Nonlinear Optical Loop Mirror-based Linear Cavity Tunable Multi-wavelength Fiber Laser

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Abstract— We propose and experimentally demonstrate a nonlinear optical loop mirror (NOLM)-based linear cavity tunable multi-wavelength fiber laser. The NOLM, providing intensity-dependent transmissivity, can effectively alleviate the mode competition so that the multi-wavelength lasing can be achieved at room temperature. By adjusting the polarization controllers (PCs), the proposed laser can generate multi-wavelength output. Moreover, the number of the lasing wavelength can be adjusted flexibly from 11 to 13 with a wavelength spacing of 0.4 nm.

1. INTRODUCTION

Multi-wavelength fiber lasers have been drawn great interest for their potential applications in wavelength division multiplexing (WDM) transmission systems, optical sensors and optical signal processing and so on. With the characteristics of low threshold broad gain bandwidth and high power conversion efficiency, the multi-wavelength erbium-doped fiber (EDF) lasers have been extensively investigated. However, the fierce mode competition prevents multi-wavelength EDF lasers from attaining stable multi-wavelength lasing at room temperature. The straight method is to cool the EDF in liquid nitrogen to overcome the homogeneous gain broadening effect [1]. Evidently, this technique is impossible for the generally practical applications. Therefore, others methods have been proposed to alleviate the mode competition for instance, adding a frequency shifter [2], inserting a semiconductor optical amplifier [3], using nonlinear gain of cascaded stimulated Brillouin scattering or stimulated Raman scattering [4], providing four-wave-mixing [5] and utilizing nonlinear polarization rotation [6, 7]. But all the above techniques inevitably add the excess complexity and the cost to the multiwavelength lasers. In contrast, the NOLM has the advantages of simple constitution and costless components [8, 9].

In this letter, we propose and experimentally demonstrate a NOLM-based linear cavity tunable multi-wavelength laser. In the proposed laser, the NOLM is used to mitigate the mode competition in the EDF. A polarization maintaining fiber (PMF)-based Sagnac interferometer acts as the comb filter. By adjusting the PCs in loops, the number of the lasing wavelength can be adjusted flexibly from 11 to 13 with a wavelength spacing of 0.4 nm in the wavelength region of 1530 nm at room temperature.

2. EXPERIMENTAL SETUP AND PRINCIPLE

As shown in Figure 1, the proposed laser consists of a pump optical source, a WDM coupler, a segment of EDF, a NOLM and a fiber Sagnac interferometer. The linear lasing cavity is formed by the NOLM and the Sagnac interferometer. The EDF is 10 m which plays a role of the gain medium. The Sagnac interferometer, which includes a 3 dB optical coupler, a polarization controller (PC1) and a segment of PMF, severs as the output port as well. The length and the refractive index difference of the PMF used in the experiment are 10 m and 6.54×10^{-4}, respectively. The comb filter is achieved and the wavelength interval is 0.4 nm. The NOLM, which consists of a 3 dB optical coupler, a polarization controller (PC2) and a 2.1-km long conventional SMF, acts as an amplitude equalizer. It is worth to note that an optimum length of the SMF in the NOLM should be selected to attain the multi-wavelength lasing. In the experiment, 1 km, 2.1 km, 5 km and 10 km SMF have been used in the NOLM, respectively. As a result, the best performance can be gained when the length of the SMF is 2.1 km. The PCs in the loops were used for polarization biasing. The output spectrum characteristics of the laser are monitored by an optical spectrum analyzer (OSA) with a resolution of 0.02 nm.

The principle of the NOLM is analyzed as follows. When the light propagates in the NOLM, the different nonlinear phase shifts will be formed due to the Kerr effect of the SMF. Moreover, the rotation of the polarization state will be accumulated in the SMF and is dependent on the light intensity. The NOLM can work as an amplitude equalizer to mitigate the mode competition

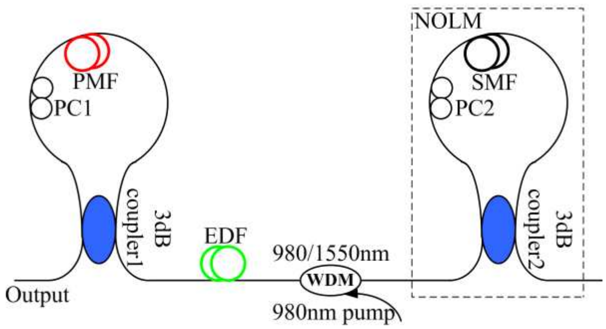

Figure 1: Experimental schematic of the proposed laser.

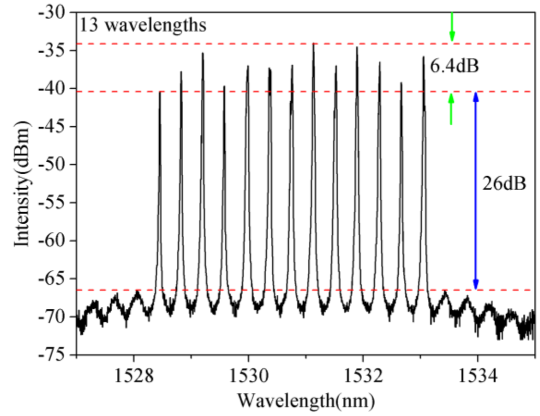

Figure 2: 13-line lasing operation.

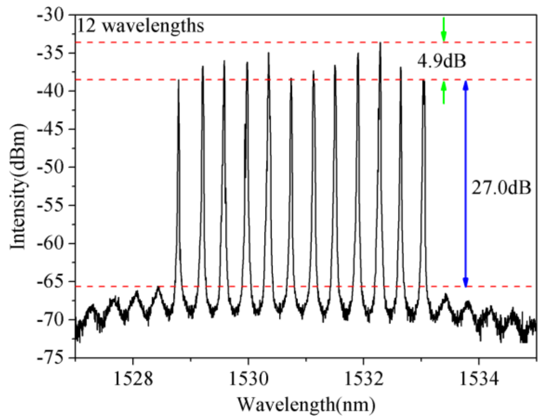

Figure 3: 12-line lasing operation.

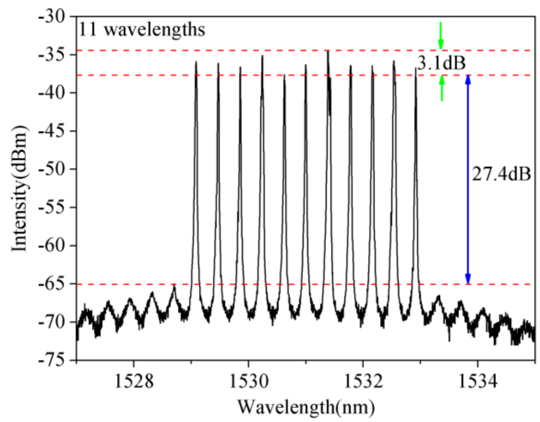

Figure 4: 11-line lasing operation.

when the PC2 is adjusted to the state where the transmissivity decreases with the signal power increasing. Consequently, the multi-wavelength oscillations can be attained when the IDL induced by the NOLM matches with the mode competition in the cavity.

3. RESULTS AND DISCUSSION

In our experiment, a 980 nm laser diodes (LD) and a 980/1550 nm WDM coupler are used. At first, the output power of the LD was increased to 200 mW and fixed. Then the PC1 was rotated to the position where the fiber Sagnac interferometer can get a comb output and fixed. By changing the PC2, the multi-wavelength oscillation can be attained around 1530 nm, as shown in Figure 2. As a result, a 13-line lasing is achieved with the bandwidth of 6.4 dB. The wavelength spacing and the side mode suppression ratios (SMSR) are 0.4 nm and 26 dB, respectively. By appropriately adjusting the PC2, the number of the lasing wavelength decreased, as shown in Figure 3. During the bandwidth of 4.9 dB, the 12-line lasing is gained and the SMSR is 27 dB. With further carefully adjusting the PC2, the evenness of multi-wavelength lasing could be improved, as shown in Figure 4. An 11-line lasing is achieved during the bandwidth of 3.1 dB and the SMSR increases to 27.4 dB. The experimental results indicate that the fluctuation of the lasing wavelength power decreases and the SMSR increases as the number of the lasing line decreasing. As far as we know, this is the first time to report the NOLM-based linear cavity tunable multi-wavelength EDF laser. Compared with our previous work [6], the proposed laser has more lasing wavelengths with 0.4 nm channel spacing and less cost, in which the expensive polarization-dependent isolator and optical circulator is not used.

To verify the stability of the proposed laser, we repeated scanning of the power fluctuation and the wavelength drift of the three channels in the 12-line laser state with 3 minutes interval within 30 minutes, as shown in Figure 5. The results show that the maximum power fluctuation is smaller than 2.2 dB, and the wavelength shift is less than 0.08 nm. In our opinions, the power fluctuation

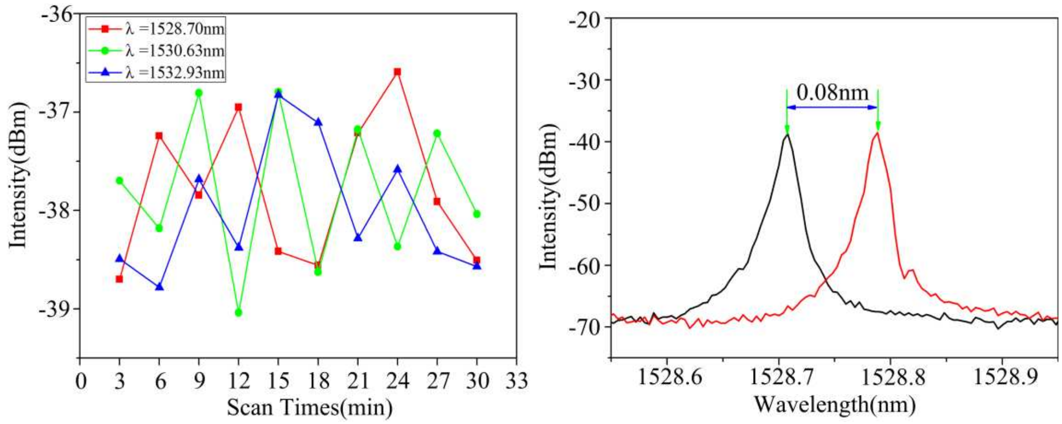

Figure 5: Power variation of three individual channels and the wavelength drift over 30 min.

is mainly caused by the stability of pump optical source's polarization state, the vibration of the experimental platform and the performance of the passive devices. Those factors can affect the polarization states of the fiber laser so that the power of lasing wavelengths and the stability of the proposed laser are fluctuating. By equipping the high performance devices and the package, the stability of the proposed laser can be highly improved.

4. CONCLUSION

In conclusion, we propose and experimentally demonstrate a NOLM-based linear cavity tunable multi-wavelength laser. By rotating the PCs, the multi-wavelength operation can be attained and the number of lasing wavelengths can be changed flexibly form 11 to 13. As a result, 11-line lasing operation within 3.1 dB bandwidth and with a SMSR of 27.4 dB was achieved experimentally. What's more, the experiment results indicate that the proposed laser can stably operate at room temperature.

REFERENCES

1. Park, N. and P. F. Wysocki, "24-line multiwavelength operation of erbium-doped fiber-ring laser," *IEEE Photon. Technol. Lett.*, Vol. 8, 1459–1461, 1996.
2. Zhou, K. J., D. Y. Zhou, F. Z. Dong, and N. Q. Ngo, "Room-temperature multiwavelength erbium-doped fiber ring laser employing sinusoidal phase-modulation feedback," *Opt. Lett.*, Vol. 28, 893–895, 2003.
3. Chen, D., H. Ou, H. Fu, S. Qin, and S. Gao, "Wavelength-spacing tunable multi-wavelength erbium-doped fiber laser incorporating a semiconductor optical amplifier," *Laser Phys. Lett.*, Vol. 4, 287–290, 2007.
4. Zhan, L., J. H. Ji, J. Xia, S. Y. Luo, and Y. X. Xia, "160-line multiwavelength generation of linear-cavity self-seeded Brillouin-erbium fiber laser," *Opt. Exp.*, Vol. 14, 10233–10238, 2006.
5. Harun, S. W., S. D. Emami, F. A. Rahman, S. Z. Muhd-Yassin, M. K. Abd-Rahman, and H. Ahmad, "Multiwavelength Brillouin/erbium-ytterbium fiber laser," *Laser Phys. Lett.*, Vol. 4, 601–603, 2007.
6. Wang, W., H. Y. Meng, X. W. Wu, W. Wang, R. Xiong, H. C. Xue, C. H. Tan, and X. G. Huang, "A nonlinear polarization rotation-based linear cavity waveband switchable multi-wavelength fiber laser," *Laser Phys. Lett.*, Vol. 10, 015104, 2013.
7. Wang, W., H. Y. Meng, X. W. Wu, W. Wang, H. C. Xue, C. H. Tan, and X. G. Huang, "Three channel-spacing switchable multiwavelength fiber laser with two segments of polarization-maintaining fiber," *IEEE Photon. Technol. Lett.*, Vol. 24, 470–472, 2012.
8. Feng, X. H., P. K. A. Wai, C. Lu, H. Y. Tam, J. Li, and B. O. Guan, "Investigation of a multiwavelength erbium-doped fiber laser employing a nonlinear high-birefringence fiber loop mirror," *Opt. Eng.*, Vol. 49, 074202, 2010.
9. Feng, X. H., C. Lu, H. Y. Tam, P. K. A. Wai, D. Y. Tang, and B. O. Guan, "Mechanism for stable, ultra-flat multiwavelength operation in erbium-doped fiber lasers employing intensity-dependent loss," *Opt. Laser Technol.*, Vol. 44, 74–77, 2012.

10. Dong, X. P., S. P. Li, K. S. Chiang, M. N. Ng, and B. C. B. Chu, "Multiwavelength erbium-doped fibre laser based on a high-birefringence fibre loop mirror," *Electron. Lett.*, Vol. 36, 1609–1610, 2000.