Tunable fiber laser based on a cascaded structure consisting of in-line MZI and traditional MZI*

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A tunable erbium-doped fiber (EDF) laser with a cascaded structure consisting of in-line Mach-Zehnder interferometer (MZI) and traditional MZI is proposed. The transmission spectrum of the in-line MZI is modulated by the traditional MZI, which determines the period of the cascaded structure, while the in-line MZI's transmission spectrum is the outer envelope curve of the cascaded structure's transmission spectrum. A stable single-wavelength lasing operation is obtained at 1 527.14 nm. The linewidth is less than 0.07 nm with a side-mode suppression ratio (*SMSR*) over 48 dB. Fixing the in-line MZI structure on a furnace, when the temperature changes from 30 °C to 230 °C, the central wavelength can be tuned within the range of 12.4 nm.
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Because of the wide potential applications in the fiber-optic communication system, fiber-optic sensing, and the fiber device testing, tunable erbium-doped fiber (EDF) lasers have attracted great attention[1-3]. For different applications, the researchers took a targeted approach to tuning[4-11]. A single-mode-multimode-single-mode (SMS) fiber structure is introduced in Ref.[12], and the output of the laser can be tuned by changing the axial strain on the multimode fiber. Xiaowei Ma et al[13] proposed a single-mode-hollow fiber-single-mode structure in the laser cavity, which can be tuned by adjusting the liquid level. In Ref.[14], two cascaded tapered structures are used to realize tunable laser output by changing the external temperature of the tapered structure. Filter cascaded technology can better suppress the intra cavity mode competition, achieve stable output laser, and increase the side-mode suppression ratio (*SMSR*). A tunable fiber laser was proposed with a cascaded filter structure based on two twin-core fiber directional couplers, by changing the curvature of a twin-core fiber, and at the pump power of 500 mW, the output laser can be tuned from 1 541.8 nm to 1 560 nm, and the *SMSR* is 58 dB[15]. A Sagnac ring with high birefringence fiber and traditional MZI cascaded filter is proposed in Ref.[16], which can improve the stability of the power and increase the *SMSR*.

In this paper, a novel and simple fiber laser based on a cascaded filter structure using an in-line MZI and a traditional MZI is demonstrated. Among them, the in-line MZI structure consists of two cascaded tapered fiber structures[17], the traditional MZI consists of two 50:50 couplers and a single mode fiber (SMF), and the difference between two arms is 0.8 mm. Compared with the single frequency selective filter structure, the proposed system can increase the *SMSR* and suppress mode competition in the cavity. Owing to the sensitive response of the tapered fiber structure to the temperature, the central wavelength can be changed when different temperatures are applied.

The in-line MZI consists of two tapered fiber structures which were fabricated by a fusion splicer, as illustrated in Fig.1.

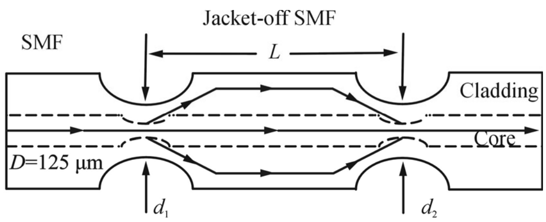

Fig.1 Structure of the in-line MZI

When the light transmits in the core mode and launches into the first taper (the waist diameter d_1 is 39 μm), part of the light is coupled to the cladding modes. After a certain distance (the middle jacket-off SMF is 63 mm long) transmission, the light will be re-coupled to the core at the second taper (the waist diameter d_2 is

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37 μm) and interfere with the rest of the light in the core mode due to the accumulated phase difference φ between the core mode and the cladding modes. It can be expressed as[18]:

$$\phi(\lambda, \Delta n_{\mathrm{eff}}, L) = 2\pi \frac{\Delta n_{\mathrm{eff}} L}{\lambda}\ , \tag{1}$$

where Δn_{eff} is the difference of the effective refractive index between the core mode and the cladding mode, L is the separation length of the two tapers, and λ is the operating wavelength.

When ambient environment varies, the effective refractive index difference, length and resonant wavelength also change into $\delta\Delta n_{\mathrm{eff}}$, ΔL and $\Delta\lambda$, respectively, and the change of the resonance wavelength is as follows:

$$\Delta\lambda = \lambda(\frac{\Delta L}{L} + \frac{\delta\Delta n_{\mathrm{eff}}}{\Delta n_{\mathrm{eff}}})\ . \tag{2}$$

When it comes to temperature, we can take the derivative of Eq.(2) with respect to temperature. It can be obtained by

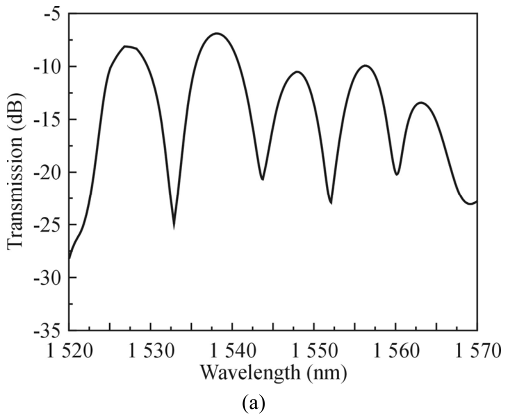
$$\Delta\lambda = \lambda(\frac{1}{L}\frac{\partial \Delta L}{\partial T} + \frac{1}{\Delta n_{\mathrm{eff}}}\frac{\partial \delta\Delta n_{\mathrm{eff}}}{\partial T})\Delta T\ . \tag{3}$$

From Eq.(3), it can be known that the temperature applied on the tapered fiber structure induces a proportional wavelength shift. Therefore, the central wavelength shift of an in-line MZI structure based ring cavity laser is proportional to the temperature.

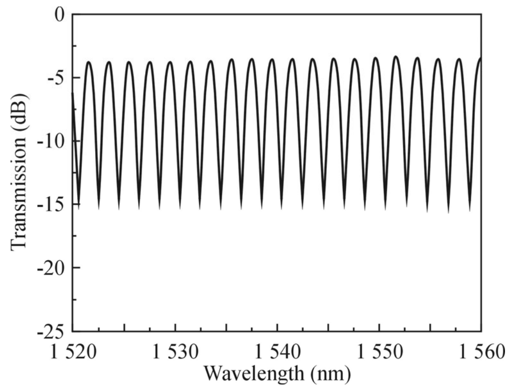
The transmission spectra with the broadband light source of in-line MZI and traditional MZI are shown in Fig.2.

The transmission spectrum of the cascaded filter is shown in Fig.3. Compared with Fig.2, the transmission spectrum of the in-line MZI structure is the outer envelope of the cascaded structure. The in-line MZI is modulated by the traditional MZI, and then the period of the cascaded structure is determined by the traditional MZI. The extinction ratio of the spectrum is higher than before.

Then the in-line MZI structure is fixed on a furnace. When temperature is changed from 30 °C to 230 °C, the superimposed spectral responses at different temperatures are shown in Fig.4.



(a)



(b)

Fig.2 Transmission spectra of (a) in-line MZI and (b) traditional MZI

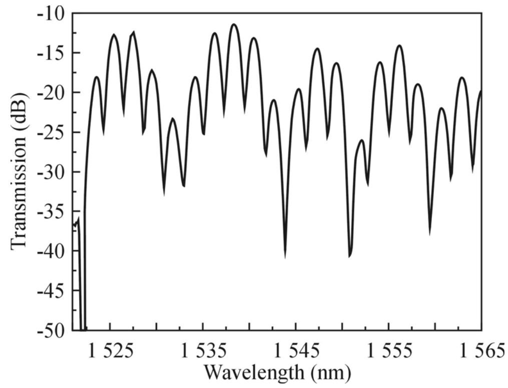
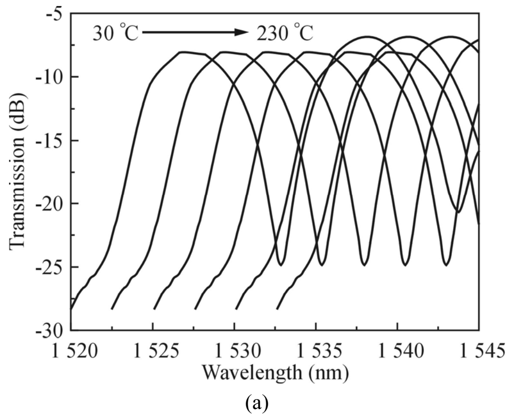
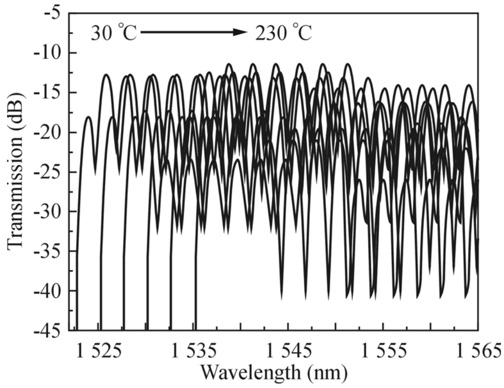


Fig.3 Transmission spectrum of the cascaded structure consisting of in-line MZI and traditional MZI

The proposed schematic diagram of the experimental setup is shown in Fig.5. A 980 nm laser diode 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. After that, the cascaded structure is used as the fiber filter. Then the output from the filter is connected to a 90:10 coupler, where a portion of the output is extracted by the 10% port to an optical spectrum analyzer (OSA) with the resolution of 0.07 nm, and the rest is fed back into the laser cavity.



(a)



(b)

Fig.4 Spectral responses against temperature for (a) in-line MZI and (b) the cascaded structure with temperature interval of 40 °C

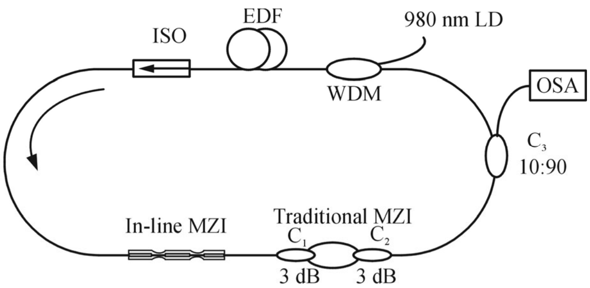
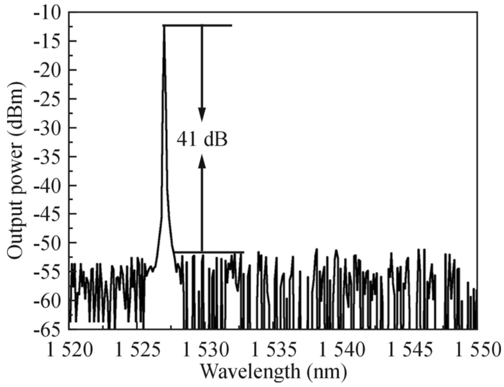


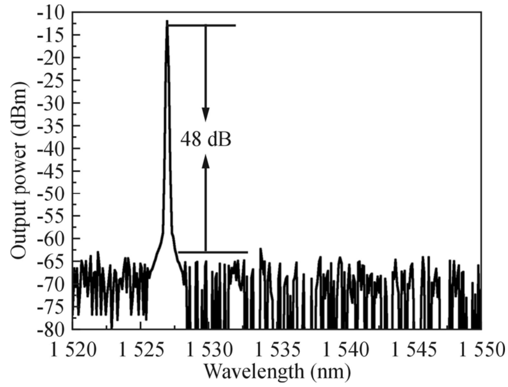
Fig.5 Schematic diagram of the experimental setup

At room temperature, the results of the experiment are shown in Fig.6. Fig.6(a) shows the laser output without the traditional MZI, which has an *SMSR* about 41 dB. When the traditional MZI is added into the laser cavity, a single wavelength at 1 527.14 nm with a linewidth less than 0.07 nm is observed with the pump power of 110 mW. The *SMSR* for the wavelength is 48 dB, much higher than before.

The power and wavelength stability is also investigated. To realize it, we let the system operate in a room environment for a period of 65 min. The fluctuations of the output power and wavelength are shown in Fig.7. The wavelength shift is less than ±0.04 nm and the optical power fluctuation is smaller than ±0.4 dB.



(a)



(b)

Fig.6 The output power of (a) in-line MZI and (b) the cascaded structure in experiment

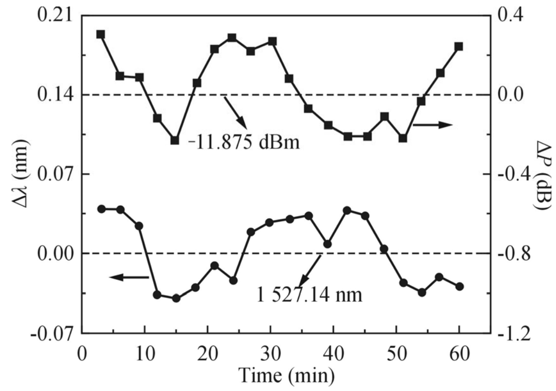


Fig.7 Fluctuations of the output power and wavelength over a period of 65 min

The lasing wavelength of the proposed technique moves to longer wavelength as the temperature increasing as shown in Fig.8. It can be seen that the lasing central wavelength varies from 1 527.35 nm to 1 539.75 nm along with the temperature increasing from 30 °C to 230 °C.

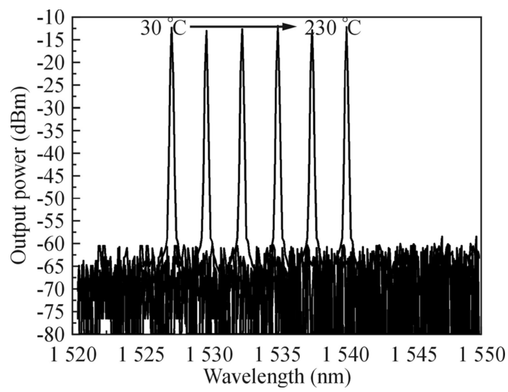


Fig.8 Output power drift with the temperature increasing (40 °C interval)

In summary, a new configuration for a tunable all-fiber ring laser is presented by using a cascaded structure consisting of an in-line MZI and a traditional MZI. The application of cascaded structure increases the *SMSR* of the output laser. A single-wavelength laser is obtained at 1 527.14 nm with the *SMSR* of 48 dB, and the wavelength of the output laser can be tuned from 1 527.35 nm to 1 539.75 nm by changing the temperature from 30 °C to 230 °C. These advantages enable this laser to be a potential candidate in laser sensing system.

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