Study on Tunable Ring Erbium-doped Fiber Laser

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Abstract. Based on the characteristics of erbium-doped fiber (EDF), the wavelength tuning of ring-fiber laser can be realized. Moreover, the laser can work well and stably even when a simple structure of tuning device is adopted. As the pump power of 300 mA is adopted, the output power of the laser is 6.747 mW, and the laser wavelength can be tuned in the range of from 1546.326 nm to 1549.736 nm, as the temperature is elevated from 18.3 ℃ to 109.8 ℃. The drift of center wavelength is linearly related with the temperature. The tuning wavelength have potential applications in the field of photoelectric devices.

1. Introduction
The tunable erbium-doped fiber (EDF) laser usually has the advantages of low laser threshold, high pump efficiency and internal quantum efficiency, substantially tunable parameters and wide tuning range. Hence, EDF laser exhibit important applications in a great number of photoelectric fields, such as, wavelength division multiplexing and time division multiplexing of optical fiber communication network, optical fiber sensing system and modern spectrum technology [1]. Fiber grating is an optical device, and can be used as a tuner which is compatible with optical fiber. From this point of view, fiber grating devices can effectively overcome the insertion loss caused by non-optical fiber tuner, and have been widely used in the tuning properties of optical fiber lasers [2,3]. In this paper, ring-shaped EDF fiber laser is studied in details, it is found that the laser wavelength can be well tuned even when the simple structure of tuning device is maintained.

2. Principles and structure

2.1. Basic principle
Fiber Bragg grating (FBG) is an important optical fiber device, of which the refractive index is periodically modulated, and consequently the optical signal transmitted in the fiber are coupled with different modes. For short-period FBG, the incident light wave satisfying Bragg condition will be coupled into the reflection mode, and the Bragg reflection condition is expressed as:

\[ \lambda_g = 2n_{eff}\Lambda, \]

in which \(\lambda_g\) is the length of the raster region, \(\Lambda\) is the grating period, \(n_{eff}\) is the effective refractive index of the optical fiber core. \(\Lambda\) and \(n_{eff}\) are dependent on the external environment, the changing range is denoted as \(\Delta\Lambda\) and \(\Delta n_{eff}\), corresponding to a shift in the wavelength, as described by the Bragg condition [4,5]. The sensitivity of the central wavelength of FBG is determined by the elastic-optical and thermo-optical properties of the fiber and the stress characteristics of loading. By differentiating equation (1), the change in the central wavelength can be expressed as:
\[
\Delta \lambda_g = 2 \left( \Lambda \frac{\partial n_{\text{eff}}}{\partial L} + n_{\text{eff}} \frac{\partial \Lambda}{\partial L} \right) \Delta L + 2 \left( \Lambda \frac{\partial n_{\text{eff}}}{\partial T} + n_{\text{eff}} \frac{\partial \Lambda}{\partial T} \right) \Delta T ,
\]

in which \( L \) is the length of diffraction grating area, \( \Delta L \) is the longitudinal elongation, \( T \) is the temperature of fiber Bragg grating. It can be found from equation (2) that the shift of reflection wavelength is related to the changed refractive index of the optical fiber core and grating constant. \( n_{\text{eff}} \) and \( \Lambda \) will be changed when FBG is subjected to axial stress or elevating temperature. As well known, the temperature controlling method is not substantial in tuning properties of FBG, but the mechanical tuning method exhibits good mechanical stability and repeatability [6].

2.2. Basic structure and experimental parameters

A 1480 nm laser diode was used as the pumping light source in the experiments, the maximum output power of the tail fiber is 300 mW, the central wavelength is 1473.92 nm, the threshold current is 24.8 mA, and the maximum pumping current is 1300 mA. As shown in Figure 1, the output light power of the laser diode almost displays a linear relationship with the pumping current. The fiber doped with 700 ppm erbium is adopted, of which the cut-off wavelength is 853.5 nm, the peak absorption coefficient at 1480nm is 2.8dB/m, the mode field diameter is 6.68um, the background loss is less than or equal to 50 dB/Km at 1200 nm, and the numerical aperture is more than or equal to 0.2. Through structural design and experimental verification, it is demonstrated that the optimized EDF length is 8 m. Erbium-doped fiber amplifier (EDFA) is used as the resonant cavity of the wavelength tunable laser, in which the light wave with the wavelength of 1550 nm oscillates back and forth to generate laser. The AQ6319 spectrometer of ANDO is used to measure the laser power and the wavelength. The minimum resolution of the spectrometer is 0.01 nm and the measurement range is from 50 nm to 2250 nm.

Figure 2 shows the experimental setup. The ring cavity is composed of a wavelength division multiplexer (WDM), an EDF, an isolator (ISO), a coupler and a FBG connected to one end of the coupler. Pump light is coupled to erbium-doped fiber using a 1480/1550 nm WDM. The wavelength range of the isolator used is 1528 ~ 1565nm. The main purpose of isolator ISO is to allow the propagation of signal light along the transmission direction, in order to eliminate the reverse interference and to protect the signal source. The noise coefficient of EDFA can be considerably reduced and the stability of the laser output can greatly be improved. The ratio of fiber coupler used is 30:70.
The 1480 nm laser diode with a forward pumping structure is adopted in this work. The signal light is incident into the erbium-doped fiber in the same direction as the pumping light. The pumping light stimulates the erbium-doped fiber through WDM directly. The number of erbium ions in the fiber will be reversed as the pumping light passes through the fiber, and the stimulated light will be reflected by the fiber Bragg grating and then returns to the WDM as a signal light. After repeated cycles, the light will be amplified many times to generate a laser. The output of the laser is tuned by changing the temperature of the grating but the pumping power is maintained as a constant. When the temperature of fiber grating is elevated, the effective refractive index will increase due to the thermo-optical effect of fiber materials. Moreover, the grating period will also be increased due to the effect of thermal expansion and cold contraction. In such a case, the central wavelength of the fiber grating is tuned. The fiber grating is heated by 202A-0 electric heating oven manufactured by Tianjin tester instrument co., ltd. And the temperature is elevated from 18.3 °C gradually up to 109.8 °C by a step of 10 °C. For given temperature, the system is stabilized for 10 minutes and, the central wavelength and bandwidth of the laser output on the spectrometer are measured.

2.3. Result and discussion
The measured laser threshold current is 70 mA, and the output optical power tends to be stable at the pump current of 150 mA. After the operating current is increased up to 750 mA, the output optical power becomes the most stable, suggesting that the optimal operating current of the laser diode is 750 mA. The output power of the laser increases with pumping power, and the bandwidth of the laser becomes narrow. Therefore, the output laser quality might be substantially improved through increasing the pump power.

The pumping current of 300 mA and the output power of 4.169 mW are selected, and Bragg grating is adopted as a filter. As the temperature of optical fiber grating is elevated from 18.3 °C to 109.8 °C, the reflected light wavelength is drifted by 3.41 nm, that is, the wavelength is drifted by about 0.4 nm, and the bandwidth is broadened by around 0.001 nm per 10 °C. The drift of center wavelength is linearly related with the temperature. As shown in Figure 3, the spectral width varies uniformly. Figure 4 displays the output laser spectra, when the temperature of optical fiber grating is 37.8 °C.

3. Conclusion
In the ring laser cavity, the continuously tuned narrow-band laser is generated with a fiber grating as the filter. The output wavelength of the laser is tuned by changing the temperature of the fiber grating. As the temperature is increases, the bandwidth of the laser output is widened and the center wavelength of the laser output is drifted substantially. The center wavelength of the output light changes with the temperature linearly. The ring laser exhibits good stability and tenability even with a simple structure.
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