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A SWITCHABLE DUAL-WAVELENGTH ALL-FIBER LASER BASED ON PANDA-TYPE PHOTOSENSITIVE POLARIZATION-MAINTAINING ERBIUM-DOPED FIBER

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ABSTRACT: *A novel swithcable dual-wavelength fiber laser using Panda-type photosensitive polarization-maintaining erbium-doped fiber (PMEDF) is proposed and experimentally demonstrated. Based on the integration of good photosensitivity and gain characteristics, two matched uniform fiber Bragg gratings (FBGs) are directly written in the PMEDF as reflectors, an all-fiber linear laser cavity with no splice in it is then obtained. Because of the high birefringence of the PMEDF, both of the FBGs show two reflection peaks corresponding to two orthogonal linear polarization modes. By adjusting the polarization controller (PC) in the cavity, three lasing outputs (single-wavelength at 1554.552 nm, single-wavelength at 1554.916 nm, and dual-wavelength at both wavelengths) are observed, respectively. The alternate wavelength switching is flexible. Repeated testing results show that a high-quality lasing output with side-mode suppression ratio (SMSR) better than 50 dB is achieved in all switching cases, the peak power of the laser either in single-wavelength output or in dual-wavelength output keeps stable with a small fluctuation less than 0.46 dB.* © 2009 Wiley Periodicals, Inc. Microwave Opt Technol Lett 52: 386–389, 2010; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.24928

Key words: *erbium-doped fiber laser; polarization-maintaining; fiber Bragg gratings; all-fiber*

1. INTRODUCTION

Wavelength switchable erbium-doped fiber lasers (EDFLs) are considered to be technically promising light sources in applications to optical fiber sensors for optical instrument testing, differential absorption measurement, and wavelength routable WDM systems [1–3]. Fiber Bragg gratings (FBGs) are ideal wavelength-selective intracavity components for fiber laser due to their advantages of fiber compatibility, ease of use, and low cost. Several kinds of FBGs have been used to realize the oscillating wavelength switching in the fiber laser such as cascaded FBG cavities [1], two overlapping cavities composed of two FBGs with a common gain medium [4], and FBGs written in multimode fibers [5]. Among them, FBGs written in high-birefringence (Hi-Bi) fiber have attracted more attention recently because of their special polarization property [6–8]. However, there are intrinsic defects existing in the Hi-Bi fiber based fiber lasers, such as relatively complicated cavity structure, the mismatch between Hi-Bi fiber, and single mode fiber or erbium-doped fiber in the laser cavity. All these can seriously affect the stability of lasing oscillation.

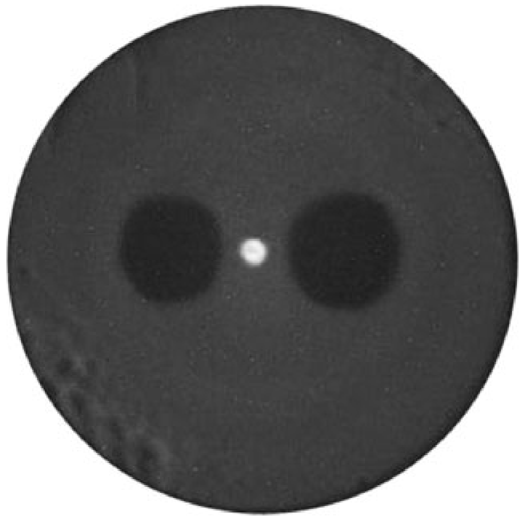

Figure 1 Cross-section of Panda-type PMEDF

In this article, a simple technique using FBGs directly written in photosensitive PMEDF for the stabilized switchable dual-wavelength erbium-doped fiber laser (EDFL) has been proposed and experimentally investigated. Due to the polarization-maintaining characteristic of the PMEDF, each FBG shows two reflection peaks corresponding to two orthogonal linearly polarized modes. Dual-wavelength lasing output is observed simultaneously, the wavelength spacing is 0.346 nm. For the linear laser cavity is all-fiber with no splice in it, the mode hopping can be effectively suppressed and the lasing output is stable. By adjusting the PC in the cavity, the switching between two single-wavelength and dual-wavelength lasing outputs is achieved.

2. CONFIGURATION OF PANDA-TYPE PMEDF

The self-made photosensitive erbium-doped fiber is fabricated by using modified chemical vapor deposition (MCVD) and solution doping method. A high doped germanium in core is to improve photosensitivity so that fiber Bragg grating (FBG) for fiber laser can be directly written in it. A side-groove method based on Panda-type scheme is used to realize the polarization-maintaining characteristic [9]. Figure 1 shows the cross-section of PMEDF by microscope.

An EXFO NR-9200 Optical Fiber Analyzer is used to measure the refractive index profiles (RIP) of PMEDF by using the near-field technique. Figure 2(a) shows the RIP of the PMEDF, the 3D RIP view is shown in Figure 2(b). The absorption coefficient of PM-EDF at 1530 nm is as high as 51 dB/m, whereas background attenuation is 13.34 dB/km at 1200 nm. The cutback wavelength is 0.942 μm. The group birefringence of PMEDF is about 1.93×10^{-4}.

3. EXPERIMENT SETUP

Figure 3 shows the configuration of the proposed fiber laser based on Panda-type photosensitive PMEDF. The 980-nm pump (with a maximum output power of 250 mw) is coupled into the

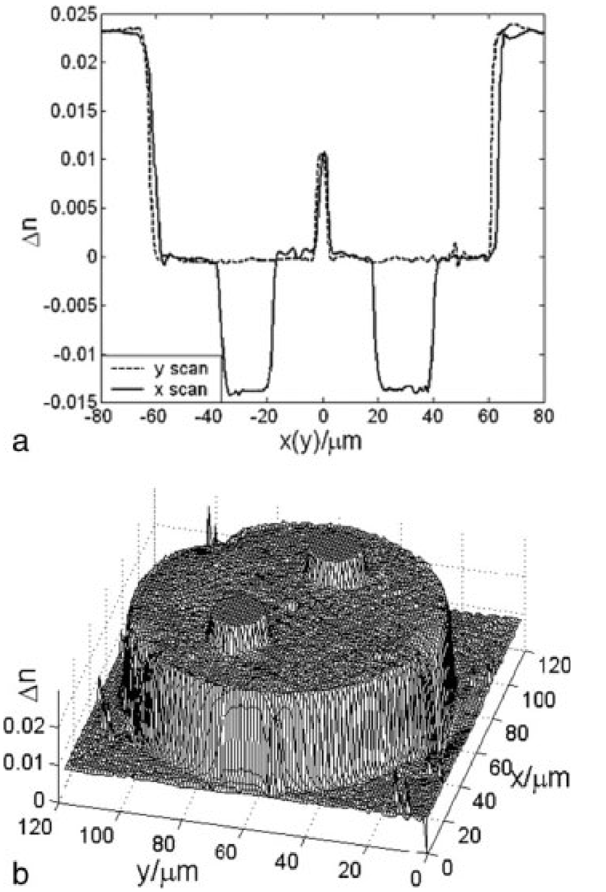

Figure 2 Refractive index profiles (RIP) of PMEDF (a) RIP view and (b) 3D RIP view

fiber laser through a 980/1550-nm WDM coupler. An isolator (ISO) at 980 nm is used for the unidirectional operation of the pump light. The linear laser cavity is composed of PMEDF (1.6 m) as intracavity gain medium and two uniform FBGs (FBG1 and FBG2) directly written in both sides of the PMEDF as reflectors by using the phase mask and UV Exposure method. There is no splice in the whole cavity (splice1 shown in Fig. 3 is the junction between laser cavity and pump input, splice2 is the junction between laser cavity and lasing output). The structure of the resonant cavity is all-fiber and quite compact.

Because of the different model refractive index along the fast and slow axis of the PMEDF, both of the FBGs exhibit two reflection peaks, one for each linear polarization mode. By a precise control, identical reflection wavelengths of the two FBGs can be achieved. The transmission spectrum of them is shown in Figure 4, two pair of matched reflection peaks lie at 1554.552 nm and 1554.912 nm, respectively. FBG1 is used as the total reflection mirror with reflectivity of 87% and FBG2 is used as partial reflection mirror with reflectivity of 47%. Both of them have such a same narrow 3-dB bandwidth of 0.06 nm

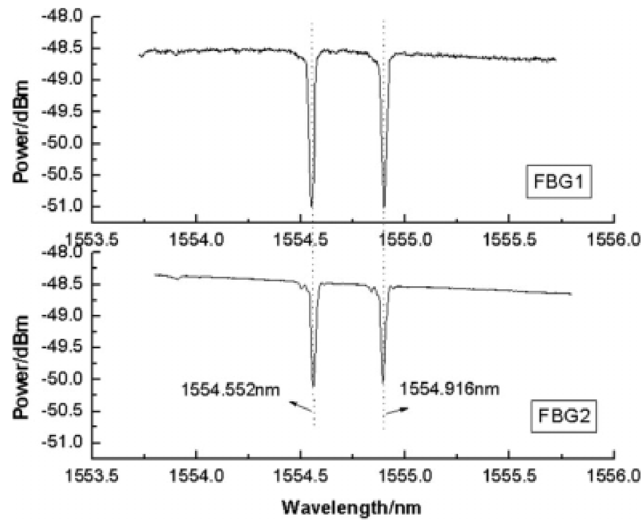

Figure 4 Transmission spectrum of FBG1 and FBG2

that this is beneficial in reducing mode competition and enhancing wavelength stabilization. However, sometimes, little mismatch between the FBGs may emerge for temperature variation. A method mentioned formerly by author in [10] is used to solve the problem. FBG2 is mounted on a fine-tuning platform (FTP), the Bragg wavelength of it can be tuned continuously under an axial strain so that the wavelength mismatch is well solved. It should be noted that all the measurements are taken in an isothermal Clean Room at 20°C, the tuning for the wavelength shift caused by temperature variation is very small and under such a tiny tuning that the spacing between the two reflection peaks of FBG2 does not changed.

The fiber-coil polarization controller (PC) is made of PMEDF in the laser cavity, which is used to adjust the polarization state of the light in the cavity and balance the gain and loss. The spectral characteristics of the laser are measured using an optical spectrum analyzer (OSA: ANDO AQ63l7C) with a resolution of 0.01 nm.

Compared with those fiber lasers based on separate EDF and Hi-Bi fiber, the fiber laser proposed in this article can naturally solve the problem of mismatch between Hi-Bi fiber and single mode fiber or EDF. Furthermore, the cavity structure is more simple and efficient than those of them.

4. EXPERIMENT RESULTS AND DISCUSSION

4.1. Dual-Wavelength and Single-Wavelength Lasing Output

The original lasing output without adjusting PC is illustrated in Figure 5(a). It is obvious that dual-wavelength oscillations are observed simultaneously. The resonant wavelengths lie at 1554.552 nm and 1554.916 nm, respectively, and the wavelength spacing is 0.364 nm, which well coincides with the results of FBGs shown in Figure 4. Notice that such a close wavelength separation cannot be achieved at room temperature

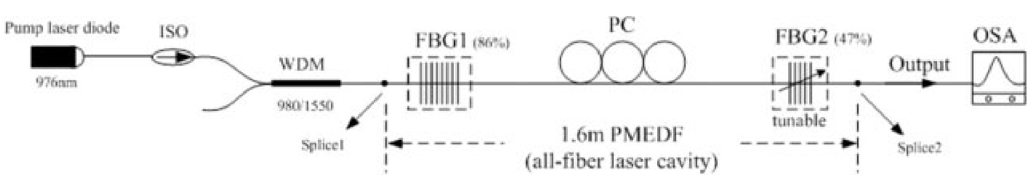

Figure 3 Configuration of the switchable dual-wavelength all-fiber laser

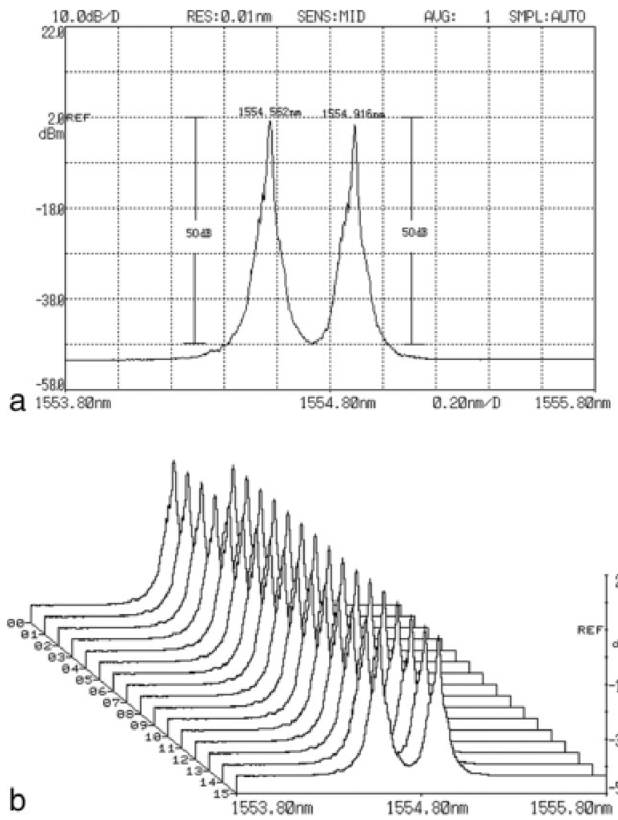

Figure 5 (a) Dual-wavelength lasing output and (b) 16-time-scan of the dual-wavelength lasing output

by simply using cascaded FBGs or overlap written FBGs [1, 4]. The pump threshold power is 32 mw.

As mentioned earlier, unlike the normal single-mode FBG, FBG written in polarization maintaining fiber has two reflection peaks corresponding to the two orthogonal polarization states. The laser fields with different polarization states greatly enhance the inhomogeneities in the laser cavity, two linearly polarized modes are excited and separated so that two resonant wavelengths are selected and oscillated simultaneously.

A 16-time scan of the lasing output with 3-min interval is taken, which is shown in Figure 5(b). Repeated results indicate that the peak power fluctuations of the two wavelengths are less than 0.46 dB. Both of them have a SMSR of better than 50 dB and 3-dB bandwidth of less than 0.1 nm. Not only is the beam quality well, but also the lasing output is quite stable.

By appropriately adjusting the states of the PC, two independent single-wavelength operations can be obtained, respectively. Figure 6(a) shows one lasing line at 1554.552 nm with a 3-dB bandwidth of 0.010 nm, which is related to one peak of the FBGs. Figure 7(a) shows the other lasing line at 1554.912 nm with a 3-dB bandwidth of 0.011 nm, which is related to the other peak of the FBGs. The SMSR of both the independent wavelengths are better than 50 dB. Likewise, lasing output stability is tested for both of them, as shown in Figures 6(b) and 7(b), respectively. The peak power fluctuations of the two separate wavelengths are both less than 0.46 dB, which indicate that the two wavelengths are stable.

4.2. Switching Between Dual-Wavelength and Single-Wavelength

As is known, due to the high birefringence of PMEDF, coupling between the two orthogonal linear polarizations modes existing

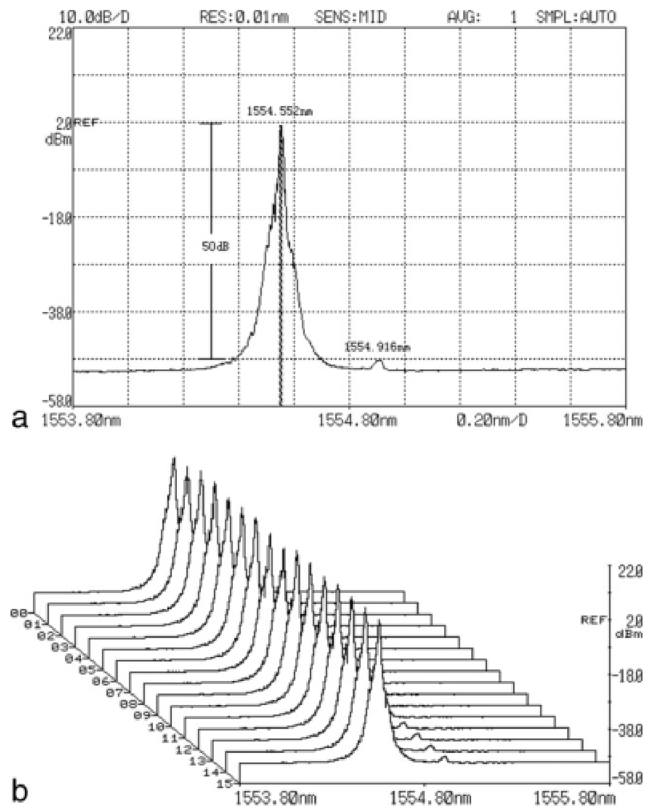

Figure 6 (a) Single-wavelength lasing output at 1554.552 nm and (b) 16-time-scan of the output at 1554.552 nm

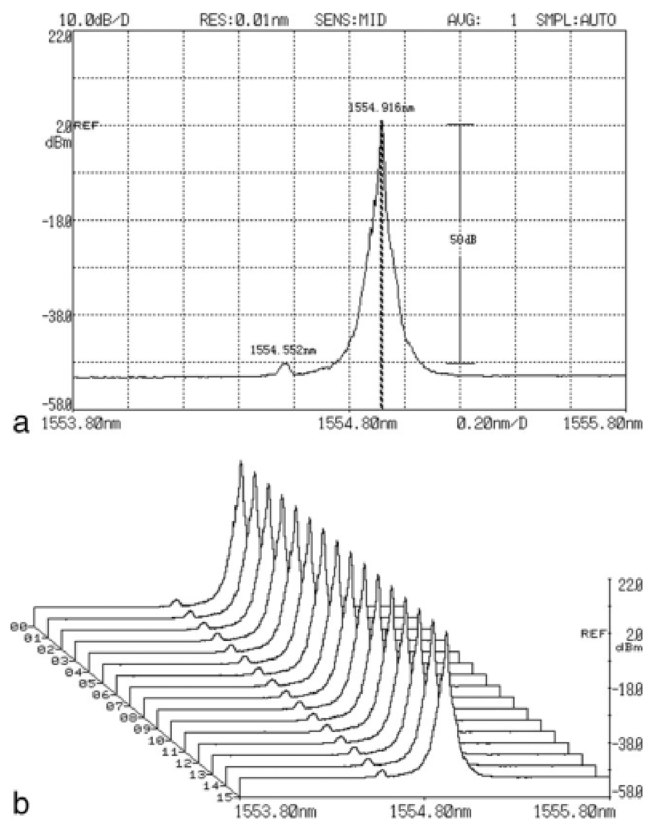

Figure 7 (a) Single-wavelength lasing output at 1554.916 nm and (b) 16-time-scan of the output at 1554.916 nm

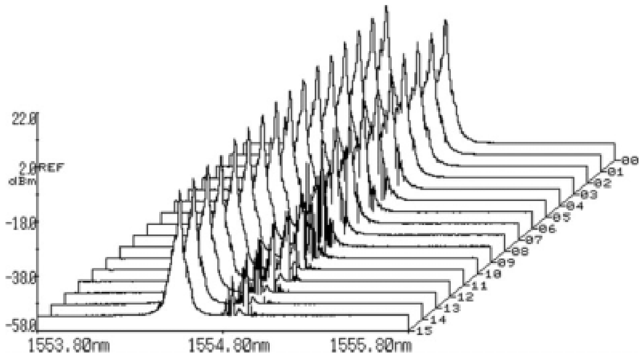

Figure 8 Controlling at single-wavelength by adjusting the PC

in the laser cavity can be well prevented. The propagation of them is independent from each other. Since adjustments on PC can effectively change the intracavity losses for each of the polarization eigenstate corresponding to the two reflection peaks of FBGs, different thresholds for the two wavelengths are produced under the adjustments. This is demonstrated in Figure 8. By continuously adjusting the PC, the intracavity loss for the lasing at 1554.916 nm turns greater, correspondingly the threshold of it gradually becomes higher. As a result, under a same input pump power, the lasing at this wavelength gets weaker and weaker till is completely suppressed. It is obvious that during the whole adjusting at 1554.916 nm, the other wavelength at 1554.552 nm keeps stable all along, neither the peak power nor the 3-dB bandwidth changes. This further proves that the two orthogonal linear polarizations modes existing in the lasing cavity are independent from each other.

Figure 9 shows the alternate-switching process. When repeatedly adjusting the PC, the intracavity loss for both of the lasing wavelengths changes periodically, different polarization eigenstates are excited by turns. The three lasing states can be alternately switched among: (1) single wavelength lasing at 1554.552 nm, (2) single wavelength lasing at 1554.916 nm, and (3) dual-wavelength lasing at both two wavelengths. The switching is flexible. It should be noted that both of the Figures 8 and 9 are schematic diagrams which are measured under a rapid scanning, such a short scan interval (about 1 s) may induce a little instability in the output. However, it is enough to illustrate the operation.

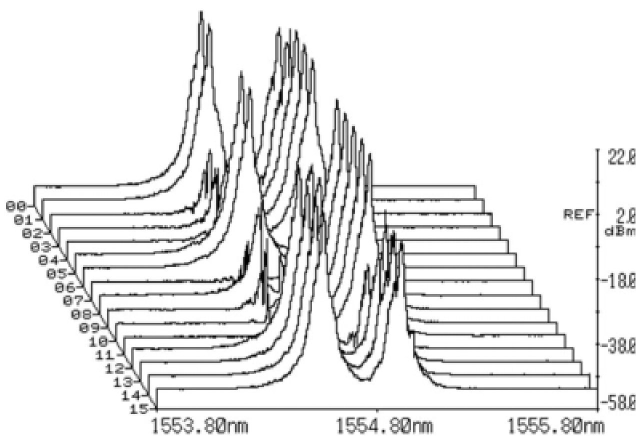

Figure 9 Alternate-switching between single-wavelength and dual-wavelength

5. CONCLUSIONS

By directly writing two matched FBGs in Panda-type photosensitive PMEDF, a compact and efficient switchable dual-wavelength erbium-doped fiber laser is proposed and experimentally demonstrated. For the whole, linear laser cavity is all polarization-maintaining and all-fiber with no splice in it; two independent orthogonally linear polarization states of the lasing light within the cavity are well maintained. When adjusting the PC in the cavity, the lasing output can be flexibly switched among two independent single-wavelength and dual-wavelength. The beam quality and output stability keep well in all cases. In short, the proposed fiber laser in this article has the potential in optical switch, optical communication, or other optical fields.

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