Single-frequency, single-polarization ytterbium-doped fiber laser by self-injection locking

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We demonstrated a stable single-frequency, single-polarization operation of ytterbium-doped fiber laser. As a novel practical method to realize single-polarization operation of fiber distributed Bragg reflector (DBR) laser, we proposed self-injection locking (SIL) with an active fiber ring feedback cavity. The laser has high output power exceeding 15 mW, wavelength of 1053.20 nm, and side-mode suppression ratio greater than 60 dB. The SIL fiber laser shows the improvements in output power and side-mode suppression compared with the fiber DBR laser. No mode-hopping is observed within 2 hours.

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Short-cavity optical fiber distributed feedback (DFB) lasers and distributed Bragg reflector (DBR) lasers are attractive as compact, stable, and tunable single-frequency laser sources[1,2]. However, most fiber DFB or DBR lasers actually operate in two orthogonal polarizations without special countermeasures against effects such as twisting[3] which are not desirable for most applications. Ytterbium-doped fiber (YDF) offers many advantages, including efficient pump absorption over broad absorption band, high peak absorption cross-section, and simple energy level system[4].

To enable higher single-mode output power and wavelength selectivity in short-cavity fiber lasers, self-injection locking (SIL) can be a very useful technique. Recently, single-frequency, single-polarization operation of Er, Yb co-doped fiber Fabry-Perot laser (FFPL) has been demonstrated in a SIL configuration with a fiber Bragg grating (FBG) and a polarizer as frequency- and polarization-selective optical feedback[5]. A practical method to realize stable single-polarization operation of fiber DFB laser by SIL with a polarization-selective optical feedback composed of a mirror and a polarizer has been proposed[6].

In this paper, we show SIL of a fiber DBR laser operating in dual polarizations and find that it can operate in a single polarization by SIL. As a practical method to realize single-polarization operation of the fiber DBR laser, we propose SIL with an ytterbium-doped active fiber ring feedback cavity and demonstrate a stable single-polarization and single-frequency operation.

The fiber DBR laser used here is realized by fabricating two same 1.5-cm-long FBGs in an ytterbium-doped fiber. The reflectivity of the grating is about 98%, the central wavelength is 1053.20 nm, and the bandwidth is about 0.12 nm. The DBR laser is fabricated between the gratings only 4.5 cm center to center. The YDF has pump absorption of 180 dB/m at 977 nm, cutoff wavelength of 920 nm, and core diameter of 5.4 μm. Figure 1 shows the output spectra from the free-running fiber DBR laser pumped at 977 nm. From the optical spectrum (Fig. 1(a)) measured by an optical analyzer (ADVANTEST Q8384) with 0.01-nm resolution, side-mode suppression ratio of 55 dB is obtained. It seems to be operating in a single mode at 1053.20 nm. By using a Fabry-Perot scanning interferometer (FP-SI) having free spectral range (FSR) $\sim$ 4 GHz and resolution $\sim$ 8 MHz, we observe that it consists of two frequencies separated by 0.8 GHz, as shown in Fig. 1(b). The laser operates in dual polarizations, the two wavelengths corresponding to the x- and y-polarization for each longitudinal mode have been folded and observed within on FSR. The

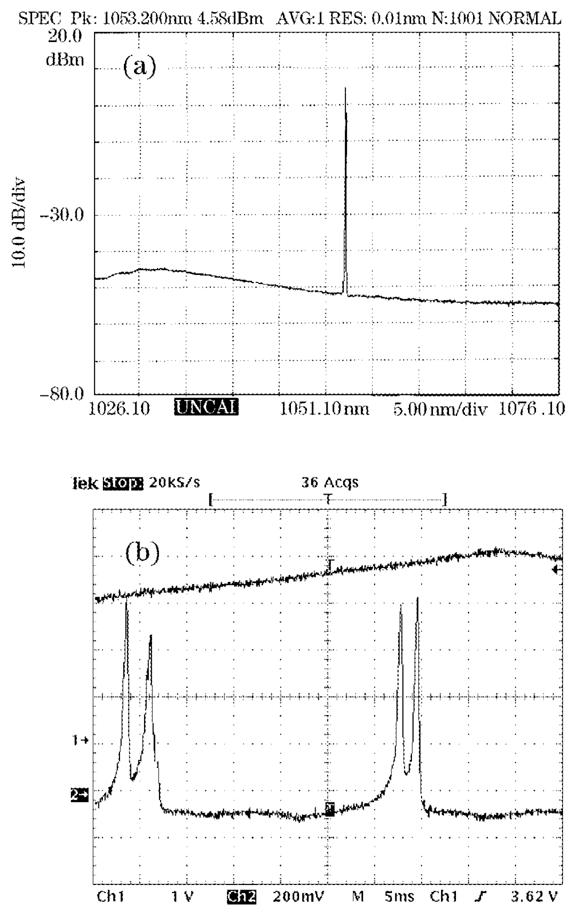

Fig. 1. Output spectra of the free running fiber DBR laser. (a) Optical spectrum measured by an optical analyzer; (b) optical spectrum measured by a FP-SI.

polarization states of the two frequencies are orthogonal. The frequency difference between the two peaks is given as $\Delta f_{\rm pol} = B \cdot f/n$, where $B = n_x - n_y$ is fiber birefringence, f is lasing frequency, and n is refractive index. A typical value of B for YDF is $\sim 10^{-6}$, giving $\Delta f_{\rm pol}$ of $\sim$ 1 GHz. The output power characteristics of the free running fiber DBR laser are shown in Fig. 2. The output power can reach 6 mW at pump power of 80 mW, with pump power threshold of 20 mW.

The configuration of the SIL YDF laser is shown in Fig. 3. It is pumped with a 977-nm laser diode through a wavelength division multiplexed (WDM) coupler. We insert a 10-m-long YDF as gain medium pumped with the residual 977-nm light in the ring cavity to enhance feedback effect. An optical isolator makes lasing propagation in a counter-clockwise direction in a traveling-wave pattern. Fiber ring lasers can prevent spatial-hole burning (SHB). The YDF used here has pump absorption of 6.7 dB/m at 977 nm, cutoff wavelength of 900 nm, and core diameter of 5.4 μm. The polarization controllers (PCs) adjust the state of polarization (SOP) of the ring cavity to select either of the two polarizations of fiber DBR laser, optimally suppress the laser noise. The single-polarization lasing is fedback to another end of the DBR laser through the YDF ring cavity and forces only one mode to lase in the fiber DBR laser.

Figure 2 also shows the output power characteristics of the SIL YDF laser. The output power can reach 15 mW at pump power of 90 mW, with a slope efficiency of 20.5%, and pump power threshold of 17 mW. The output power is enhanced compared with that of fiber DBR laser.

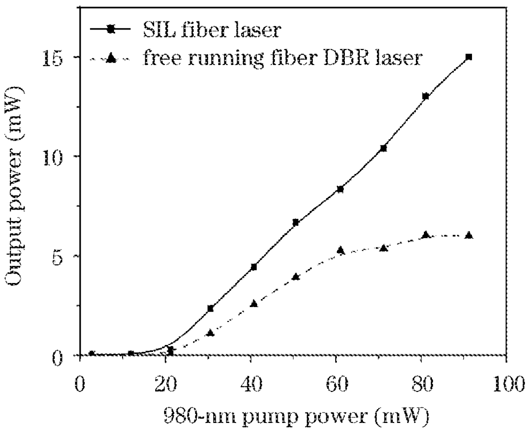

Fig. 2. Output power characteristics of free running fiber DBR laser and SIL fiber laser.

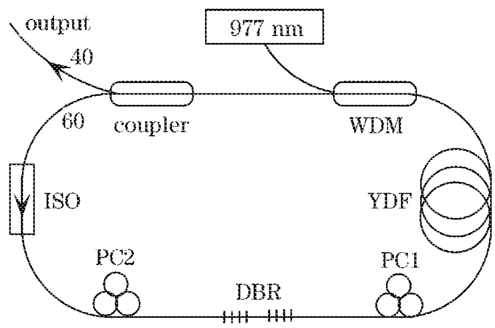

Fig. 3. The configuration of the SIL fiber laser. ISO: optical isolator.

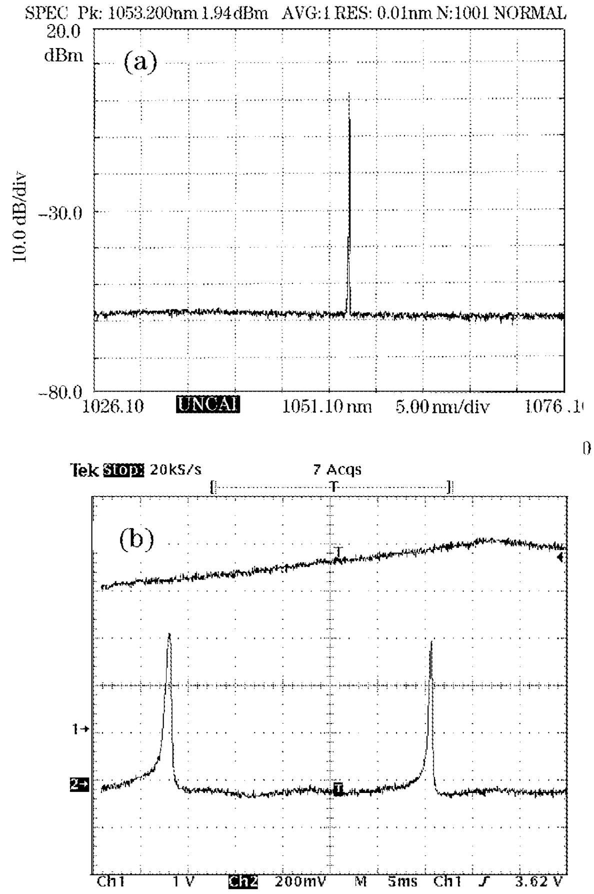

Fig. 4. Output spectra of the SIL YDF laser. (a) Optical spectrum measured by an optical analyzer; (b) optical spectrum measured by a FP-SI.

Figure 4(a) shows the output optical spectrum of SIL fiber laser with 0.01-nm resolution. The side-mode suppression ratio of $\sim$ 60 dB is greater than $\sim$ 55 dB of the free running fiber DBR laser. Single-frequency and single-polarization operation in SIL fiber laser is easily confirmed by observing the high resolution optical spectrum obtained from the FP-SI. A sample single-polarization spectrum of SIL-fiber laser is shown in Fig. 4(b), and the spectral linewidth is 8 MHz. Because of the limitation of 8-MHz resolution of the used FP-SI, the potential linewidth of the fiber laser less than 8 MHz can be expected. We find that this laser maintains single-frequency and single-polarization operation for more than 2 hours, and the output power is very stable as observed using a power meter. Thus, we believe that SIL is a simple, robust, and useful technique to realize single-frequency and single-polarization fiber lasers.

In conclusion, we have demonstrated that the YDF laser can successfully operate in single-frequency and single-polarization by SIL. As a practical method to realize single-mode operation of fiber DBR laser, we propose SIL with an active fiber ring feedback cavity, and demonstrate a stable single-polarization operation. The SIL fiber laser shows the improvement in output power and side-mode suppression compared with the fiber DBR laser. The laser has a high output power of $\sim$ 20 mW, wavelength of 1053.20 nm, and side-mode suppression ratio greater than 60 dB. No mode-hopping is observed within 2 hours. The laser can be used as fiber sensor or provide high performance seed laser source for high power laser system, such as for high-resolution spectroscopy. Also the operating wavelength can be extended to 1.55 μm when using the Er, Yb co-doped fiber for the application in dense wavelength division multiplexing (DWDM) system.

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