Multi-wavelength thulium-doped fiber laser by using Sagnac loop mirror

Lewen Zhou[1, 2], Pengbai Xu[1, 2], and Xinyong Dong[1, 2]*
[1]School of Information Engineering, Guangdong University of Technology, Guangzhou 510006, China
[2]Guangdong Provincial Key Laboratory of Information Photonics Technology, Guangzhou 510006, China
*E-mail: dongxy@gdut.edu.cn

2021 19th International Conference on Optical Communications and Networks (ICOCN) | 978-1-6654-2446-2/21/$31.00 ©2021 IEEE | DOI: 10.1109/ICOCN53177.2021.9563674

***Abstract*—A multi-wavelength thulium-doped fiber laser based on a Sagnac loop mirror is demonstrated. By increasing pump power and adjusting the state of polarization, stable laser outputs with single, double, three, four or five wavelengths are realized within the spectral range between 1954 and 1975 nm. The laser has a high side-mode suppression ratio (SMSR) of 40-50 dB.**

Keywords-Multi-wavelength; Thulium-doped fiber laser; Sagnac loop mirror

I. INTRODUCTION

Multi-wavelength fiber lasers have attracted extensive attention due to their potential applications in optical fiber sensing, optical communication and optical signal processing [1]. Multi-wavelength laser output can be achieved by using intra-cavity comb filters, such as Lyot filter [2], Sagnac loop mirror [3] and Mach-Zehnder interferometer [4]. It can also be achieved by using the non-linear optical effects such as four-wave mixing and stimulated Brillouin scattering [5].

Multi-wavelength lasers operating at 2 μm wavelength band by using Thulium-doped fiber (TDF) have become a hot research topic in recent years due to their many advantages including wide lasing spectral range, eye safety wavelength, and high brightness [6]. Various optical fiber comb filters were studied to achieve multi-wavelength laser output at 2 μm. In 2015, a tunable TDF laser (TDFL) based on a Sagnac loop mirror was reported [7]. In 2017, a multimode fiber interferometer was used to achieve a multi-wavelength TDFL with 9 laser lines [8]. In 2018, a micro-fiber Fabry-Perot interferometer was used to achieve a TDFL with up to three lasing wavelengths [9]. In 2020, a four-mode fiber based Sagnac loop mirror was used to achieve a wavelength switchable TDFL [10]. However, the number of lasing wavelengths in these reported TDFLs is usually limited and the side-mode suppression ratio (SMSR) is not high enough.

In this work, we demonstrate a multi-wavelength TDFL by using a Sagnac loop mirror. Stable laser outputs with single, double, three, four or five wavelengths are achieved within the spectral range between 1954 and 1975 nm. The SMSR is as high as 40-50 dB.

II. EXPERIMENTAL SETUP AND PRINCIPLE

The experimental setup of the proposed multi-wavelength TDFL is shown in Fig. 1. A 1.5 m-long double-cladding TDF with core diameter of 10 μm and cladding diameter of 130 μm was used as the gain medium. The TDF was pumped by using a 793 nm laser diode (LD) with output power up to 15 W through a 793/2000 nm wavelength-division multiplexer (WDM). A 3-dB coupler (Coupler 1) with its two pigtails on the left being fused spliced together was used as a loop mirror. The Sagnac loop mirror was formed by using a 3-dB coupler (Coupler 2), a 2.2 m-long polarization maintaining fiber (PMF) and a polarization controller (PC). An optical spectrum analyzer (OSA, AQ6376) with wavelength resolution of 0.1 nm was used to measure the laser output spectrum.

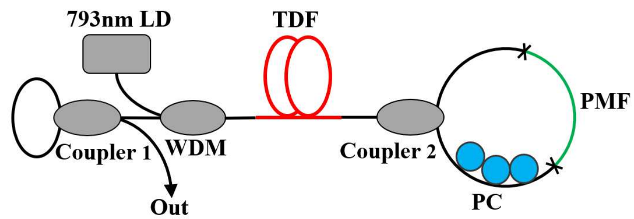

Figure 1. Experimental setup of the multi-wavelength TDFL.

III. EXPERIMENTAL RESULTS AND DISCUSSION

In the experiment, by increasing pump power and adjusting polarization state via the PC, laser output was achieved when pump power reached 1.25 W. Further increasing pump power, the single-wavelength laser output turned stable. Fig. 2 shows the measured output spectrum of the single-wavelength TDFL. The operating wavelength is 1968.07 nm, the pump power is 1.42 W and the SMSR is about 40 dB.

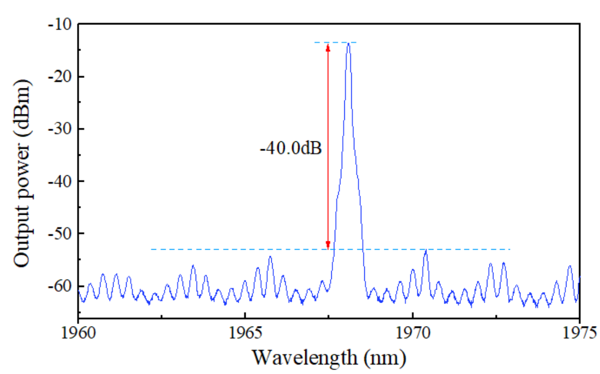

Figure 2. Output spectrum of the TDFL operating at single wavelength.

When pump power was increased to 1.58 W, two lasing peaks operating at 1968.1 and 1974.7 nm were observed, as shown in Fig. 3. Their SMSR are 40.9 and 43.3 dB, respectively. When pump power was increased to 1.94 W, laser output with three peaks was realized, as shown in Fig. 4. The peak wavelengths and SMSR are 1958.5, 1965.4 and 1974.7 nm, and 40.3, 39.3 and 44.3 dB, respectively.

When pump power was increased to 2.12 W, laser output with four lasing peaks was realized. Fig. 5 shows the laser output spectrum. The peak wavelengths are 1956.2, 1958.5, 1960.8 and 1963.1 nm, respectively, and the minimum SMSR is 42.3 dB.

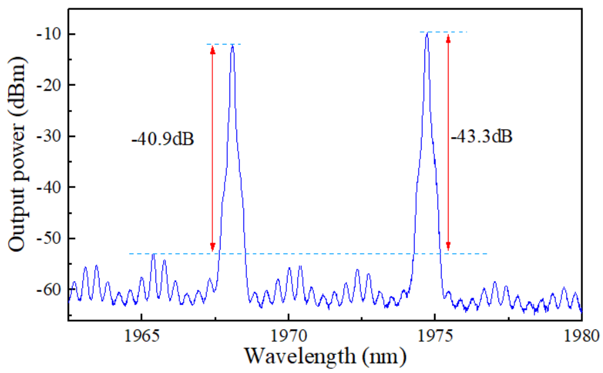

Figure 3. Output spectrum of the TDFL operating at dual-wavelength.

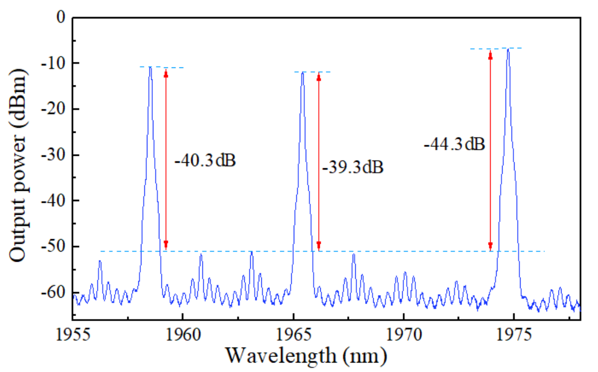

Figure 4. Output spectrum of the TDFL operating at three-wavelength.

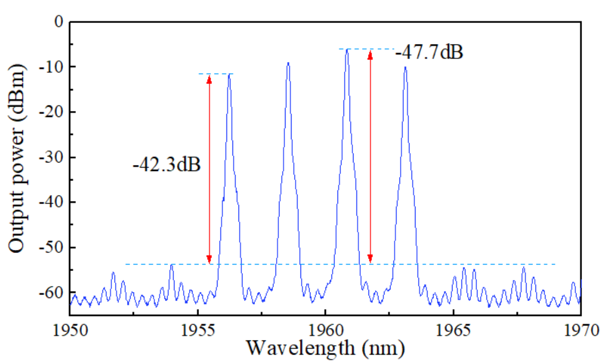

Figure 5. Output spectrum of the TDFL operating at four-wavelength.

When pump power was increased to 2.83 W, laser output with five lasing peaks was realized, as shown in Fig. 6. The peak wavelengths are 1954.1, 1956.4, 1963.2, 1965.5 and 1969.8 nm, respectively. The lowest SMSR is 40.0 dB, and the highest SMSR can reach 49.4 dB.

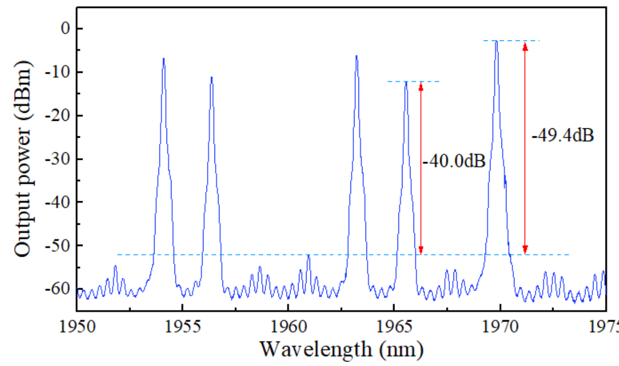

Figure 6. Output spectrum of the TDFL operating at five-wavelength.

To test stability of the laser output, we recorded the laser output spectrum of five lasing peaks every 3 minutes within 15 minutes at room temperature. Fig. 7 shows the measured five output spectra of the five-wavelength TDFL. No obvious variation in peak wavelength is observed.

The power fluctuations of the five lasing peaks are shown in Fig. 8. The maximum fluctuations are 1.77, 2.06, 1.78, 1.87 and 2.64 dB, respectively. The power fluctuations were mainly caused by mode competition between different lasing modes and the influences of environment such as vibrations.

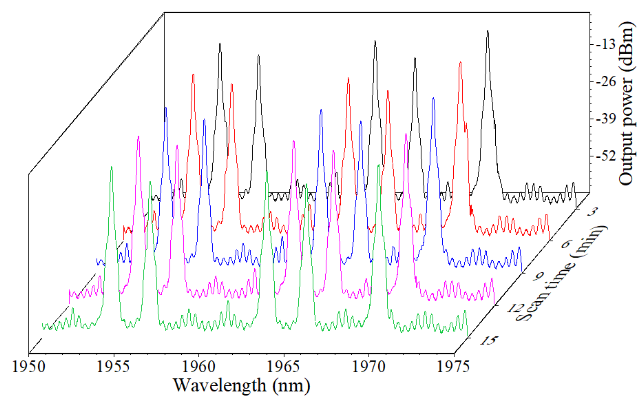

Figure 7. Stability measurement results of the five-wavelength TDFL.

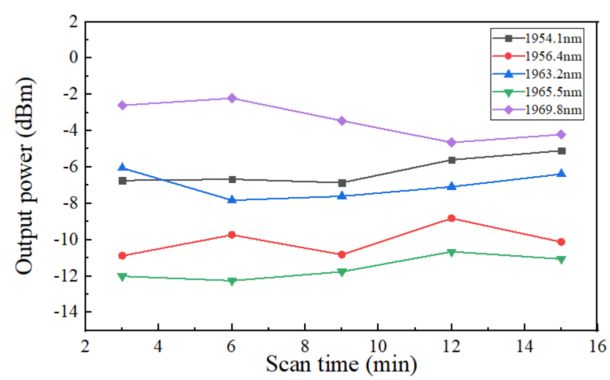

Figure 8. Power fluctuations of lasing peaks of the five-wavelength TDFL.

IV. Conclusion

We have demonstrated a multi-wavelength TDFL operating at 2 μm by using a Sagnac loop mirror. Stable laser outputs with single, double, three, four or five wavelengths were achieved within the spectral range between 1954 and 1975 nm. High SMSR of 40-50 dB was obtained.

Acknowledgment

This work was supported by the National Natural Science Foundation of China (Nos. 61775204 and 11974083) and the National Key Research Project (2020YFB805804) and in part by the Program for Guangdong Introducing Innovative and Enterpreneurial Teams.

References

[1] Z. Yan, X. Li, Y. Tang, P. P. Shum, X. Yu, Y. Zhang, and Q. J. Wang, “Tunable and switchable dual-wavelength Tm-doped mode-locked fiber laser by nonlinear polarization evolution,” Optics Express, 23(4), 4369–4376 (2015).

[2] S. Liu, F. Yan, T. Feng, “Multi-wavelength thulium-doped fiber laser using a fiber-based Lyot filter,” IEEE Photonics Technology Letters, 2016, 28(8):864-867.

[3] Y. Liu, X. Dong, M. Jiang, “Multi-wavelength erbium-doped fiber laser based on random distributed feedback,” Applied Physics B, 2016, 122(9):240.

[4] J. D. Filoteo-Razo, J. C. Hernandez-Garcia, J. M. Estudillo-Ayala, “Multi-wavelength Er–Yb-doped fibre ring laser using a double-pass Mach–Zehnder interferometer with a Sagnac interferometer,” Optics & Laser Technology, 2021, 139:106994.

[5] T. Huang, X. Li, P. P. Shum, “All-fiber multiwavelength thulium-doped laser assisted by four-wave mixing in highly germania-doped fiber,” Optics Express, 2015, 23(1):340.

[6] K. Scholle, S. Lamrini, P. Koopmann, “2 μm laser sources and their possible applications,” Frontiers in Guided Wave Optics & Optoelectronics, 2010.

[7] T. Wang, W. Ma, Z. Peng, “Multi-wavelength narrow linewidth thulium-doped fiber laser operating at 1.9μm using a tunable Sagnac fiber period filter,” Journal of Optics, 2015, 44(3):210-214.

[8] H. Ahmad, A. S. Sharbirin, M. Z. Samion, “All-fiber multimode interferometer for the generation of a switchable multi-wavelength thulium-doped fiber laser, ”Appl Opt, 2017, 56(21):5865-5870.

[9] M. Wang, Y. Huang, Y. Li, “Multi-wavelength thulium-doped fiber laser using a micro fiber-optic Fabry–Perot interferometer,” IEEE Photonics Journal, 2018, 10:1-8.

[10] Y. Guo, F. Yan, T. Feng, “Switchable multi-wavelength thulium-doped fiber laser using four-mode fiber based Sagnac loop filter,” IEEE Photonics Journal, 2020, 12(2):710061.