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Wavelength-switchable erbium-doped fiber ring laser employing a chirped Moiré fiber grating

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Abstract A simple and cost-effective wavelength-switchable fiber ring laser based on a chirped moiré fiber grating (CMFG) and an erbium-doped fiber amplifier (EDFA) is proposed, and stable wavelength lasing oscillations at room temperature is experimentally demonstrated. To serve as a wavelength selective element, the CMFG possesses excellent comb-like filtering characteristics including stable wavelength interval and ultra-narrow passband, and its fabrication method is easy and flexible. The measured optical signal-to-noise ratio reaches the highest value of 50 dB and the power fluctuation of each channel output is less than 0.5 dB within an hour. The output laser power of different channels is almost identical (difference of less than 1 dB) within the tunable range. Methods to optimize the laser performance are also discussed and the superiority of the CMFG is experimentally demonstrated.

Key words fiber optics; fiber laser; erbium-doped; chirped moiré grating

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1 Introduction

Fiber lasers exhibit many attractive features such as inherent single transversal mode and compatibility with optical fiber systems. In recent years, there is a surge of interest in multi-wavelength and wavelength-switchable fiber lasers, since they are potentially useful for dense wavelength division multiplexed (DWDM) fiber communication systems, optical fiber sensor networks, and spectroscopy. The most important key component of these fiber lasers is a wavelength selection filter. Among versatile techniques[1~14], a fiber Bragg grating (FBG) is an ideal intra-cavity device to select the lasing wavelength, for example, the FBG written in multimode fiber[5,6], cascaded FBGs[7-13], and FBGs in Sagnac loop[14]. The FBG has significant advantages such as fiber compatibility, superior spectral reflectivity, and cost effectiveness. For the implementation of wavelength switching, various techniques have been used based on polarization control of the laser cavity[5,6] or fiber loop mirror[14], variable optical attenuator (VOA) between cascaded FBG segments[7], control of Raman pump[8], polarization control of high-birefringence fiber grating[10], spectral polarization-dependent loss element[11], amplitude modulator[12], and optical bi-stability[13]. However, most of these methods are limited to only 2 or 3 switchable wavelengths and the individual switching of each FBG cannot be accomplished yet.

In this paper, the chirped Moiré fiber grating (CMFG) written in normal hydrogen-loaded optical fiber is chosen to implement wavelength selection. The CMFG is an ideal transmissive comb filter with stable wavelength spacing, narrow filtering bandwidth, and uniform channel transmittance. It has extra advantages of easy fabrication, compactness, and flexible tuning of wavelength interval within a large band depending on the chirp value. A simple ring laser configuration based on a five-passband CMFG as an wavelength selective element is proposed. Stable wavelength-switchable lasing oscillations with wavelength spacing of about 0.25 nm have been experimentally demonstrated. The measured optical signal-to-noise ratio reaches the highest value of 50 dB and the power fluctuation of each wavelength is less than 0.5 dB within an hour.

2 Principle of the CMFG and laser configuration

A CMFG consists of two superimposed linearly chirped FBGs (CFBGs), which have the same chirp value and peak index modulation, but different central wavelengths. Usually, it can be formed by writing two CFBGs successively into the same part of a fiber and using the same phase mask with only

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a small longitudinal offset D between the double exposures which are adopted in this paper and depicted in Fig.1. In essence, the moiré technique makes the refractive index modulation of the fiber core have a slowly varying sinusoidal envelope and introduces a π-phase-shift between two closely spaced sections of grating, resulting in the formation of one or more ultra-narrow passbands. For a given chirp, the interval of the passbands can be tuned by the offset D while the channel number is related to D and the grating length L[15]. This fabrication method obviously possesses a great advantage of repeatability and flexibility.

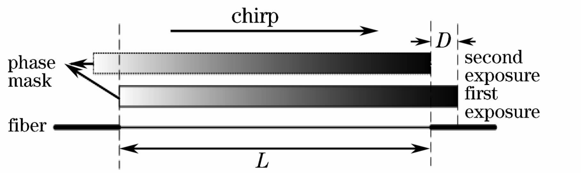

Fig.1　Fabrication of CMFG by dual-exposure with chirped phase mask

The schematic of the experimental setup for the proposed wavelength-switchable fiber ring laser is shown in Fig.2. A CMFG containing five transmission peaks is incorporated in the ring cavity serving as a comb-like multi-channel filter to provide periodic loss in the spectrum domain for multi-wavelength lasing.

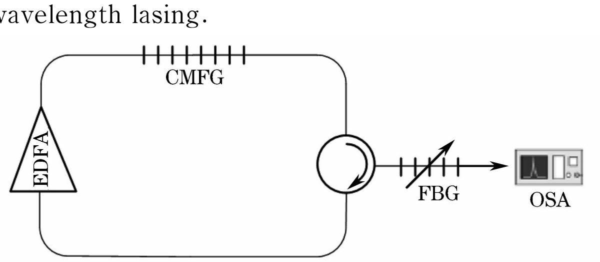

Fig.2　Schematic of the experimental setup

A uniform fiber Bragg grating (UFBG) owing a reflectivity of about 90% and a narrow bandwidth of 0.05 nm is utilized as the wavelength-tunable reflective mirror and the output port of the laser. Fig.3 displays the measured reflective spectrum of the UFBG and the transmission spectrum of the CMFG. The peak wavelength of the former is tuned by precise temperature controlling to align with one of the five peak wavelengths of the latter, and lasing will occur at the wavelength of that channel. The circulator in the ring cavity provides unidirectional lasing oscillation. An optical spectrum analyzer (OSA, ANDO AQ6319) with the highest resolution of 0.01 nm is used to do all the measurements. It should be noted that the observed transmittance non-uniformity of five narrow transmission peaks of the CMFG in Fig.3 is limited by the scanning resolution of the OSA.

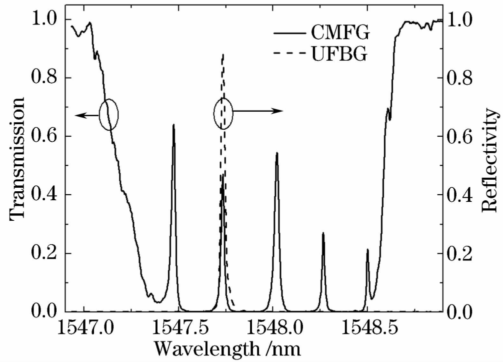

Fig.3　Reflective spectrum of the UFBG and transmission spectrum of the CMFG

Initially, the amplified spontaneous emission (ASE) from the erbium-doped fiber amplifier (EDFA) passes through the CMFG which is supposed to act as a comb filter and the five needed in-band elements along with the extra-band light is left. Then the uniform FBG cooperated with the circulator will pick out one of the five elements by tuning its peak wavelength and reflect most of the needed light back to the ring structure. The selected element is subsequently amplified by the EDFA. After passing through the CMFG and reflected by the UFBG, a larger portion of the selected wavelength power is reintroduced to the EDFA and reinforced. Such a process will continue until overall gain of the EDFA is equal to the loss of the cavity and a stable lasing operation can be established.

3　Experimental results and discussion

The tuning result of the fiber laser is shown in Fig.4. When the UFBG is tuned continuously, lasing operation occurs at 1547.494, 1547.750, 1548.016, 1548.274, and 1548.504 nm corresponding to the five peak wavelengths of the CMFG. The output power difference among the five lasing oscillations is less than 1 dB and the optical signal-to-noise ratio of each laser output is about 50 dB. The −3 dB

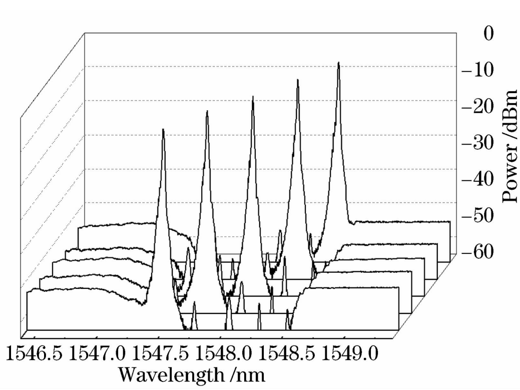

Fig.4　Measured individual lasing output spectrum of the fiber laser

bandwidth of each laser output spectrum is only ~12 pm. Sixteen successive scans of the system output with a time interval of five seconds are carried out, and the result of lasing at 1547.75 nm is recorded in Fig. 5, which indicates a good short-time wavelength stability of the laser. In order to study the long-time stability of the multi-wavelength operation at room temperature, the output power fluctuation at each peak wavelength is measured for an hour and it is less than 0.5 dB.

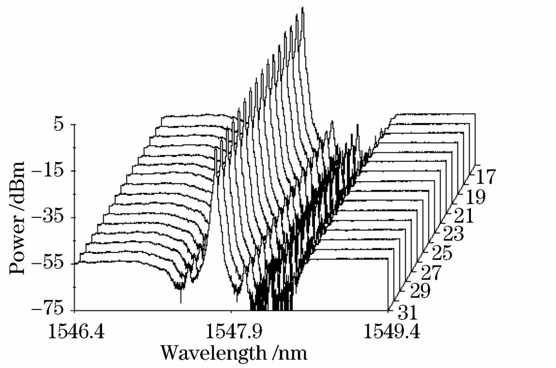

Fig. 5 Measured lasing output spectra with sixteen times repeating scans

In the experiment, connecting joint of every two components in the laser configuration is active FC-PC joint and this increases the cavity loss. By replacing the active joints with splicing ones, lower threshold and higher output power can be obtained.

The phase mask with which the CMFG is fabricated has a chirp of 1 nm and five transmission peaks with an interval of 0.25 nm are achieved. With this phase mask, variable wavelength amount and interval can be realized by precisely tuning the offset D during the grating fabrication process, but all the transmission peaks of the CMFG are limited in the bandwidth determined by the phase mask period and the fiber parameters. More wavelengths and wavelength interval meeting the DWDM requirements are expected when using a phase mask with a higher chirp value.

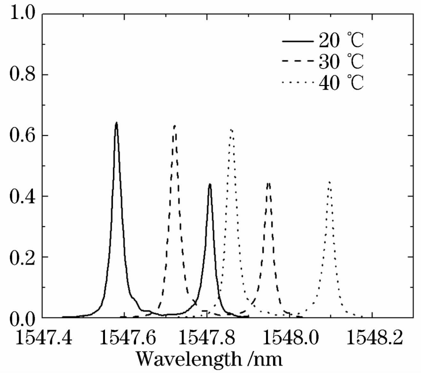

Fig. 6 Transmission temperature property of CMFG

We also experimentally investigated the temperature dependence of the CMFG and the results are shown in Fig. 6. The transmission-peak wavelengths shift with the temperature simultaneously and have the same temperature coefficient as the normal FBG. Therefore, the lasing wavelength can be fine tuned by controlling the temperature of the CMFG and the uniform FBG, keeping the wavelength spacing invariant. Moreover, the lasing wavelength can also be tuned continuously over the wavelength range that the two gratings can sustain. From Fig. 6, it is obvious that the transmittances of the transmission peaks remain the same when the temperature is changed. Large fluctuation of the lasing output power is prevented which may be caused by the transmission property change of the CMFG filter.

Lasing operation can also be established even though the CMFG is not inserted in the ring cavity. To verify the superiority of the CMFG, a comparison of the lasing output is given in Fig. 7 when the stop-band of the UFBG overlap with one of the five passbands and is away from the band of the CMFG. It is clear that the optical signal-to-noise ratio is remarkably raised by the use of CMFG.

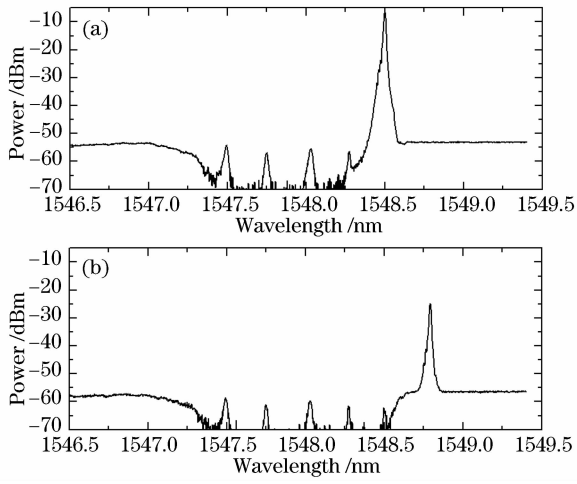

Fig. 7 Laser output comparison with CMFG (a) and without CMFG (b)

4 Conclusion

A simple and cost-effective wavelength-switchable erbium-doped fiber ring laser based on an EDFA and a CMFG has been successfully demonstrated. The laser output powers of different channels are almost identical (difference less than 1 dB) within the tunable range. The measured optical signal-to-noise ratio of every laser output reaches the highest value of 50 dB and the output is stable at room temperature with small intensity variation, which is less than 0.5 dB during an hour. It is the ultra-narrow comb filtering characteristic of the CMFG that the proposed fiber laser can accomplish multiple wavelength switching and high optical signal-to-noise ratio. Besides, the fabrication technology of CMFG is less expensive and more flexible. All these make it an excellent wavelength selective component in the lasing operation. This laser scheme presents a simple and cost-effective solution to produce wavelength-switchable lasing oscillation at room temperature. It has wide applications in optical sensing, optical telecommunication and instrumentation.

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