# Switchable dual-wavelength erbium-doped fiber laser with tunable wavelength*

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A switchable dual-wavelength erbium-doped fiber laser (EDFL) with tunable wavelength is demonstrated. The ring cavity consists of two branches with a fiber Bragg grating (FBG) and a spherical-shape structure as fiber filters, respectively. By adjusting the variable optical attenuator (VOA), the laser can be switched between the single-wavelength mode and the dual-wavelength mode. The spherical-shape structure has good sensitivity to the temperature. When the temperature changes from 30 °C to 190 °C, the central wavelength of the EDFL generated by the branch of spherical-shape structure varies from 1 551.6 nm to 1 561.8 nm, which means that the wavelength interval is tunable.

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Dual-wavelength erbium-doped fiber lasers (EDFLs) have been extensively exploited in recent years[1-5]. In order to realize the operation in dual-wavelength mode, various filters have been employed in the ring laser cavity. Jianqun Cheng et al[6] employed a linear cavity configuration which used a polarization-maintaining photonic crystal fiber (PMPCF) Sagnac loop as a filter. Hui Zou et al[7] designed a configuration which consists of a Mach-Zehnder interferometer (MZI) cascaded with a tunable Sagnac filter in the fiber ring cavity, and by using a comb filter, a dual-wavelength fiber ring laser was realized. Xiaoying He et al[8] proposed a filter based on fiber Bragg grating (FBG) and chirped FBG (CFBG). However, these schemes are relatively complex and expensive.

Recently, new kinds of MZIs are used as fiber filters in fiber lasers[9,10], such as concatenated tapers, multimode-single mode-multimode (MSM) fiber structure and single-mode core-offset structure. And due to their good sensitivities to axial strain, temperature and refractive index, tunable fiber lasers can be achieved. Hui Zou et al[11] proposed a twin-core fiber (TCF) comb filter fabricated by splicing a homemade TCF between two standard single mode fibers (SMFs), in which the wavelength of the laser can be tuned from 1 558.04 nm to 1 553.62 nm by applying axial strain to the TCF. However, the procedure is relatively complex. Xia Hao et al[12] exploited single-mode core-offset structure as a filter in the ring cavity. The lasing central wavelength varies from 1 547.7 nm to 1 558.1 nm when the temperature changes from 30 °C to 270 °C. But it might be a challenge to fabricate the parallel offset attenuators by conventional fusion splicer. Lin Ma et al[13] used single-mode no-core fiber structure as a filter, and the wavelength of fiber laser was tuned based on the refractive index characteristics. However, the cost of no-core fiber is relatively high.

In this paper, a switchable dual-wavelength EDFL with tunable wavelength is designed. Because a variable optical attenuator (VOA) is introduced, the wavelength of the laser output is switchable by controlling the cavity loss. Moreover, owing to the sensitivity of the spherical-shape structure to the temperature, the wavelength interval can be adjusted when different temperatures are applied. Compared with other structures, the proposed structure has a lower cost. Furthermore, when it is used in the ring cavity, the output wavelength of the EDFL is switchable and tunable.

The schematic diagram of the experimental setup is shown in Fig.1. A 980 nm laser diode (LD) is used as the pump source, and connected to a 7 m-long erbium-doped fiber (EDF) through a 980 nm/1 550 nm wavelength division multiplexer (WDM). When the light reaches the 50:50 coupler C1, it is separated into two paths. The 50% of the light goes through a spherical-shape structure, while the rest of light transmits from port 1 to port 2 of

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the circulator. After being reflected by the FBG to port 3 of the circulator, the light goes through a VOA to coupler C2. The two paths of light are coupled at the 50:50 coupler C2, and then reach the 10:90 coupler C3. A portion of the output is extracted by the 10% port to an optical spectrum analyzer (OSA) with resolution of 0.07 nm, and the rest is fed back into the laser cavity.

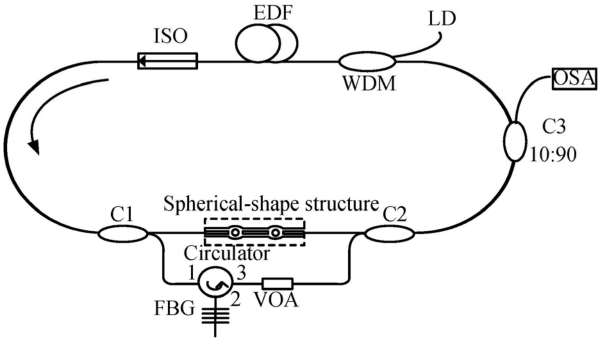
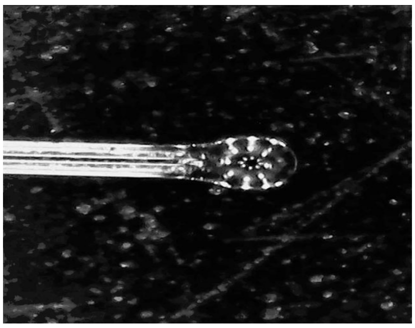
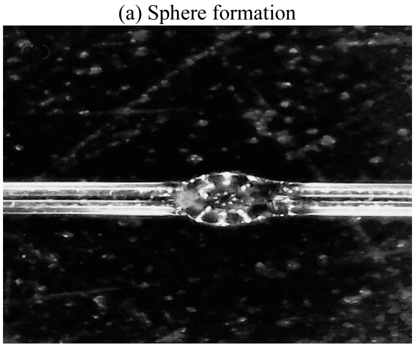



**Fig.1 Schematic diagram of the experimental setup**

The spherical-shape structure consists of two cascaded spherical-shape joints which are fabricated by a fusion splicer. Fig.2 shows the microphotographs of spherical-shape joint. A section of SMF (8.2 μm /125 μm) is cleaved and cleared, and the end of the SMF becomes a sphere after being discharged as shown in Fig.2(a). Then the end of the sphere is spliced to another section of SMF. After fusion splicing, the spherical-shape joint is realized as shown in Fig.2(b).



(a) Sphere formation



(b) Joint fusion

**Fig.2 The microphotographs of spherical-shape joint**

The schematic diagram of the spherical-shape structure is illustrated in Fig.3. The longitudinal diameter $D_1$ and the horizontal diameter $D_2$ of the left sphere are 191 μm and 207 μm, while the longitudinal diameter $D_3$ and the horizontal diameter $D_4$ of the right sphere are 194 μm and 205 μm, respectively. The separation length $L$ is 40 mm between two spherical-shape joints. The transmission spectrum under the broadband light source is shown in Fig.4. Due to the splice loss of spherical-shape structure, the insertion loss of above branch through the spherical-shape structure is larger than that of the other branch. When the VOA is introduced, the loss of the FBG branch can be adjusted to obtain single-wavelength or dual-wavelength laser output.

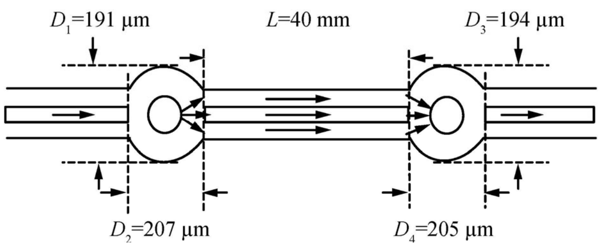



**Fig.3 Schematic diagram of the spherical-shape structure**

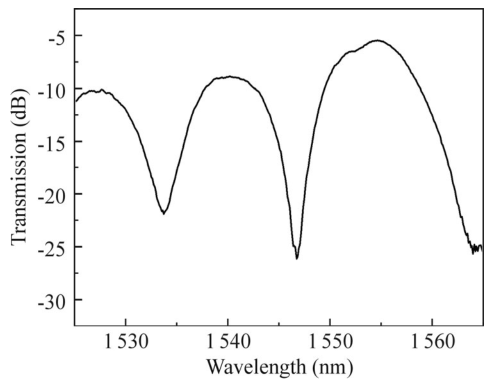



**Fig.4 The transmission spectrum of the spherical-shape structure**

At room temperature, by adjusting the VOA, the loss of the FBG branch is changed. When the attenuation of the VOA is equal to zero and the pump power is 120 mW, the insertion loss caused by spherical-shape structure is larger than that of the FBG branch. The single wavelength can be obtained at $\lambda_1$=1 539.9 nm corresponding to the center wavelength of FBG, and the output spectrum is illustrated in Fig.5. The side-mode suppression ratio (*SMSR*) is 53 dB, and the output power is −5.95 dBm.

When the attenuation of the VOA increases to make sure the loss of the branch through spherical-shape structure is less than that of the FBG branch, as shown in Fig.6, the laser appears at the wavelength of $\lambda_2$=1 551.1 nm, which is corresponding to the maximum gain in the EDF and the maximum transmission in the spherical-shape structure. The *SMSR* is 45 dB, and the output power is −17.19 dBm. Therefore, by adjusting the

VOA, the single wavelength output can be switched between $\lambda_1$ and $\lambda_2$.

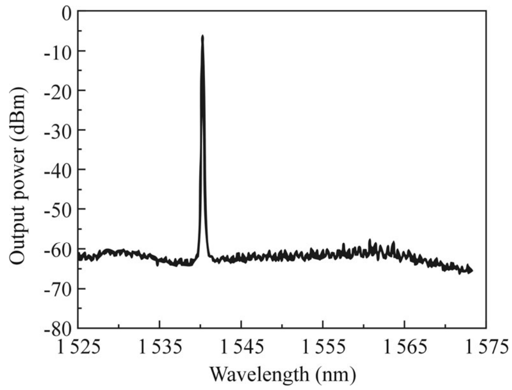



**Fig.5 Single wavelength output at 1 539.9 nm**

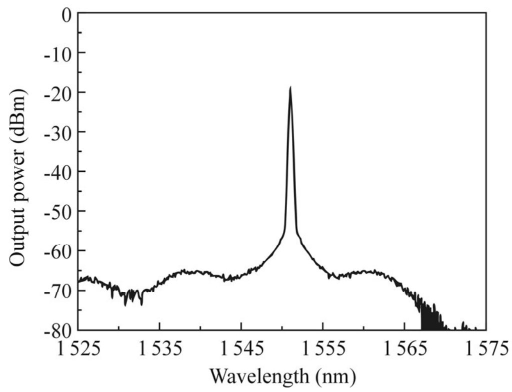



**Fig.6 Single wavelength output at 1 551.1 nm**

When the attenuation of the VOA increases to make sure that the losses in the two paths are equal, $\lambda_1$ and $\lambda_2$ can be observed simultaneously in Fig.7.

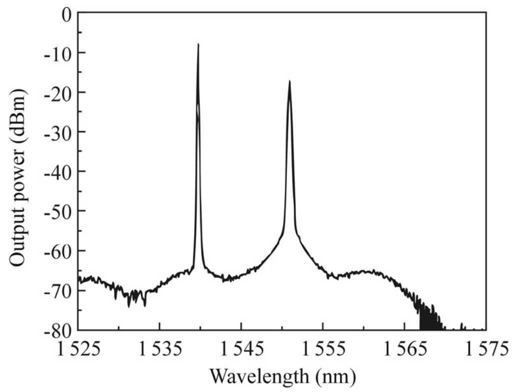



**Fig.7 Dual-wavelength output at 1 539.9 nm and 1 551.1 nm**

Then, fix the spherical-shape structure on a furnace. When the temperature changes from 30 °C to 190 °C, due to the sensitivity of the spherical-shape structure to temperature, the pass-band of the transmission spectrum under the broadband light source is red-shifted, as shown in Fig.8(a). Consequently, the lasing wavelength moves to the longer wavelength with the increase of temperature as shown in Fig.8(b). It can be seen that one lasing central wavelength stays at 1 539.9 nm, and the other varies from 1 551.6 nm to 1 561.8 nm with the increase of temperature. As shown in Fig.8, the peak power fluctuates in the tuning process. If the stability of the pump LD and the operation surroundings can be improved, a more stable dual-wavelength lasing will be expected.

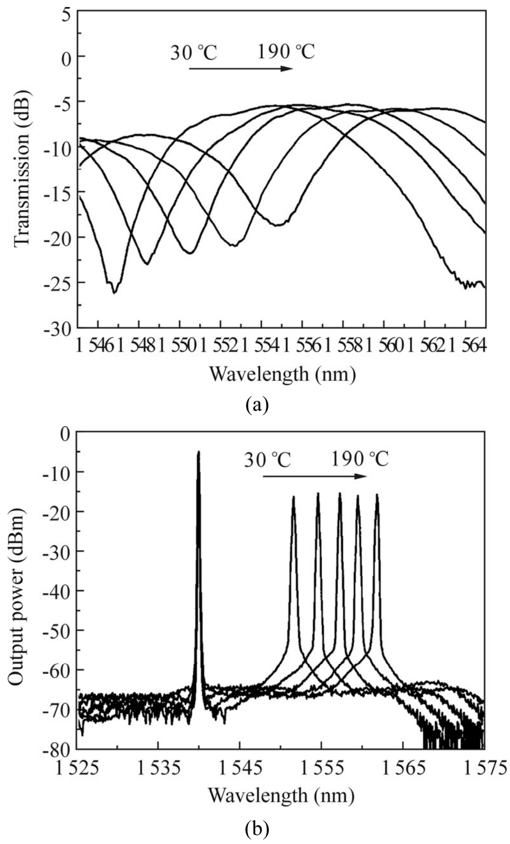



**Fig.8 (a) Transmission spectra of the spherical-shape structure filter and (b) the tunable wavelength outputs of the laser at different temperatures of 30 °C, 70 °C, 110 °C, 150 °C and 190 °C**

A switchable dual-wavelength EDFL is proposed by using FBG and spherical-shape structure as the fiber filters. By adjusting the VOA, the laser can easily switch between single-wavelength mode and dual-wavelength mode. At room temperature, when the laser operates at dual-wavelength mode and the pump power is 120 mW, the peak power of output is measured to be −7.94 dBm at 1 539.9 nm, and the *SMSR* is about 52 dB, while the peak power of output is measured to be −17.19 dBm at 1 551.1 nm and the corresponding *SMSR* is about 45 dB. The experimental results also demonstrate that when the temperature applied on spherical-shape structure changes from 30 °C to 190 °C, one of the lasing central wavelength varies from 1 551.6 nm to 1 561.8 nm. When the proposed structure is used in the ring cavity, the output wavelength of the EDFL is switchable and tunable, which has more benefits in WDM systems.

## References

[1] Wei He, Lianqing Zhu, Xiaoping Lou, Mingli Dong, Yinmin Zhang, Fei Luo and Xiaohuai Chen, Journal of Optoelectronics·Laser **25**, 1081 (2014). (in Chinese)

[2] Silvia Diaz and Manuel Lopez-Amo, Optical Engineering **53**, 036106 (2014).

[3] Tiegang Sun, Yubin Guo, Tianshu Wang, Jiayu Huo and Le Zhang, Optics and Laser Technology **67**, 143 (2015).

[4] Ye Cao, Guoqiang Jia, Junfa Zhao and Zhengrong Tong, Journal of Optoelectronics·Laser **24**, 833 (2013). (in Chinese)

[5] Xiaohui Li, Xueming Liu, Dong Mao, Xiaohong Hu and Hua Lu, Optical Engineering **49**, 094303 (2010).

[6] Jianqun Cheng, Jianrong Qiu and Shuangchen Ruan, Optics and Laser Technology **58**, 110 (2014).

[7] Hui Zou, Shuqin Lou, Guolu Yin and Wei Su, IEEE Photonics Technology Letters **25**, 1003 (2013).

[8] Xiaoying He, D. N. Wang and C. R. Liao, Journal of Lightwave Technology **29**, 842 (2011).

[9] Hae Young Choi, Myoung Jin Kim and Byeong Ha Lee, Optics Express **15**, 5711 (2007).

[10] Zhibo Liu, Yang Li, Yan Liu, Zhongwei Tan and Shuisheng Jian, IEEE Photonics Technology Letters **25**, 2050 (2013).

[11] Hui Zou, Shuqin Lou and Guolu Yin, Optics and Laser Technology **45**, 629 (2013).

[12] Xia Hao, Zhengrong Tong, Weihua Zhang and Ye Cao, Optics Communications **335**, 78 (2015).

[13] Lin Ma, Yanhui Qi, Zexin Kang, Yunlong Bai and Shuisheng Jian, Optics and Laser Technology **57**, 96 (2014).