Dual wavelength erbium-doped fiber laser with a lateral pressure-tuned Hi-Bi fiber Bragg grating

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Tunable dual wavelength erbium-doped fiber laser (EDFL) with stable oscillation at room temperature is proposed and demonstrated. This laser utilizes a Bragg grating fabricated in a high birefringence fiber as the wavelength-selective component, and then achieves the stable dual wavelength oscillation by introducing the polarization hole burning effect. Furthermore, by applying lateral strain upon the fiber Bragg grating (FBG), the space of the laser dual wavelengths can be tuned continuously.

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Multi-wavelength fiber lasers have attracted a lot of interest in recent years because of its potential applications in optical wavelength division multiplexing (WDM) systems, fiber sensors, and fiber-optics instrumentation. Because of the predominantly homogeneous line broadening of an erbium-doped fiber laser (EDFL), the gain cross-saturation between different wavelengths prevents the building of simultaneous multi-wavelength oscillation in it.

Various technologies to reduce the wavelength competition have been applied to achieve stable multi-wavelength oscillation. One effective method is to reduce the large homogeneous broadening linewidth by cooling the erbium-doped fiber in liquid nitrogen (77 K)[1,2], but it is not well suited to practical applications. Many other methods for operation of EDFL at room temperature are investigated. Stable multi-wavelength operation was demonstrated by using a specially designed erbium-doped twincore fiber to introduce inhomogeneity to fiber[3]. Using an elliptical core erbium-doped fiber as gain media is also able to achieve that purpose due to its inhomogeneity[4]. A structure employing polarization hole burning effect for achieving stable dual-wavelength oscillation at room temperature, in which a Bragg grating on a high birefringence fiber was used, was proposed[5]. However, in that structure, the two laser output wavelengths interval is only fixed at 0.23 nm, because the birefringence property in the high birefringence fiber is fixed.

In this paper, we demonstrate a tunable dual-wavelength EDFL operating at room temperature with the use of a birefringence fiber Bragg grating (FBG) applied the lateral strain on. The wavelength space of this laser can be tuned by changing the lateral strain on it, mainly due to the strain-optic effect. The configuration of the laser is shown in Fig. 1. The laser linear cavity is formed between a Sagnac fiber loop mirror and a Bragg grating inscribed in a birefringence fiber. The fiber loop mirror is used as a perfect reflective component. A polarization controller (PC) is inserted in the cavity, through which we can control the state of polarization (SOP) of light in the cavity. The gain medium is a 12-m-long erbium-doped fiber whose doping concentration is 400 ppm. The erbium-doped fiber is pumped by a 980-nm diode laser with 100-mW output power, and the pump light is coupled into the gain medium through a 980/1550-nm WDM coupler. In order to tune the wavelengh space of the laser, the Hi-Bi FBG is placed in a tuning frame, which is shown in the inset of Fig. 1. The tuning frame is made of two pieces of perspex and a screw. The Hi-Bi FBG, along with a support bare fiber keeping the balance of tuning frame, is put between such two pieces of perspex and can be imposed with a lateral strain by screw. The output spectra of the laser are monitored by an optical spectrum analyzer with the resolution of 0.1 nm.

The laser output spectrum of Hi-Bi FBG without being tuned is illustrated in the Fig. 2. As shown in this figure, the side mode suppression ratio (SMSR) is 38 dB, and the peak power of each wavelength is −11.21 dBm. The dual wavelengths of the laser are observed at 1556.66

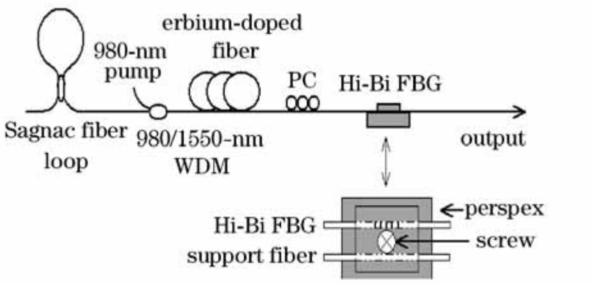

Fig. 1. Experimental setup of the tunable dual-wavelength EDFL.

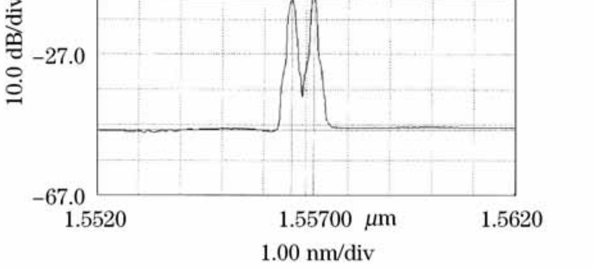

Fig. 2. Output spectrum of dual-wavelength EDFL without being tuned.

and 1557.18 nm, respectively, and the wavelength space is 0.52 nm, which is very well coincided with the theoretical result. Because the beat length of our Hi-Bi fiber is 3.1 mm in the wavelength region of 1550 nm, the wavelength space of a Bragg grating written in it is approximately 0.52 nm corresponding to the Bragg wavelength difference between the birefringence axes.

By monitoring the dual-wavelength oscillation for a long time, we can find that the two wavelength light power can be maintained stably at the room temperature. This stable oscillation is owing to the introducing inhomogeneous broadening of the gain by the polarization hole burning effect, which is explained below. Unlike the normal single-mode FBG, a Bragg grating inscribed in a section of Hi-Bi fiber has two reflective peaks corresponding to the Bragg wavelengths of the fast and slow axis of the Hi-Bi fiber, respectively[6]. Besides, the polarizations of two reflective peaks are orthogonal polarization mode of the Hi-Bi fiber. Feedback of a FBG in a Hi-Bi fiber would excite two linearly polarized longitudinal modes that are separated both in wavelength and polarization in the laser cavity. As a result of the polarization hole burning effect[7], two orthogonal polarization modes, which are selected by the Hi-Bi FBG, can be oscillated simultaneously.

When adjusting the PC, we can achieve three lasing states: 1) single wavelength lasing at 1556.66 nm, 2) single wavelength lasing at 1557.18 nm, 3) dual-wavelength lasing at both two wavelengths. This suggests that adjustments on PC effectively change the intracavity losses for both of the fiber laser polarization eigenstates, corresponding to the Hi-Bi FBG's two wavelengths. In the first state, the adjustments on PC produce different thresholds for each of the modes, therefore the polarization mode of 1556.66 nm is excited due to its low threshold. In the second state, the other mode is excited with the same principle. In the last state, both wavelengths are lasing due to the same thresholds for both modes.

Using tuning frame to apply a lateral strain on the Hi-Bi FBG, we can change the wavelength space of the dual-wavelength laser. Figure 3 shows the output spectrum of the laser when a lateral strain is imposed by rotating the screw of the tuning frame 20°. The dual wavelengths are 1556.8 and 1557.48 nm, respectively, and the SMSR is 35.6 dB. Comparing to the laser without tuning, the wavelength space of this tuned laser has altered from 0.52 to 0.68 nm. The basic theory of the tuning frame is listed below[6].

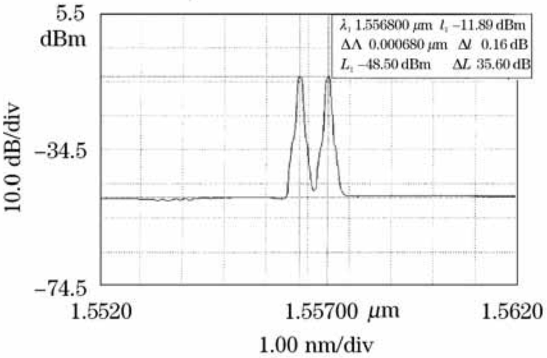

Fig. 3. Output spectrum of dual-wavelength EDFL with screwed angle of 20°.

The Bragg wavelength λ of a FBG is given by

$$\lambda = 2\Lambda \cdot n_{\mathrm{eff}}, \tag{1}$$

where Λ and n_{eff} are, respectively, the period of the refractive index modulation along the grating and the effective index of the fundamental mode in the undisturbed FBG. For a Hi-Bi FBG, we assume the birefringence axes are aligned with x, y axes, and the Bragg wavelength λ_x and λ_y differ from each other due to the birefringence in the fiber. When a lateral strain is applied on the fiber, the refractive index will change due to the strain-optic effect. In this condition, the FBG periodicity deformation is negligible. Therefore, the Bragg reflective wavelength changes can be derived by only calculating the core refractive index changes caused by the strain-optic effect.

For x polarization

$$\Delta\lambda_x = -n_x^3 \cdot \Lambda \cdot (p_{11}\varepsilon_x + p_{12}\varepsilon_y + p_{12}\varepsilon_z), \tag{2}$$

for y polarization

$$\Delta\lambda_y = -n_y^3 \cdot \Lambda \cdot (p_{12}\varepsilon_x + p_{11}\varepsilon_y + p_{12}\varepsilon_z), \tag{3}$$

where p_{11} and p_{12} are photoelastic coefficients, ε_x, ε_y and ε_z are the strain component in the x, y, and z directions, respectively. Therefore when the lateral strains ε_x and ε_y are applied on Hi-Bi FBG, the wavelength space of two reflective peaks will change, thus the laser output spectrum will change accordingly.

In conclusion, we have demonstrated a tunable stable dual-wavelength EDFL laser at room temperature by using a Hi-Bi FBG as wavelength selective component. Adjusting a polarization controller in the cavity can achieve either single or dual wavelength laser output with mutually orthogonal polarization. Applying lateral strain on the Hi-Bi FBG with a tuning frame, we can tune the wavelength space of the laser.

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