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Single Frequency Ytterbium Fiber Laser From Linear Cavity with Loop Mirror Filter

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Single frequency ytterbium fiber laser was demonstrated by combining polariztion controller and loop mirror filter in linear laser cavity. Spatial hole burning effect was eliminated by adjusting polarization controller appropriately. The loop mirror with unpumped ytterbium fiber as a narrow bandpass filter can discriminate laser longitudinal modes efficiently. Output power up to 11.7 mW at 1064 nm were obtained for lauched pump power of 68 mW at 976 nm, the slope efficiency is about 22%. [DOI: 10.1143/JJAP.43.L1379]

KEYWORDS: loop mirror filter, dynamic Bragg grating, spatial hole burning, nonlinear wave mixing, single frequency laser

Single frequency fiber lasers are of great importance in many applications, such as wavelength division multiplexing, coherent communications, optical fiber sensors and high-resolution spectroscopy. At present, most work on single frequency fiber lasers has been concentrated on: 1) fiber ring laser,[1] which need intracavity filters and optical isolators, make it complex and expensive; 2) short linear cavity distributed Bragg reflector (DBR) fiber lasers,[2,3] because of the short fiber cavity, it can not absorption pump power efficiently, the output power is not high; 3) fiber distributed feedback (DFB) lasers,[4,5] which are popular at present.

In our experiment, we proposed to combine simple fiber linear cavity with polarization controller (PC) and loop mirror filter (LMF)[6] to generate single frequency laser. PC was used to make the wave polarization perpendicular in the gain fiber in order to eliminate spatial hole burning effect, and LMF acted as very narrow filter to select laser frequency. From this fiber laser system, stable single frequency 1064 nm laser was obtained. The maximum output power was 11.7 mW, considering the pump power of 68 mW, the slope efficiency was about 22%. The total system was simple, compact, stable and reliable.

As we know, for linear laser cavity, there exits spatial hole burning (SHB) effect in the gain material, which can arouse multilongitudinal mode oscillation, and reduce the laser coherence easily.[7] So this is a serious problem for generating single frequency laser. This effect is produced by the nonlinear wave mixing of the two counterpropagating waves in laser gain material. If we destroy the interference of the two waves, we can eliminate SHB effects. This can be done, by arranging the cavity such that the polarization of the counterpropagating waves will be perpendicular in the laser gain material.[8] In our experiment, we used simple PC to satisfy this condition, as shown Fig. 1.

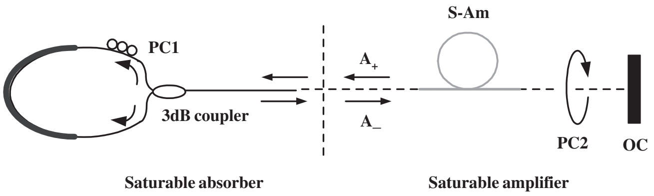

Fig. 1. The laser oscillator is composed by two sections. The first one is the saturable amplifier section (the right section). In this one, PC2 is used to control the wave polarization and eliminate the SHB effect. The second one is the saturable absorber section (the left section), it is a LMF (loop mirror with saturable absorber) act as a very narrow filter.

In our experiment, we also introduced LMF to suppress the unwanted laser longitudinal modes. In Fig. 1, the left section is the LMF, which is a loop mirror with saturable absorber. The unpumped ytterbium fiber was used as the saturable absorber, which could not be used for passive mode locking because of its long time response compared with the cavity round-trip time. In the saturable absorber, the two counterpropagating waves formed an interference patterns, such that generated an absorption Bragg grating. This grating is a dynamic Bragg grating, more efficient than the normal fiber Bragg grating for discriminating laser frequency. The bandwidths of this absorption grating can cover sub-MHz to GHz range, which is approximately proportional to the inverse of the length of the saturable absorber. In addition, the length of the cavity was decreased remarkably when the loop mirror with the saturable absorber replaced linear cavity with the saturable absorber, because the length of the LMF was not included in the total length of the cavity. Clearly, this is advantageous to generate single frequency laser.

The experiment setup is shown in Fig. 2. Ytterbium doped single mode single clad fibers were used as the gain fiber and saturable absorber material, the ytterbium concentration was about 24000 ppm. The gain fiber had a length of 15 cm, the length of saturable absorber in the LMF was selected as 1.2 m and 5 m in the different experiments. The cavity was restricted by the LMF and FBG for 1064 nm wavelength, the overall cavity length was about 1 m. PC2 was used in the laser gain section to adjust the wave polarization in order to eliminate SHB effect. WDM1 was used to input 976 nm LD pump laser, and WDM2 to output the residual pump power. We measured and analyzed the laser frequency with a scanning Fabry-Perot interferometer (Newport SuperCavity SR-150), which had a free spectral range (FSR) of 6 GHz.

As we mentioned before, the bandwidths of LMF is

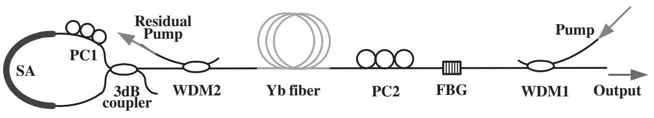

Fig. 2. Experiment setup of the single frequency ytterbium fiber laser. The length of gain fiber is 15 cm, and the length of SA is 1.2 m or 5 m, the reflectivity of FBG is 80% at 1064 nm, the bandwidth is 0.47 nm.

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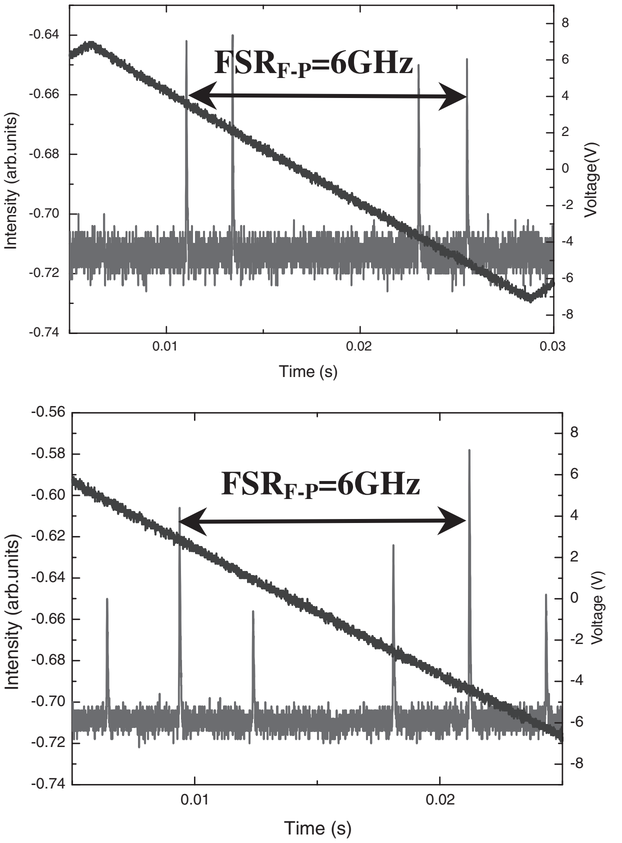

Fig. 3. 2 line and 3 line laser oscillate when using 1.2 m saturable absorber.

approximately proportional to the inverse of the length of the saturable absorber. So, the length of the unpumped ytterbium fiber should be selected carefully. At first we used 1.2 m ytterbium fiber as the saturable absorber. In the experiment process, firstly, we generated 1064 nm laser by increasing pump power to appropriate value. Then rotated PC1 to maximize the loop mirror reflection and laser output power. Next rotated PC2 to change the polarization of the waves to eliminate SHB effect. When adjusting the pump power, we observed the laser oscillation. During the adjusting process that pump power was less than 57 mW, stable 2 line or 3 line laser oscillation could be observed as shown in Fig. 3, but single frequency laser did not appeared. When the pump power was higher than 57 mW, multilongitudinal modes oscillation started.

Next, we used 5 m ytterbium fiber as the saturable absorber, repeated the same operation as above. As long as the pump power was increased up to laser threshold, single frequency 1064 nm laser was generated. The oscillation was very stable until pump power up to 68 mW. Figure 4 shows a scan over one FSR and confirms that only one longitudinal laser mode is present. The maximum laser power was 11.7 mW, the slope efficiency is about 22%, as shown in Fig. 5. When increasing the pump power more than 68 mW, multilongitudinal modes appeared, and the frequency was not stable. This happened, because when the pump power was increased more, the laser power in the cavity became higher, which was easy to induce strong SHB, but the PC2 and LMF with 5 m saturable absorber could not suppress this strong effect at this time.

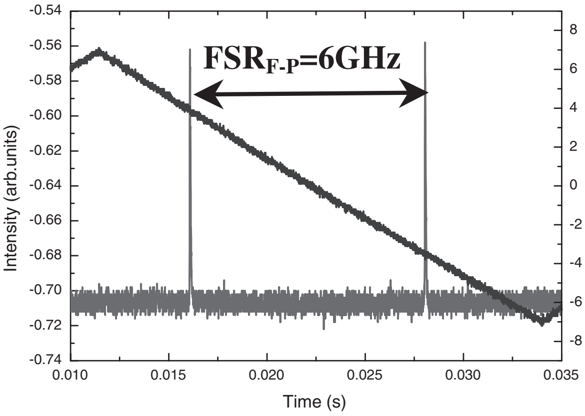

Fig. 4. Single frequency laser oscillate when using 5 m saturable absorber.

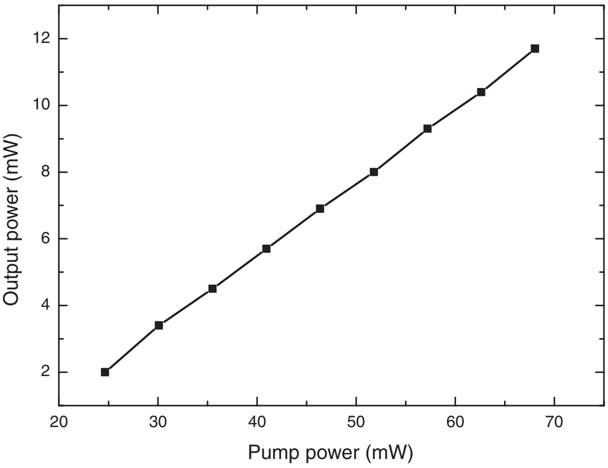

Fig. 5. The output power of 1064 nm single frequency laser as a function of the pump power.

Compared the two experiments, we can find that LMF with 5 m saturable absorber is more efficient than that one with 1.2 m saturable absorber. This appeared, because the absorption coefficient of ytterbium fiber at 1064 nm wavelength is very weak, the corresponding dynamic Bragg grating formed by the absorption will be weak. This is disadvantageous to suppress laser frequency. In order to solve this problem, in our experiment we used high doped ytterbium fiber (Yb concentration is 24000 ppm) as the saturable absorber. In this case, 5 m fiber has more absorption than 1.2 m one, which can suppress laser frequency more efficiently. So, the absorption of the saturable absorber is an important parameter, it can determine the effectiveness of the laser cavity for suppressing multi mode oscillation and for stabilizing the single frequency oscillation. After optimizing the length of the saturable absorber and of the gain fiber, more higher power single frequency 1064 nm laser is expected in the near future.

In summary, we have demonstrated single frequency 1064 nm fiber laser by using polarization controller and loop mirror filter in linear laser cavity. This provides us a feasible and efficient method to generate single frequency laser. Such lasers can find applications in a wide range, such as signal detection, coherent communications, and high-resolution spectroscopy.

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