A compact single-polarization erbium-doped fiber laser by exploiting vernier effect

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A compact single-polarization fiber laser with fiber Bragg gratings inscripted in a polarization-maintaining erbium-doped germanosilicate fiber is demonstrated experimentally. The single-wavelength and single-polarization regime of our studied laser is achieved by applying a radial stress upon one of two gratings and stretching the other one axially to adjust the reflection peak match. Two single-wavelength and single-polarization lasing lines are realized respectively with fine power stability.

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Single-wavelength erbium-doped fiber lasers (EDFLs) have recently attracted considerable interest of the researchers all over the world because of their lower threshold, high power conversion efficiency, and their worldwide applications in optical fiber communication, optical fiber sensor, and spectroscopy. However, two orthogonal linear polarization modes will exit simultaneously in these lasers if no special measures have been taken. Consequently the polarization mode competition will be introduced and induce the power perturbation due to little difference between the mode-propagation constants of the two polarization modes[1,2]. So a single-polarization fiber laser is needed to improve the power stability of the output lasing line. Single-polarization fiber distributed feedback (SP-DFB) lasers exploiting injection locking[3], apodization[4], and twisting[5] have been reported. Similarly, Single-polarization distributed Bragg reflector (SP-DBR) lasers using injection locking[6], polarization-dependence gain effect[7], and employing birefringent fiber Bragg gratings (FBGs) as reflectors[3,8] have been realized. Likewise, a single-polarization frequency-modulated fiber ring laser by using a erbium-doped fiber (EDF) as the saturable absorber is presented by Ou *et. al*[9]. Moreover, in our former studies, we have demonstrated swithchable dual-wavelength EDFLs based on the photosensitive polarization-maintaining EDFs (PM-EDFs) fabricated in our laboratory[10−12].

In this letter, a compact single-polarization EDFL (SP-EDFL) using two FBGs written directly in a photosensitive PM-EDF as the reflectors is proposed and experimentally demonstrated. The Hi-Bi FBG fabricated in the PM-EDF makes its reflection spectrum split into two peaks corresponding to the two orthogonal linear polarized modes respectively. Furthermore, if a radial stress is applied upon one of the two FBGs, its wavelength of the peak will become a bit greater than that of the other FBG without any stress. It is comparatively easy for one to make only one pair of reflection peaks overlapping for the two FBGs by stretching the second FBG at axial direction. In short, the single-wavelength and single-polarization regime of our proposed laser is achieved by introducing different cavity losses for the two polarized modes which are parallel with two principle axes respectively. By employing the vernier effect, two single-wavelength and single-polarization oscillations are implemented with their output powers of 8.923 and 9.202 dBm, and operating wavelengths of 1554.548 and 1554.890 nm, respectively. Because there are no splices in the laser cavity with all-PM configuration, the power stability can be further improved. Their power perturbations of the laser are observed to be less than 0.3 dB over more than 1 h.

The experimental configuration of the proposed laser is shown in Fig. 1. The compact fiber laser consists of an 80-cm-long photosensitive PM-EDF, two FBGs incripted directly at both ends of the EDF, a 980/1550-nm WDM coupler, a 974-nm pigtailed laser diode, and an isolator. The PM-EDF is fabricated by our Optical Fiber Group in Institute of Lightwave Technology, Beijing Jiaotong University with the birefringence of $\sim 3\times10^{-4}$ and the peak absorption at 1530 nm of 25 dB/m, and the EDF is pumped by a 974-nm laser diode via the WDM coupler. The isolator at the output end is used to prevent the light reflected from the fiber cut returning the laser cavity back. Finally, the spectral characteristics of

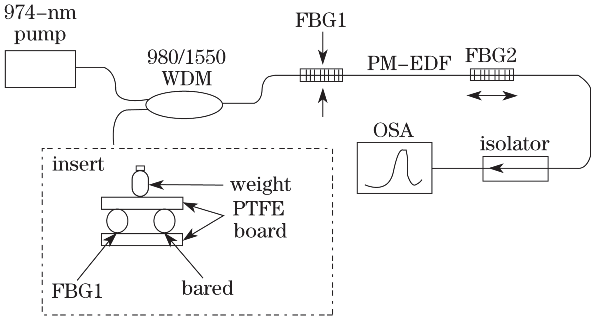

Fig. 1. Experimental configuration of the proposed laser and a cross section of the device providing the radial stress on the FBG1 (surrounded by the broken line[13]).

the laser are measured in an optical spectrum analyzer (Ando Corporation, model AQ6317C with a resolution of 0.01 nm).

Two FBGs are written by using phase mask method. The photosensitive PM-EDF is exposed to ultraviolet (UV) radiation from a KrF excimer laser with its energy of 80-mJ per pulse at 248 nm and its repetition rate of 8 Hz. A phase mask with its pitch period of 1068 nm is exploited in the inscription. The transmission spectrum of the FBG1 is shown in Fig. 2. The two Bragg wavelengths of reflection peaks are 1554.569 and 1554.869 nm. The wavelength difference between the two peaks is 0.3 nm, and the 3-dB bandwidth of each peak is ~ 0.03 nm. The reflectivity for corresponding polarization states is about 85%. Since the two FBGs are fabricated in the same fiber with a uniform birefringence, there is no wavelength difference. In order to make the wavelength spaces of the two FBGs different, we apply a radial stress on the FBG1 to widen its wavelength space by ~0.04 nm. When the FBG2 suffers an axial stretch, its two reflection peaks will shift to higher wavelength synchronously. In order to realize the peak match for corresponding polarizations during stretching the FBG2, comparatively lower initial reflection wavelengths of the FBG2 are demanded. To do so, a pretreated stretch is applied during the inscription of the FBG2. The resonance wavelengths of the FBG2 are 1554.524 and 1554.824 nm, and the reflectivity of the FBG2 for corresponding polarization states is considered to be lower than that of the FBG1 due to further less exposure to UV radiation as the lasing lines are proposed to radiate from the FBG2. Figure 3(a) shows the reflection spectra of the FBG1 enduring the radial stress and the one of FBG2 free of any stretch.

As shown in Fig. 3(a), the two FBGs have various wavelength spaces between their reflection peaks because of the radial stress applied on the FBG1. In this initial condition, the left peaks (corresponding to the linear polarized mode parallel with fast axis) of two FBGs overlap a little, while the right peaks (corresponding to the polarization parallel with slow axis) mismatch completely. When the EDF is pumped with the power of 23 dBm, the laser can operate at a single-wavelength regime. Then by stretching the FBG2, the two peaks shift to the position where only the left peaks of two FBGs match perfectly (Fig. 3(b)). The output power increases to the maximum at 1554.548 nm. When we stretch the FBG2 further, its reflection peaks move to the position as shown in Fig. 3(c). At this position, the right peaks of the two FBGS overlap well, but the left peaks mismatch. During this process, the wavelength of lasing line is switched from 1554.548 to 1554.890 nm; correspondingly, its polarization state is changed from the one parallel with fast axis to the other parallel with slow axis. The measure taken here to realize the single-wavelength and single-polarization regime works as a vernier do, so it is called vernier effect.

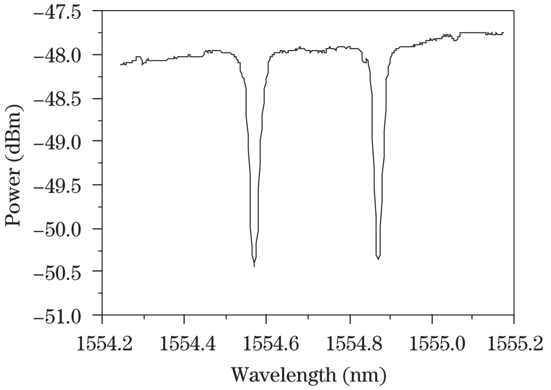

Fig. 2. Transmission spectrum of the FBG1.

By taking advantage of the vernier principle, the single-wavelength and single-polarization lasing are realized in our experiment. The 16-time repeated scans of the lasing spectra which are measured in an interval of 5 min over more than 1 h are shown in Fig. 4. It can be seen that the wavelength and power of the lasing line are 1554.548 nm and 8.923 dBm, respectively. Similarly, the wavelength and the power are 1554.890 nm and 9.202 dBm, respectively. The 3-dB bandwidth and the optical signal-to-noise ratio

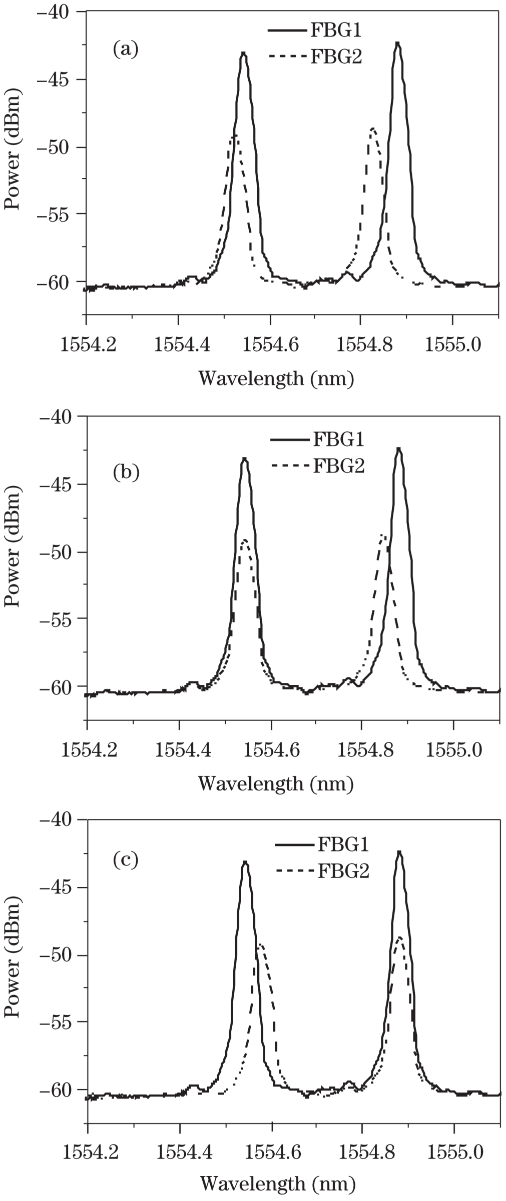

Fig. 3. Reflection spectra of the two FBGs. (a) In initial state; (b) with left peaks matching; (c) with right peaks overlapping.

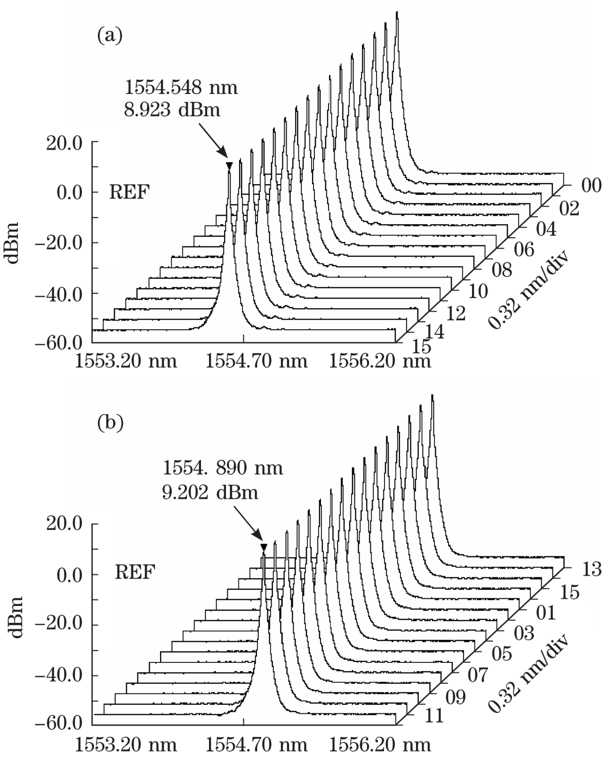

Fig. 4. 16-time repeated scans of the single-wavelength, single-polarization lasing spectra. The lasing line operating at (a) 1554.548 nm and (b) 1554.890 nm.

(SNR) are less than 0.01 nm and more than 55 dB, respectively. The wavelengths of single-polarization lasing lines are determined by the reflection wavelengths of the FBG1. However, the powers of the two lasing lines differ by near 0.3 dB, which is absolutely caused by the slight reflectivity difference of FBGs for the two linear polarized modes. During the measurement over more than 1 h, the output power fluctuates at a range of less than 0.3 dB, that is, the power stability is considerably fine.

As we all know, the two orthogonal polarized modes are reflected at difference wavelengths from a Hi-Bi FBG, and the wavelength space is exclusively determined by the index difference of the PM fiber. Consequently, the two linear polarized modes are separated in frequency domain due to the Hi-Bi FBGs fabricated directly at the PM-EDF in our experiment. Furthermore, the two orthogonal polarized modes reflected from Hi-Bi FBGs can be well maintained in the all-PM laser cavity. By exploiting vernier effect, a man-made polarization-dependent cavity loss is introduced to the laser cavity. The wavelength space of the FBG1 enduring the radial stress is a little broader than that of the FBG2 by ∼0.04 nm, and greater than the 3-dB bandwidth of each reflection peak. It makes sure that when one tunes two reflection wavelengths of the FBG2 synchronously by stretching it, only a pair of reflective peaks of the two FBGs can match, which means only a polarized mode can oscillate in the cavity. In this way, the single-wavelength and single-polarization emissions are obtained. The fine power stability is attributed primarily to the single-polarization regime because the polarization mode competition can be restrained extremely in our proposed laser. The second reason for the power stability is that the all-PM laser cavity without any splices for the polarization state can be kept well in the laser cavity.

In summary, a compact single polarization EDFL based on vernier effect is demonstrated. The laser cavity is closed by two Hi-Bi FBGs inscripted at a photosensitive PM-EDF directly. A radial stress is applied on one of the two FBGs to broaden its wavelength space between its two reflection peaks and the other one is stretched to adjust the peak match. In this way, the single-wavelength and single polarization oscillations are realized with good power stability.

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