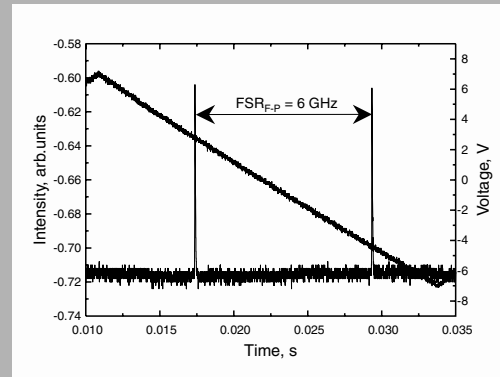


Abstract: Single frequency 1083 nm ytterbium fiber laser was demonstrated by introducing loop mirror filter and polarization controller in linear laser cavity. The loop mirror with unpumped ytterbium fiber as a narrow bandwidth filter discriminated and selected laser longitudinal modes efficiently. Spatial hole burning effect was restrained by adjusting polarization controller appropriately. The laser linewidth was about 2 KHz. Output power up to 14 mW were obtained under the launched pump power of 100 mW at 976 nm, the corresponding optical-optical conversion efficiency was 14%, the slope efficiency was 18%. The measurement of RIN and power stability indicated the stable operation of the laser.



Single frequency operation verified using a scanning Fabry-Perot interferometer with FSR=6 GHz

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1083 nm single frequency ytterbium doped fiber laser

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Received: 27 May 2005, Accepted: 31 May 2005

Published online: 3 June 2005

Key words: 2KHz single frequency fiber laser; loop mirror filter; dynamic Bragg grating; helium pumping

PACS: 42.55.Wd, 42.60.By

1. Introduction

Narrow linewidth single frequency lasers at 1083 nm have important applications in atomic and molecular spectroscopy. For example, such laser sources have been used to study the multiplet of the helium atom [1] with the aim of improving measurement precision for the fine structure constant, pushing the uncertainty down to the level of a few parts in 10^8 . Usually, there are several ways to supply narrow linewidth 1083 nm laser source: Flash-pumped LNA solid state lasers can deliver several watts in a continuous wave (cw) regime with a 2-GHz bandwidth [2]; Semiconductor lasers around 1083 nm offer larger tuning ranges and operation on a single frequency with a linewidth of 100 KHz [1]; Ytterbium doped fiber laser operated at 1083 nm, but the linewidth envelope was about 1-3GHz [3]. Refer to narrow linewidth fiber laser generation; there is an efficient method to use one section of unpumped gain fiber as the saturable absorber (SA), act as very narrow filter [4–8]. In detailed, the researchers used

one section unpumped fiber as the SA, in which counter-propagating waves can form very narrow dynamic absorption grating, such that to select single longitudinal mode. If the SA was placed in the fiber loop mirror, the total device was called loop mirror filter (LMF) [9].

In the references [4–8], they generated 1.5 μm single frequency laser using erbium doped fiber as the gain material and absorber. It is easy to optimize the length of gain fiber and SA for erbium doped fiber, because of the large cross-section of emission and absorption at 1.5 μm . In our experiment, we adopted ytterbium (Yb) doped fiber as the gain material and as the SA in the LMF in order to generate single frequency 1083 nm laser. For Yb fiber, the absorption cross-section at 1083 nm is as weak as $2 \times 10^{-27} \text{ m}^2$ [10]. So we must use highly doped Yb fiber as SA, at the same time optimize the length of gain fiber and SA carefully ensuring the enough gain and effective dynamic absorption grating at 1083 nm. We also restrained spatical hole burning (SHB) effect in the laser material using the

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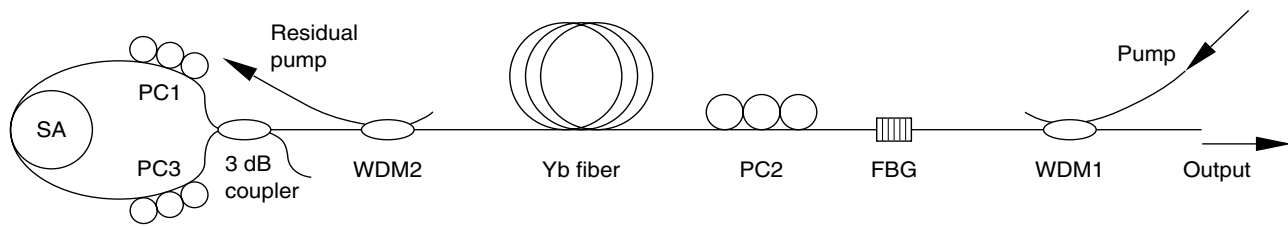


Figure 1 Experiment setup of the single frequency ytterbium fiber laser. The laser oscillator is composed by two sections. The left section is the loop mirror filter acting as a very narrow filter, the right section is the gain fiber, PC2 is used to control the wave polarization and restrain the SHB effect

simple polarization controller (PC). From this fiber laser system, stable single frequency 1083 nm laser was generated, the maximum output power was 14 mW, and the linewidth was about 2 KHz. To our knowledge, this is first time to generate single frequency 1083 nm laser based on linear cavity with Yb fiber LMF.

2. The principle of single frequency operation

The experiment setup is shown in Fig. 1, the left section is the LMF, which is a loop mirror with SA. The unpumped ytterbium fiber was used as the SA, in which the two counterpropagating waves formed an interference patterns, such that generated Bragg grating. This grating is a dynamic absorption Bragg grating, more efficient than the normal fiber Bragg grating for discriminating and filtering laser longitudinal modes, because of the narrower bandwidth covering sub-MHz to GHz range. As we know, for linear laser cavity it is easy to produce spatial hole burning (SHB) effect in the gain material, which can arouse multilongitudinal mode oscillation, and reduce the laser coherence [11]. The SHB 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 restrain SHB effects to some extent. In our experiment, we used simple PC (as shown PC2 in Fig. 1) to adjust the polarization state of the counterpropagating waves, such that to make the polarizations perpendicular and destroy the interference of them.

3. The experiment process and result

Ytterbium doped fiber was used as the gain fiber and saturable absorber; the length of them was 25 cm and 16 m, respectively. The cavity was restricted by the LMF and the FBG with reflectivity of 90% as the output coupler, the overall linear cavity length was about 1 m. PC1 and PC3 in the LMF was used to control the polarization state of the laser waves in order to optimize the reflection of the LMF. PC2 was used in the laser gain section to adjust the wave polarization. WDM1 was used to input 976 nm LD pump laser, and WDM2 to output the

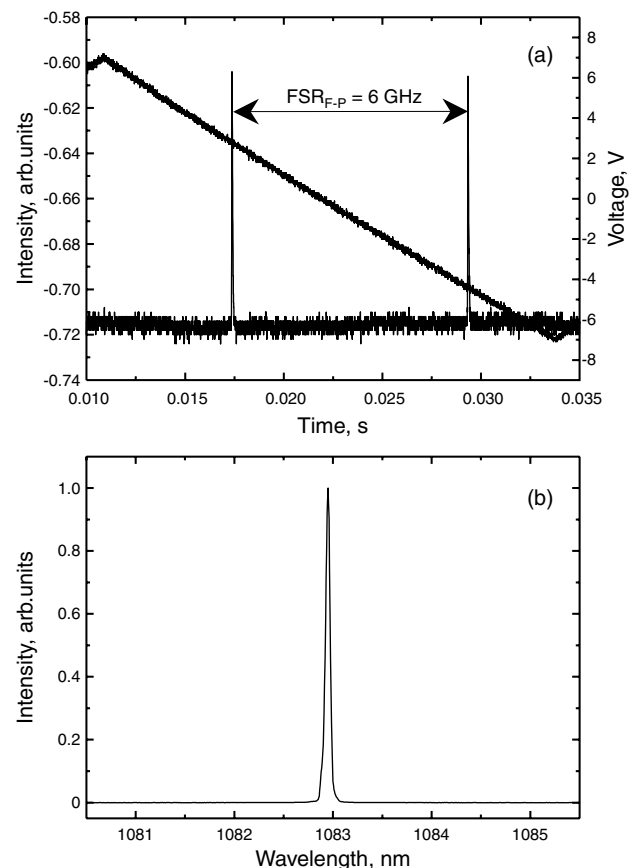


Figure 2 (a) Single frequency operation verified using a scanning Fabry-Perot interferometer with FSR=6GHz. (b) Emission spectrum of the laser operating at 1083 nm. The resolution of the optical spectrum analyzer is 0.05 nm

residual pump power ensuring the Yb fiber in LMF is not pumped. 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 and a resolution of 150 KHz.

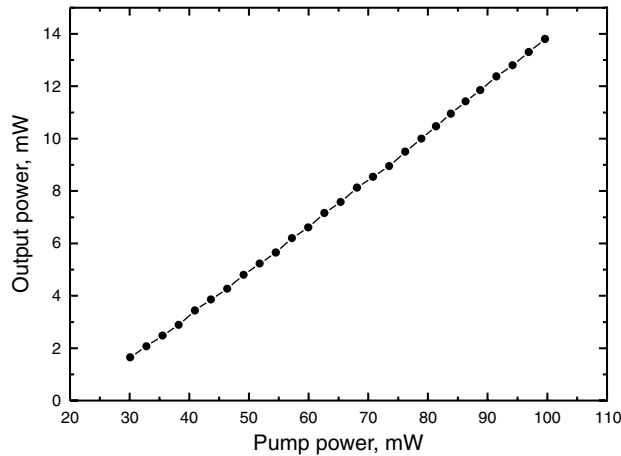


Figure 3 The output power of 1083 nm single frequency laser as a function of the pump power

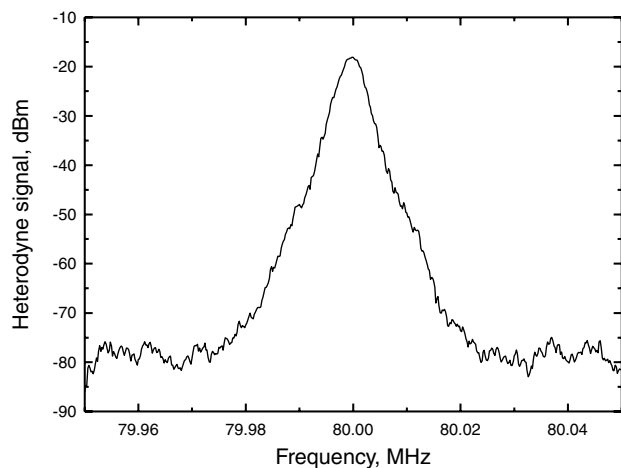


Figure 4 Lineshape of the heterodyne signal measured with 25 km delay fiber. From the signal taken 3 dB down from the maximum value we estimate the FWHM of the laser spectral linewidth is about 2 KHz

In the experiment process, firstly, we generated 1083 nm laser by increasing pump power to appropriate value. Then rotated PC1 and PC3 to maximize the loop mirror reflection and laser output power. Next rotated PC2 to change the polarization of the counterpropagating waves. When adjusting the pump power, we observed the laser oscillation. As long as the pump power was increased up to laser threshold, single frequency 1083 nm laser was generated. Fig. 2a shows a scan over one FSR and confirms that only one longitudinal laser mode is present. The single frequency oscillation was very stable, there was no mode hopping during one hour's observation. The maximum laser power was up to 14 mW when the pump power increased to 100 mW, the corresponding optical-optical

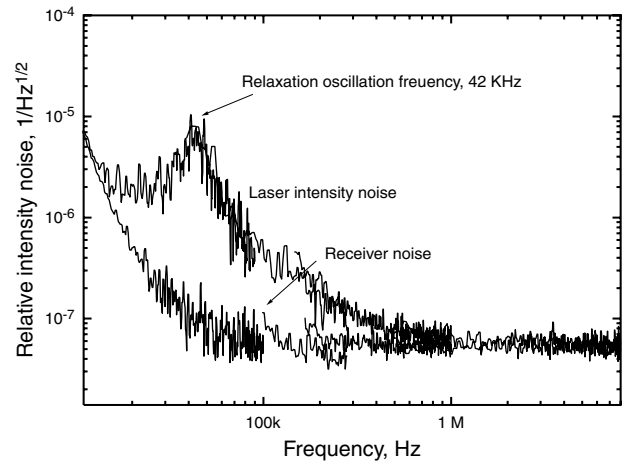


Figure 5 Laser relative intensity noise spectrum between 0 and 8 MHz. The receiver noise spectrum is shown for comparison

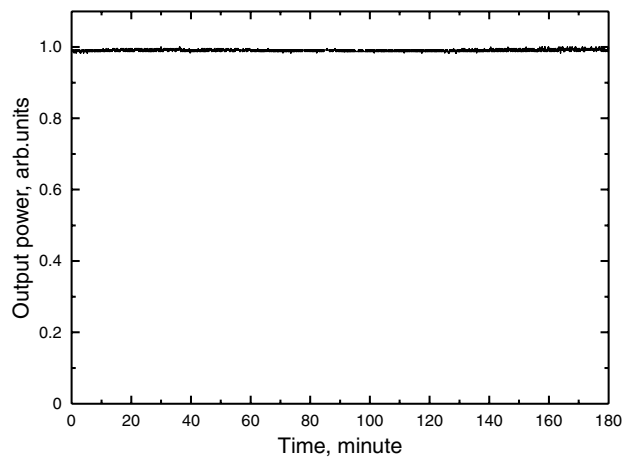


Figure 6 The stability of the output power during more than 3 hours' measurement in room temperature

conversion efficiency was about 14%, the slope efficiency was about 18%, as shown in Fig. 3. When increasing the pump power more than 100 mW, multilongitudinal modes appeared, and the frequency was not stable. This is 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 could not suppress this strong effect in this condition.

The linewidth of the laser was measured using the delayed self-heterodyne method. Firstly, the laser beam was splitted into two beams by 3 dB coupler, then one beam was delayed by 25 km single mode fiber, the other beam was through an acousto-optic modulator (AOM) with a carrier frequency of 80 MHz. After that, the two beams was combined at a beam splitter and analyzed by an RF spec-

trum analyzer (Anritsu MS 2661C), whose frequency resolution was set at 1 KHz and 10 times averaging. Fig. 4 shows the result of the measurement. From the heterodyne signal, we take 3 dB down from the maximum value to estimate its bandwidth, which is about 4 KHz. The laser linewidth is equal to the half-width of the heterodyne signal, which is about 2 KHz. The relative intensity noise (RIN) of our laser source was also measured using the RF spectrum analyzer (Anritsu MS2661C) with 50- Ω load, and the optical detector with a bandwidth of around 200 MHz. Fig. 5 shows the laser RIN spectrum from 0 to 8 MHz. There is a peak in the signal spectrum at about 42 KHz, which is the relaxation oscillation frequency of the laser. No other noise components are observed for frequencies up to 8 MHz.

Finally, the stability of the output power was measured over more than 3 hours; the result is shown in Fig. 6. In-room temperature, we find that the output power fluctuates less than 0.8% during the entire period of 3 hours.

4. Conclusion

Single frequency 1083 nm fiber laser was demonstrated by introducing loop mirror filter and polarization controller in linear laser cavity. Loop mirror filter discriminated and filtered the laser longitudinal modes efficiently. The SHB effect was restrained by controlling the light polarization in the linear cavity. The maximum output power was 14 mW, the linewidth of the laser was about 2 KHz. The RIN and

power stability of the laser was also measured, which indicated the stable operation of the single frequency laser.

Acknowledgements This work is partly supported by the 21st Century COE program of Ministry of Education, Science and Culture of Japan.

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