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Tunable Channel Spacing of Dual-wavelength Erbium-doped Fiber Ring Laser using a Single Fiber Bragg Grating with Two Coil Heaters

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Abstract : Stable and tunable dual-wavelength erbium-doped fiber ring laser (EDFL) using a single fiber Bragg grating (FBG) and two coil heaters is proposed and demonstrated. Installing two identical coils into a single FBG, the FBG is symmetrically divided into two different portions. While a current supply to the coil, the refractive index of the FBG under the coil is changed. The FBG can operate as a joint of two different FBGs. Due to the thermo-optic effect of a fiber, the resonance wavelength split into two peaks. The spacing between two adjacent channels was changed as much as the difference of heating power. It was tuned up to 3 ㎚ of wavelength under the electrical power with a 1000 ㎽. Moreover, the lasing wavelength can be individually tuned without influencing to the adjacent channel.

Key words : Dual wavelength laser, Fiber bragg grating, Erbium-doped fiber, Tunable fiber ring laser, Thermo-optic effect

1. Introduction

Multi-wavelength fiber lasers working at room temperature are of great interest as attractive optical source in wavelength-division multiplexed (WDM) communication systems, optical sensors, and various photonic applications. Several methods for multi-wavelength operating at room temperature have been investigated, which include frequency-shifted feedback[1], Sagnac loop interferometer[2],[3], the use of high birefringence fibers[4]-[5], and distributed Bragg reflector[6]. Recently, dual-wavelength fiber laser using a single fiber Bragg grating (FBG) written on the splice joint between two different fibers was reported[7]. The shift in resonance wavelengths was achieved by temperature change but it was not able to tune the channel separation. Some researches have proposed other technologies for varying the space of resonance wavelength[3]-[8]. But they require different FBGs, comb filters, or nonlinear materials. These configurations are not simple, economy, and practical.

In this study, a dual-wavelength EDFL based on a single-gain medium and a single FBG written on the standard

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single-mode fiber (SMF) is proposed and demonstrated. In order to dual wavelength operation, two identical coil heaters are prepared to control the refractive index of a FBG. The FBG area of a fiber is inserted into the coils and divided into two regions. According to the refractive index change by heating power, the channel spacing and resonance wavelength can be changed. A stable dual-wavelength operation at room temperature was guaranteed by the symmetric separation of the reflection peak of the FBG.

2. Operating Principle and Design

When a FBG experiences temperature variation, Bragg wavelength will be shifted by the refractive index change of a fiber and the fiber elongation. Shift in Bragg wavelength $\varDelta\lambda_B$ is given by differentiating the Bragg wavelength.

$$\lambda_B = 2n_{eff}\varLambda \quad (1)$$

$$\varDelta\lambda_B = 2\varDelta n_{eff}\varLambda + 2n_{eff}\varDelta\varLambda \quad (2)$$

where n_{eff} is the unperturbed effective refractive index, $\varDelta n_{eff}$ is the refractive index change, $\varLambda$ is the Bragg grating period, and $\varDelta\varLambda$ is the fiber elongation. Under the circumstances of noexternal perturbation except temperature, the first term on the right-hand side of Eq. (2) is dominant because the thermally induced fiber elongation is relativelysmall to the change of refractive index. Such variation of refractive index caused by the temperature change is given by

$$\frac{\varDelta n}{n} = \left(\frac{\partial n}{\partial T}\right)_\rho \frac{\varDelta T}{n} + \left(\frac{\partial n}{n}\right)_T = \left(\frac{\partial n}{\partial T}\right)_\rho \frac{\varDelta T}{n} - \frac{n^2}{2}\left[(P_{11}+P_{12})\epsilon_r + P_{12}\epsilon_z\right] \quad (3)$$

where P_{11} and P_{12} are the Pockels coefficients of the core and ε_r and ε_z are the radial and the axial stain in the core, respectively. The first term on the right-hand side of Eq. (3) represents variation of refractive index as a function of temperature and second term is related to the photo-elastic effect expressed in terms of the strains and Pockels coefficients. Fora bare FBG, the second term on the right-hand side of Eq. (3) is negligible due to comparatively small change of the strain in the core. Note that the refractive index of a single FBG written on a commercial single-mode fiber can be partially changed by means of a local heating of the FBG region. In this study, two coils are used for dividing and heating the FBG.

The configuration of proposed tunable dual-wavelength EDFL is shown in Fig. 1

The power of 980 nm pump laser is launched into the erbium-doped fiber (EDF) with a length of 10 m, which is used as a gain medium. A single FBG is connected to the laser cavity via the 3-dB coupler. In order to separate the FBG with a length of 2mm to two parts, two coil heaters are fabricated using Ni-Cr wire, which has a diameter of 200 ㎛ and a resistance of 153Ω m. The radius of the coil is about 160 ㎛ but the resistance of coil1 is 38 Ωnd the other one is 48 Ω By inserting the fiber into the coils, the FBG is installed as shown in Fig. 1 (b). If the different current is individually applied to the coils, a single resonance wavelength will be split due to the difference of refractive index change of the two parts of FBG.

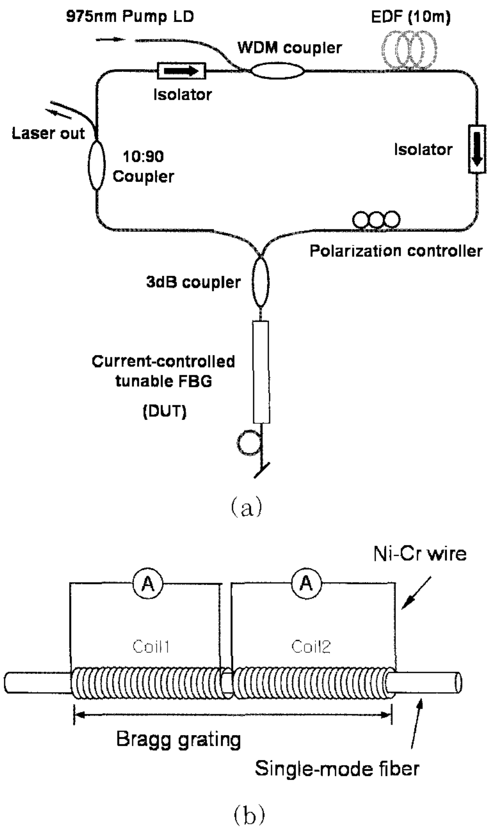


Fig. 1 (a) Schematic diagram of proposed tunable dual-wavelength EDFL and (b) current-controlled tunable FBG with two coil heaters

3. Results and discussion

The reflection spectra of the FBG in terms of the change of applied current are shown in Fig. 2. Two current sources are used for generating the electrical power of the coil heaters, respectively. When the current of 30 mA and 70 mA are supplied to the coil1 and coil2, respectively, the reflection spectrum is slightly separated as much as 1.3 nm. In this experiment, the reflection peaks are appeared at 1548.56 and 1547.22 nm. More difference of two currents is induced more channel separation between two peaks, as shown in Fig. 2 (b). One can notice that one channel can be precisely controlled without affecting the neighbors.

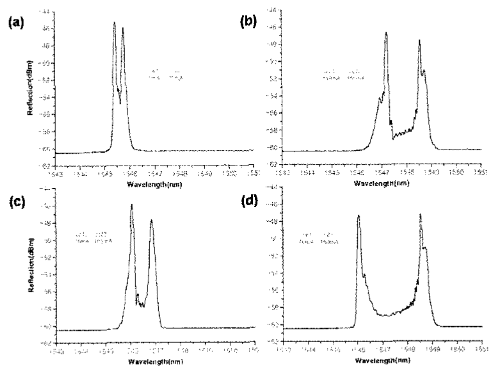


Fig. 2 Reflection spectra of the FBG with different current to the coil 1 and the coil 2. (a) coil 1: 30mA and coil 2: 70mA, (b) coil 1: 110mA and coil 2: 150mA, (c) coil 1: 70mA and coil 2: 100mA, and (d) coil 1: 70mA and coil 2: 150mA

Fig. 2 (c) and (d) show the reflection spectra when the current of coil2 is changed 100mA to 150mA during the current of coil1 is kept in 70mA. The reflection peak which is controlled by the coil2 moves to the longer wavelength while another one is unchanged. The fact that the reflection peak of a FBG is split and tuned give some hints to realized the tunable spacing of dual wavelength EDFL. To implement the stable and tunable dual-wavelength EDFL, the proposed FBG with two coils is connected to the fiber laser configuration via 3 dB coupler as shown in Fig. 2 (a). Note that the reflection spectra shown in Fig. 2 are almost symmetrically separated. If the gain balance for two different wavelengths in EDFL is not guaranteed, one can not expect stable dual-wavelength lasing at the room temperature due to the homogeneous line broadening of EDF as a gain medium. With the uniform structure of the coil and symmetric installation into the FBG, dual wavelength operation is easily established.

Fig. 3 shows the measured output spectra of the tunable EDFL during the current applied two coils changes. The EDFL shows only one lasing wavelength (solid line) while there is no current to the coils. When the current of 100 ㎃ flows to the coil2 (dotted line), the FBG acts as the connection of two different FBGs. This phenomenonis based on the thermally-induced refractive index change of the fiber by the coil heaters.

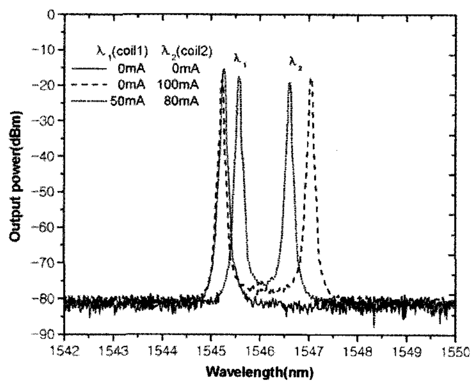


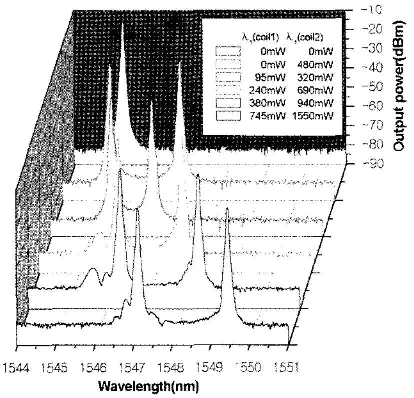
Fig. 3 The optical spectra for showing tunable channel spacing of the dual-wavelength EDFL by the current change. The current induces the separation of the resonance peak

The wavelength separation, $\lambda_2 - \lambda_1$ is about 1.8 ㎚ and the side-mode suppression is over 60 ㏈. The resonance wavelength of another half of the FBG is not affected. The current to the coil1 increase 0mA to 50mA and coil2's current decreases 100mA to 80mA, λ_1 moves to longer wavelength and λ_2 goes to shorter wavelength (short dotted line). The shift in each lasing wavelength is only dependent on the heating power provided to the each coil.

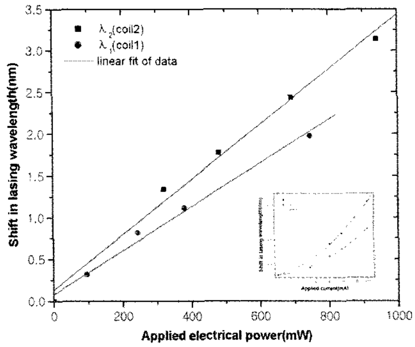
The relationship between absolute wavelength position and electrical power to each coils is demonstrated. Fig. 4(a) depicts 3-dimentional output power spectra for showing the tunable resonance wavelength and changeable wavelength spacing during the electrical power varies up to 1550mW. The single FBG with two coils are well acting as two reflectors inside the ring cavity. But the careful adjustment of the state of polarization using polarization controller was needed for obtaining the continuous dual-wavelength operation. The relationship between shift in lasing wavelength and applied electrical power is represented in Fig. 4(b). When the applied current is transformed to the electrical power, the shift in resonance wavelengthis linearly proportional to the electrical power. Since the peaks are separately controlled by the coil heater, the channel spacing can be varied up to 3-㎚ wavelength under the electrical power of 1000 ㎽. From the linear fitting of the measured data, the electrical power sensitivities of the resonance wavelengths for coil 1 and coil 2 were about 2.7 pm/㎽ and 3.3 pm/㎽, respectively.

The stability of the dual-wavelength EDFL for the different current is shown in

Fig. 5. The repeated measurement results of the output power are scanned seven times for 5 minutes. Applying the current of 110 ㎃ to the coil 2 and no current to the coil 1, the laser output are very stable as shown in Fig. 5(a). When the current is simultaneously supplied to the coil1 and coil 2 as much as 80mA and 120mA, respectively, the oscillation is also quite stable. The variations of peak powers are less than 1 dB.



(a)

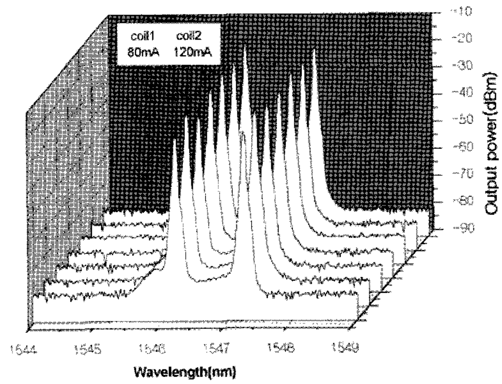


(b)

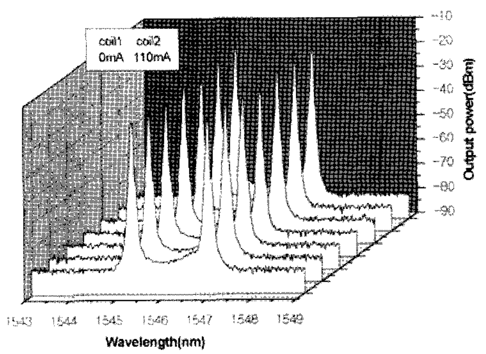
Fig. 4 Shift in dual wavelengths of the EDFL as a function of an electrical power. (a) 3-dimentional transmission spectra versus electrical power and (b) The linear relationship between electrical power and shift in resonance wavelength

4. Conclusion

Stable and tunable dual-wavelength EDFL has been successfully demonstrated by incorporating two identical coil heaters on a FBG. Based on the thermo-optic effect of a fiber, the refractive index of a single FBG is separately controlled by two coil heaters. By adjusting the current supplied to the coils, each resonance wavelength was independently tuned without interference of the adjacent wavelength position. The difference of



(a)



(b)

Fig. 5 The stability of the dual-wavelength EDFL (7 times repeated scans). (a) The current is supplied to the coil 2. The coil 1 has no current and (b) the different currents flow to the two coils

electrical power supplied to the coils is linearly related to the channel spacing between two resonance wavelengths. Maximum wavelength separation of 3 ㎚ at a 1000-㎽ of electrical power is achieved. The proposed dual wavelength fiber laser is able to use the sensing element of optical fiber sensor applications and tunable source of optical fiber communications.

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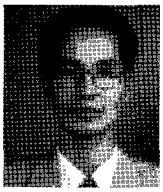

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