Tunable and switchable dual-wavelength erbium-doped fiber laser based on in-line tapered fiber filters*

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A tunable and switchable dual-wavelength erbium-doped fiber laser (EDFL) based on all-fiber single-mode tapered fiber structure has been demonstrated. By adjusting the variable optical attenuator (VOA), the laser can be switched between the single-wavelength mode and the dual-wavelength mode. When the temperature applied on the tapered fiber structure varies, the pass-band varies and the wavelength of the output laser shifts correspondingly. When the temperature changes from 30 °C to 180 °C, the central wavelength of the EDFL generated by branch A shifts from 1 550.7 nm to 1 560.3 nm, while that of branch B shifts from 1 530.8 nm to 1 540.4 nm, indicating the wavelength interval is tunable. These advantages enable this laser to be a potential candidate for high-capacity wavelength division multiplexing systems and mechanical sensors.
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Dual-wavelength erbium-doped fiber lasers (EDFLs) have attracted much interest in recent years due to their applications in sensing[1] and microwave photonic generation[2]. Because of homogeneous gain broadening, it is difficult to obtain stable dual-wavelength operation at room temperature. Different methods have been proposed to solve this problem, such as cooling of the erbium-doped fiber (EDF) in liquid nitrogen[3], the use of four-wave mixing effect in the highly nonlinear fiber[4], enhancing the polarization hole burning (PHB) by utilizing a fiber Bragg grating (FBG) written in a high birefringence (Hi–Bi) fiber[5] and improving the spectral hole-burning (SHB) effect in the EDF[6]. Recently, new-style Mach Zehnder interferometers (MZIs) are used as fiber filters in fiber lasers[7,8], such as spherical-shape structure[9], single mode-multimode-single mode (SMS) fiber structure[10] and single-mode core-offset structure[11]. And due to their good sensitivities to axial strain, temperature and refractive index, tunable fiber lasers can be achieved. Hui Zou et al[12] proposed a twin-core fiber (TCF) comb filter fabricated by splicing a homemade TCF between two standard single mode fibers. The wavelength of the laser can be tuned from 1 558.04 nm to 1 553.62 nm by applying axial strain on the TCF. However, the procedure is relatively complex. Xia Hao et al[13] exploited a single-mode core-offset structure as 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[14] used a single-mode no-core fiber structure as filter and the wavelength of fiber laser can be tuned based on the refractive index characteristic. However, the cost of no-core fiber is relatively high.

In this paper, a switchable dual-wavelength EDFL with tunable wavelength is demonstrated. Because of the VOAs in the cavity, the wavelength of the laser output is switchable by controlling the cavity loss. Moreover, owing to the sensitive response of the tapered fiber structure to the temperature, the wavelength interval can be adjusted from 9.7 nm to 30.1 nm 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 tapered fiber structure was fabricated by a fusion splicer which consists of two abrupt tapers. Two abrupt fiber tapers made of single-mode fiber (8.2 μm/125 μm) were concatenated to form an MZI filter which is illustrated in Fig.1(a). Compared with the traditional optical MZI structures, the advantage of the MZI filter fabricated by us is the extinction ratio of the spectrum can be controlled when fabricating the taper. The length of the middle jacket-off single mode fiber is 36 mm and the waist diameter of the left taper d_1 is 38 μm. When fabri-

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cating the second taper, the manual mode was used to operate. Adjust the discharging current strength constantly while observing the spectrum. When the output spectrum is stable and has a maximum extinction ratio, the waist diameter of the right taper d_2 is 35 μm. This method to fabricate tapered structure as fiber filter may be beneficial to generate more stable laser with higher side mode suppression ratio (*SMSR*). The microscope image of a representative taper is shown in Fig.1(b). When the light transmits in the core mode and launched into the first taper, part of the light is coupled to cladding modes. After a certain distance transmission, the light will be re-coupled to the core at the second taper and interferes with the rest of the light in the core mode due to the accumulated phase difference between the core mode and the cladding modes. When the VOA is introduced, the loss of the branch can be adjusted to obtain single-wavelength or dual-wavelength laser output.

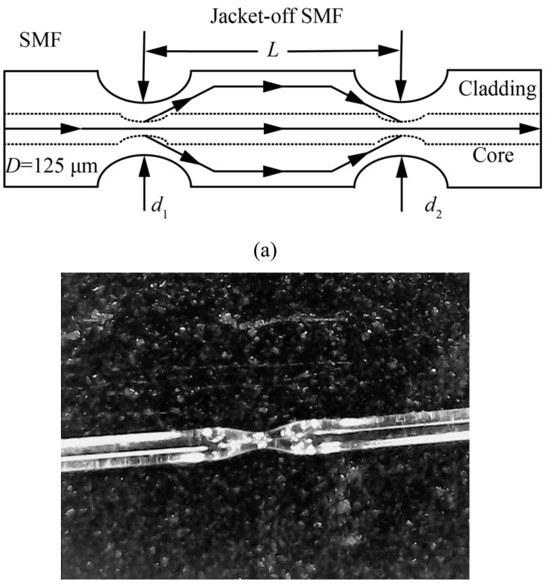


Fig.1 (a) Schematic diagram of the two-taper MZI; (b) Microscope image of a representative taper

The schematic diagram of the proposed experimental setup is shown in Fig.2. A 980 nm laser diode (LD) is used as the pump source and connected to a 7-m-long EDF through a 980 nm/1 550 nm wavelength division multiplexer (WDM). The other end of the EDF is then connected to an optical isolator (ISO) which is used to suppress the undesired reflection and ensure the light transmission in the same direction. When the light reaches the 50:50 coupler C_1, it is separated into two paths. 50% of the light goes through one tapered fiber structure in branch A, while the rest of light transmits through the other tapered fiber structure in branch B. The VOAs are used to adjust the losses in branches A and B. The two paths of the light are coupled at another 50:50 coupler C_2, then reach the 10:90 coupler C_3. 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.

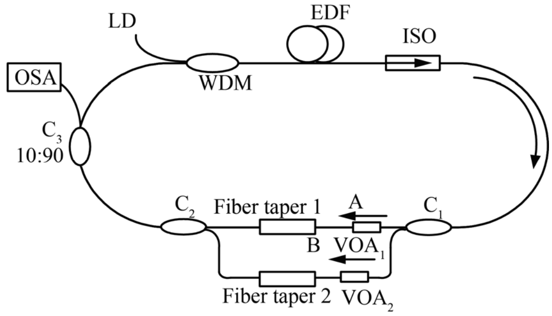


Fig.2 Schematic diagram of the experimental setup

At room temperature, when the attenuation of the VOAs is equal to zero and the pump power is 120 mW, the insertion losses of branches A and B are equal. A dual-wavelength (λ_1=1 530.2 nm, λ_2=1 550.1 nm) laser is produced, as shown in Fig.3. The *SMSR* is more than 43 dB and the output power is more than −13.75 dBm.

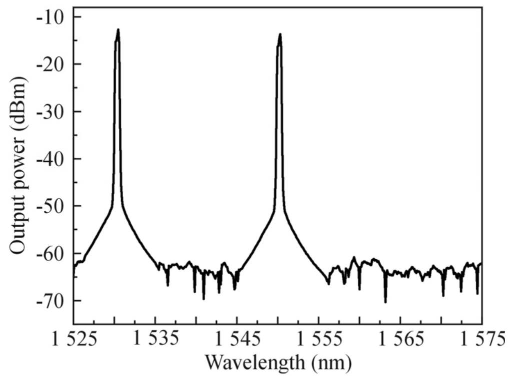


Fig.3 Dual-wavelength output at 1 530.2 nm and 1 550.1 nm

When the attenuation of the VOA_1 in branch A increases, the loss of the branch B is less than that of branch A. As shown in Fig.4(a), the single wavelength can be obtained at the wavelength of λ_1=1 530.2 nm, the *SMSR* is over 48 dB, and the output power is −11.32 dBm. Then, in the same way, changing the attenuation of the VOA_2 in branch B, another single wavelength is obtained at the wavelength of λ_2 =1 550.1 nm, the *SMSR* is over 48 dB, and the output power is −11.37 dBm, as shown in Fig.4(b). Therefore, by adjusting the VOAs, single wavelength operation can be switched between λ_1 and λ_2.

When the attenuation of the VOAs is equal to zero, fix the branches B and A on a furnace successively. When the temperature changes from 30 °C to 180 °C, due to the sensitive response of the tapered fiber structure to temperature, the lasing wavelength moves to the longer wavelength with the temperature increasing as shown in Fig.5. It can be seen that the lasing central wavelength varies from 1 530.8 nm to 1 540.4 nm in branch B, and in branch A it varies from 1 550.7 nm to 1 560.3 nm. That is to say the wavelength interval can be adjusted from 9.7 nm to 30.1 nm when different temperatures are applied. As shown in Fig.6, the peak intensity fluctuation is very little (0.8 dB) along with the temperature increasing gradually. If the stability of the pump LD and the operation surroundings could be improved, a more stable dual-wavelength lasing with tunable wavelength interval would be expected.

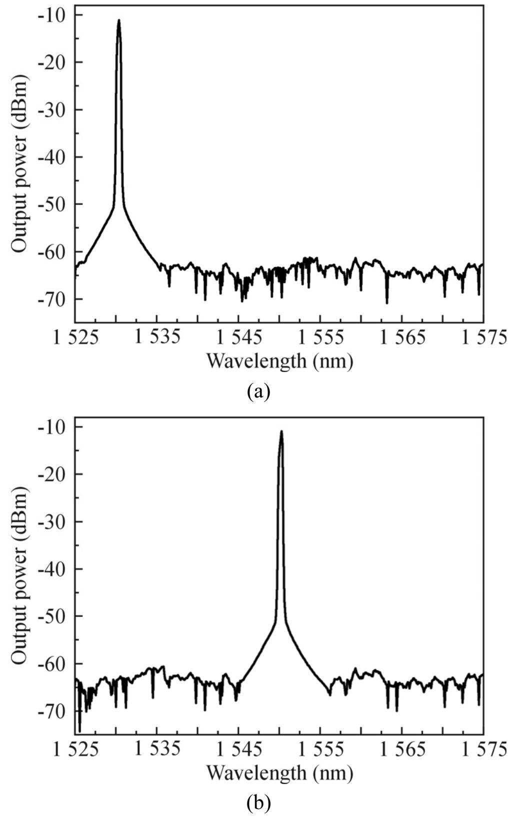
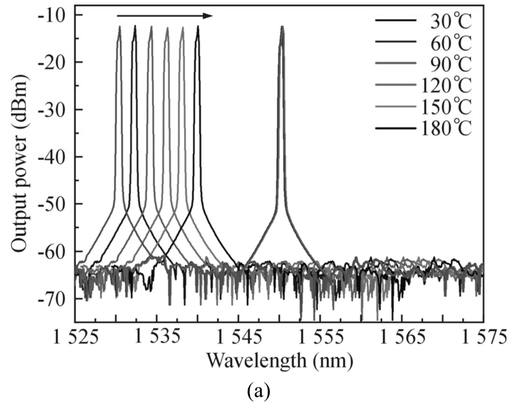


Fig.4 (a) Single-wavelength output at 1 530.2 nm; (b) Single-wavelength output at 1 550.1 nm

A switchable dual-wavelength EDFL is proposed by using two different in-line tapered fiber structures as the fiber filters. By adjusting the VOAs, the laser can be easily switched between single-wavelength mode and dual-wavelength mode. At room temperature, when the



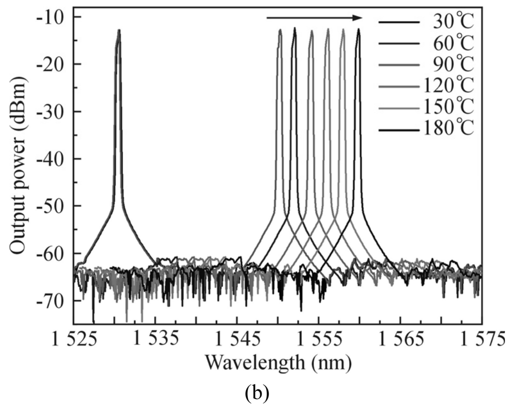


Fig.5 Spectral responses at different temperatures: (a) Output laser of branch B; (b) Output laser of branch A

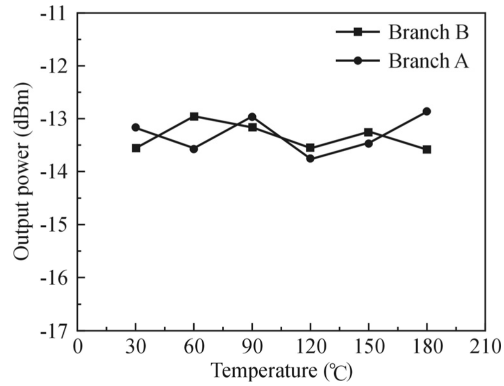


Fig.6 Fluctuations of the output peak intensities against temperature

laser operates at dual-wavelength mode and the pump power is 120 mW, the output peak power is measured to be more than −13.75 dBm and the *SMSR* is over 43 dB, while the output peak power is measured to be more than −11.37 dBm and the *SMSR* is over 48 dB when it operates at single-wavelength mode. The experimental results also demonstrate that when the temperature applied on the structure changes from 30 °C to 180 °C, the wavelength interval can be adjusted from 9.7 nm to 30.1 nm. The power fluctuation is less than 0.8 dB along with the temperature increasing gradually. 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.

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