasek, M. Rochette, S. LaRochelle, and M. Tetu, "Room temperature multifrequency erbium-doped fiber lasers anchored on the ITU frequency grid," J. Lightwave Technol. **18**, 825-831 (2000).
3. Y. Liu, X. Feng, S. Yuan, G. Kai and X. Dong, "Simultaneous four-wavelength lasing oscillations in an erbium-doped fiber laser with two high birefringence fiber Bragg gratings," Opt. Express **12**, 2056-2061 (2004).
4. X. Feng Y. Liu, S. Yuan, G. Kai, W. Zhang and X. Dong, "L-band switchable dual-wavelength erbium-doped fiber laser based on a multimode fiber Bragg grating," Opt. Express **12**, 3834-3839 (2004).
5. D. S. Moon, U. Paek and Y. Chung, "Polarization controlled multi-wavelength erbium-doped fiber laser using fiber Bragg grating written in few-mode side-hole fiber with an elliptical core," Opt. Express **13**, 5574-5579 (2005).
6. X. Liu and C. Lu, "Self-stabilizing effect of four-wave mixing and its applications on multiwavelength erbium-doped fiber lasers," IEEE Photon. Technol. Lett. **17**, 2541-2543 (2005).
7. Y. -G. Han, T. V. A. Tran, and S. B. Lee, "Wavelength-spacing tunable multiwavelength erbium-doped fiber laser based on four-wave mixing of dispersion-shift fiber," Opt. Lett. **31**, 697-699 (2006).
8. S. Pan, C. Lou and Y. Gao, "Multiwavelength erbium-doped fiber laser based on inhomogeneous loss mechanism by use of a highly nonlinear fiber and a Fabry-Perot filter," Opt. Express **14**, 1113-1118 (2006).
9. E. Desurvire, J. L. Zyskind and J. R. Simpson, "Spectral gain hole-burning at 1.53 μm in erbium-doped fiber amplifiers," IEEE Photon. Technol. Lett. **2**, 246-248 (1990).
10. J. L. Zyskind, E. Desurvire, J. W. Sulhoff and D. J. Digiovanni, "Determination of homogeneous linewidth by spectral gain hole-burning in an erbium-doped fiber amplifier with GeO_2:SiO_2 core," IEEE Photon. Technol. Lett. **2**, 869-871 (1990).
11. J. W. Sulhoff, A. K. Srivastava, C. Wolf, Y. Sun, and J. L. Zyskind, "Spectral-hole burning in erbium-doped silica and fluoride fibers," IEEE Photon. Technol. Lett. **9**, 1578-1579 (1997).

#72662 - $15.00 USD Received 5 July 2006; revised 17 August 2006; accepted 18 August 2006

12. M. Tachibana, R. L. Laming, P. K. Morkel and D. N. Payne, "Gain cross saturation and spectral hole burning in wideband erbium-doped fiber amplifiers," Opt. Lett. **16**, 1499-1501 (1991).

1. Introduction

Multiwavelength erbium-doped fiber lasers (EDFLs) have attracted considerable interest in recent years due to their potential application in wavelength division multiplexed (WDM) fiber-communication systems, fiber sensors, optical instrument testing and microwave photonic system [1-8]. It is well known that at room temperature, the homogeneous line width is ~11 nm for an aluminum-silicate glass EDF and 3~4 nm for a germanium-silicate glass EDF [9-11]. Therefore, it is generally thought that it is difficult to obtain stable dual- or multiwavelength lasing at room temperature in an ordinary erbium-doped fiber linear or ring laser cavity. In order to achieve stable multiwavelength lasing at room temperature, the main challenges for the EDFLs are to suppress the unstable mode competition induced by the homogenous line broadening and cross-gain saturation of erbium-doped fiber (EDF). To overcome this drawback, various approaches including cooling the EDF to 77 K by liquid nitrogen [1], using a frequency-shifted feedback technique within a laser cavity [2], and introducing polarization hole burning (PHB) effect by utilizing polarization-dependence components such as fiber Bragg gratings with several reflectivity peaks into the laser cavity [3-5], have been proposed. More recently, stable multiwavelength EDFLs were reported by incorporating a highly nonlinear fiber such as a length of highly nonlinear photonic crystal fiber or dispersion-shifted fiber in the laser cavity [6-8]. Since the mode competition can be effectively suppressed by four-wave mixing effect or an inhomogeneous loss mechanism of the high nonlinear fiber, stable multiwavelength operation could be achieved.

In this letter, a suppressant effect for homogenous line broadening and cross-gain saturation induced by deep signal saturation in an ordinary erbium-doped fiber ring laser (EDFRL) was observed and experimentally studied. Results show that the effect was helpful to obtain stable multiwavelength lasing at room temperature in the EDFRL, which offers a new and simple approach to achieve stable multiwavelength EDF lasing. Stable two- and three- wavelength lasing oscillations were achieved based on that effect in the ordinary EDFRL for the first time to our best knowledge. The maximum power fluctuation over a long-time observation of more than 30 minutes is less than 0.1 dB and 0.5 dB for two-wavelength lasing with a spacing of 1.28 nm and 0.76 nm, respectively.

2. Experimental setup

A schematic diagram of the experimental setup is shown in Fig. 1. The laser's ring cavity consists of a 980/1550 wavelength division multiplexing (WDM) coupler, a section of EDF, a 10:90 fiber coupler, a sampled fiber Bragg grating (SFBG) connected with a circulator, a variable optical attenuator (VOA) and a polarization independence isolator (ISO). The EDF was pumped by a laser diode, with a maximum output power of 98 mW at 980 nm wavelength, through the WDM coupler. The EDF, whose absorption coefficient at 1530 nm is 27.2 dBm, is high erbium-doped concentration fiber fabricated by Highwave Optical Technologies Corporation. The length of EDF used in our experiment is about 3 m. The SFBG, which has 7 reflection peaks within 3-dB bandwidth, was used for a multiwavelength selective component in conjunction with the optical circulator that also served as an optical isolator. Figure 2 shows the transmission spectrum of the SFBG. The wavelength spacing between adjacent reflection bands and the central wavelength of the SFBG are 1.28 nm and 1548.52 nm, respectively. The VOA was used to obtain the balance of the gain and loss among the peak wavelength of the SFBG and initiated the multiple lasing operations in the cavity. The 10% port of the fiber coupler acted as the output port of the laser. An ANDO AQ6317B optical spectrum analyzer (OSA) with resolution of 0.05 nm was used to do all the measurement.

#72662 - $15.00 USD Received 5 July 2006; revised 17 August 2006; accepted 18 August 2006

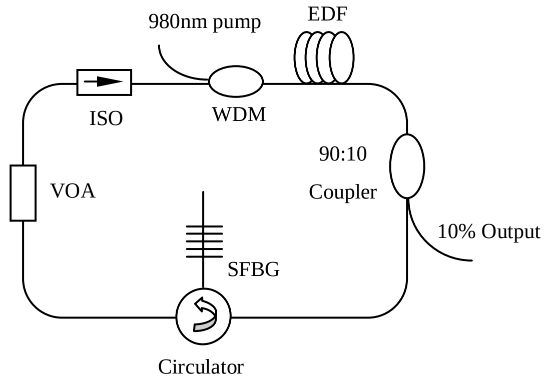

Fig. 1. Schematic diagram of the experimental setup

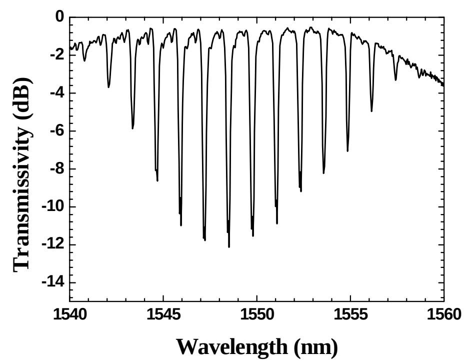

Fig. 2. Transmission spectrum of the SFBG.

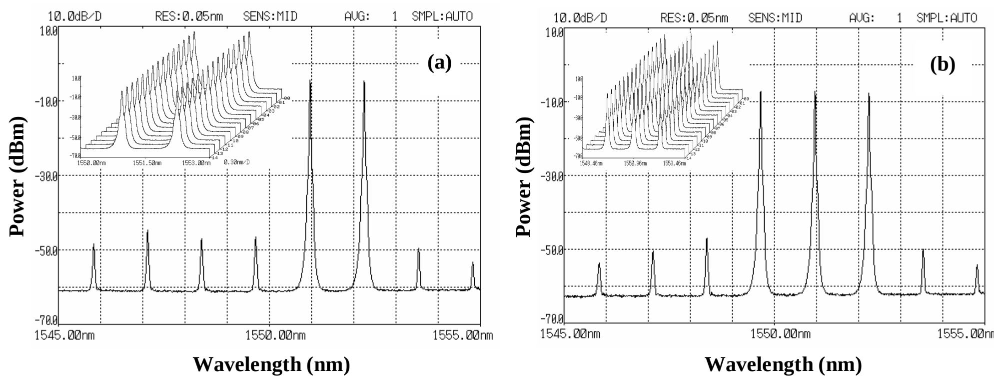

Fig. 3. Output spectra of the multiwavelength EDFRL with (a) dual-wavelength lasing and (b) three-wavelength lasing achieved by adjusting the VOA.

3. Experimental results and discussion

The length of the EDF was optimized for having the flattest multiwavelength spectrum at a selected saturation level. By adjusting the VOA, the gain and loss among the peak wavelengths of the SFBG could be carefully balanced and a different number of multiwavelength lasing lines could be obtained. The output spectra with two-wavelength and three-wavelength lasing are shown in Fig. 3(a) and Fig. 3(b), respectively. The upper data of the spectra show the main settings of the OSA in doing all the measurement in this paper. The sweep time of the OSA for completing one sample point measurement under the condition of these settings is about 1 ms. The peak lasing wavelengths are 1550.96 nm and 1552.24 nm for the dual-wavelength laser output and 1549.67nm, 1550.96 nm and 1552.24 nm for the three-wavelength laser output, respectively. The peak powers measured by the OSA are –4.69 dBm at 1550.96 nm and –4.74 dBm at 1552.24 nm for the dual-wavelength lasing oscillation, –7.18 dBm at 1549.67 nm, -7.01 dBm at 1550.96 nm and –7.65 dBm at 1552.24 nm for the three-wavelength lasing oscillation, respectively. The insets of the Fig. 3 are the 16 times repeated scanning spectra of the two- and three-wavelength lasing oscillations with a time interval of 5 seconds, which indicates the short-time stability of the laser is very well. In order to evaluate the long-time stability of the multiwavelength operation at room temperature, we also measured the fluctuation in output power at each peak wavelength for more than half an hour. The experimental results are shown in Fig. 4. For the dual-wavelength lasing oscillation, the

#72662 - $15.00 USD Received 5 July 2006; revised 17 August 2006; accepted 18 August 2006

maximum power fluctuations, integrated over smaller than 1 ms estimated by the sweep time of the OSA, at the peak wavelengths of 1550.96 nm and 1552.24 nm are 0.091 dB and 0.098 dB, respectively, that is, the output powers are so stable that the peak fluctuations are less than 0.1 dB. Compared with the dual-wavelength lasing output, the power fluctuations for the three-wavelength lasing oscillation are slightly bigger. The maximum power fluctuations at the wavelengths of 1549.67nm, 1550.96 nm and 1552.24 nm are 0.676 dB, 0.726 dB and 0.489 dB, respectively.

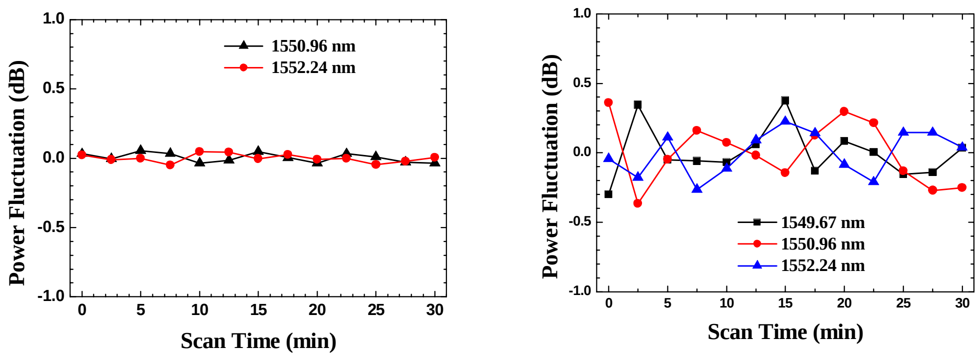

Fig. 4. Power fluctuation of the multiwavelength EDFRL during scanning: (a) for dual-wavelength lasing, the power fluctuations are less than ~0.1 dB; (b) for three-wavelength lasing, the power fluctuations are less than ~0.8 dB.

It is somewhat surprising that we can obtain so stable dual- and three-wavelength lasing in the ordinary EDFRL at room temperature, since it is known that the homogeneous line width for EDF at room temperature is more than several nanometers at 1550 nm (at least 2 nm). In order to have an insight into the mechanism of stable multiwavelength operation, we did some experiments as follows.

Firstly, we replaced the EDF with another type of EDF, whose absorption coefficient at 1530 nm is about 23.5 dBm and fiber length was chosen for insuring almost the same saturation level as the above EDF estimated by the approximately same ASE spectrum shape. We also replaced the pumped EDF part (ISO-WDM-EDF) with a commercial low noise EDFA produced by Photonik Company, who offers 16 dBm output saturation power and also has a similar ASE shape with pumped EDFs it replaced. In those two cases, we obtained stable dual- and three-wavelength lasing oscillations with almost the same output power stability as shown in Fig. 4.

Secondly, we found experimentally that the ISO before the WDM coupler in Fig. 1 played an important role in achieving stable multiwavelength operation of the laser. Figure 5 shows the power fluctuations of the dual-wavelength EDFL during scanning without the ISO in the ring laser cavity. The maximum fluctuations observed are 1.25 dB at 1550.96 nm and 1.52 dB at 1552.24 nm, respectively, which indicates that the stability of the laser becomes worse compared with the case of incorporating the ISO.

The third experiment replaced the SFBG in Fig. 1 with two common fiber Bragg gratings (FBGs) written in photosensitive fiber using a phase mask method. The reflectivities of the two FBGs are both more than 99%, and the center wavelengths are 1550.38 nm and 1551.14 nm, respectively, and thus have a wavelength spacing of 0.76 nm. Figure 6 shows the single-scan and repeated scanning output spectra of the dual-wavelength EDFL using the two FBGs. We also measured the fluctuation in output power at each wavelength for more than half an hour. The experimental results are shown in Fig. 7(d). The maximum power fluctuations at the wavelengths of 1550.38 nm and 1551.14 nm are about 0.49 dB and 0.44 dB, respectively, that is, the output powers are so stable that the peak fluctuations are less than 0.5 dB integrated over smaller than 1 ms by the OSA.

The fourth experiment investigated the effect of the saturated signal level in the laser cavity on the stability of the dual-wavelength lasing oscillations via changing only the pump power acting on the EDF in Fig. 1 (using the two FBGs). As shown as in Fig. 7, the smaller the pump power is, the larger the power fluctuations of the lasing wavelengths are. For example, the power fluctuation at 1551.14nm is 1.56 dB over 15 minutes of scanning when the pump power is 20 mW, while the value over 30 minutes of scanning becomes less than 0.45 dB when the pump power is 98 mW. This indicates that the saturation level of signals in the laser cavity has an important impact on the stability of the multiwavelength lasing oscillations.

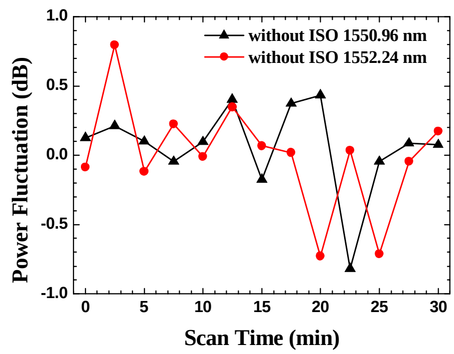

Fig. 5. Power fluctuation of the multiwavelength EDFRL during scanning without the ISO. The maximum fluctuations are 1.25 dB at 1550.96 nm and 1.52 dB at 1552.24nm, respectively.

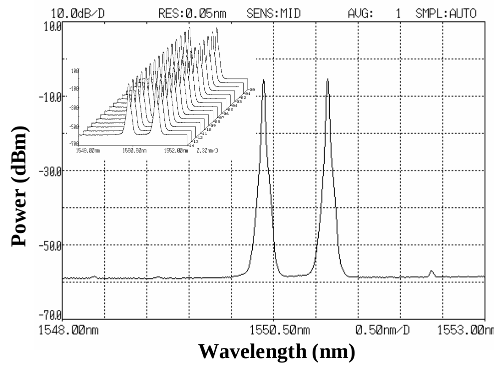

Fig. 6. Output spectra of the dual-wavelength EDFRL obtained using the two common FBGs. with 0.76 nm wavelength spacing.

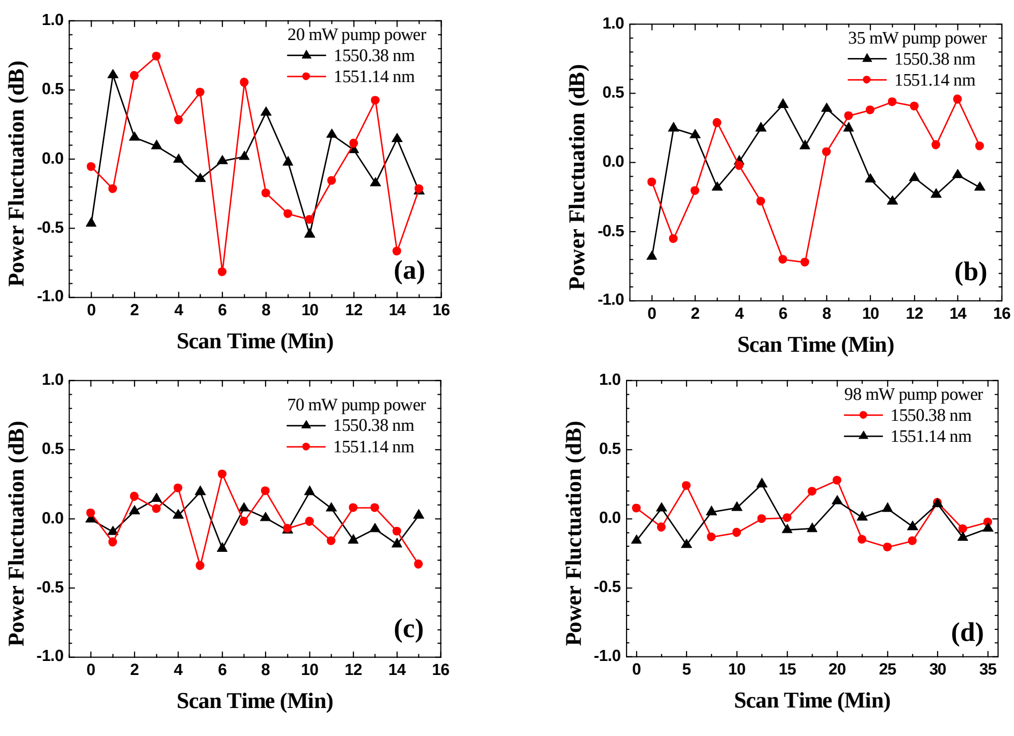

Fig. 7. Power fluctuations of the dual-wavelength EDFRL using the two FBGs with different pump power. The maximum fluctuations for 20 mW, 35mW, 70 mW and 98 mW pump powers are (1.15, 1.56) dB, (1.10, 1.18) dB, (0.41, 0.66) dB and (0.49, 0.44) dB at wavelengths of 1550.38 nm and 1551.14 nm, respectively.

#72662 - $15.00 USD Received 5 July 2006; revised 17 August 2006; accepted 18 August 2006

For these experimental results, we believe the PHB effect and nonlinear assistant effects such as four-wave mixing for stable multiwavelength operation were absent in the EDFRLs. We think that the main mechanism for the observed stable multiwavelength operation is an inhomogeneous broadening effect induced by a deeply saturated hole-burning effect. Due to spectral hole burning effect which becomes obvious at room temperature when the signal input into the EDF are deeply saturated [9-10], the inhomogeneous line broadening effect plays a dominant role, effectively suppressing the mode competition induced by the homogenous line broadening and cross-gain saturation of the EDF. Evidence has also been published that the usage of a 980-nm pumped LD in the EDFRL is helpful to obtain lower cross-saturation effect [12]. Additionally, our experimental results also show that reverse propagating light is a disadvantage in stabilizing multiwavelength lasing and the EDFRL must be effectively isolated. Therefore, we presume that it is difficult to obtain stable multiwavelength lasing in a linear fiber laser cavity.

4. Conclusion

In conclusion, we have demonstrated that stable multiwavelength lasing oscillations at room temperature could be achieved by exploiting a deeply saturated spectral hole-burning effect in ordinary erbium-doped fiber ring laser cavity. Dual-wavelength lasing oscillations obtained by this method were so stable integrated over smaller than 1 ms by the OSA that the maximum power fluctuation over a long-time observation of more than 30 minutes is less than 0.1 dB and 0.5 dB for 1.28 nm and 0.76 nm wavelength spacing, respectively. We believe that this technique provides another simple approach to achieve stable multiwavelength EDF lasing at room temperature and also gives insight into spectral hole-burning effect in applications of multiwavelength EDFLs.

Acknowledgments

This work is supported by the Tianjin Natural Science Foundation under Grant No. 06YFJZJC00300, the National Key Basic Research and Development Programme of China under Grant No. 2003CB314906, the National Natural Science Foundation of China under Grant No 60407005 and open project foundation of Key Laboratory of Opto-electronic Information Science and Technology, Ministry of Education in Nankai University.

#72662 - $15.00 USD Received 5 July 2006; revised 17 August 2006; accepted 18 August 2006