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Frequency Locking of a Single-Frequency Fiber Laser with Dual-Wavelength External Frequency-Stabilized Light Source

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***Abstract*—We investigated the frequency control characteristics of a narrow line-width single frequency fiber laser locked to one of the laser frequencies of two external frequency-stabilized lights with each different wavelength.**

Introduction

In future dense wavelength division multiplexing (DWDM) systems, narrow line-width light sources with high frequency stability are indispensable for DWDM backup sources with ITU-T grid. Fiber lasers enable us to realize narrow line-width operation due to the long cavity length. So far, various fiber lasers locked to the ITU-T grid have already been reported using periodic filters [1-3]. However, it is very difficult to control precisely a oscillation frequency, because the frequency fluctuates easily due to environmental perturbation compared to semiconductor laser diodes. To control such frequency, we proposed previously a single-frequency fiber laser using a saturable absorber controlled with a frequency-stabilized external light source [4, 5]. The oscillation frequency was successfully tuned to the frequency of the external light, and the high frequency stability was achieved.

In this paper, we apply this frequency locking technique for the external light source with dual-wavelength spectrum. The oscillation frequency of the fiber laser can be locked to one of the external light source by adjusting the bandpass filter in the laser cavity. The obtained frequency stability is as high as the stability of the external light source.

Experimental setup

Figure 1 shows the setup of a single-frequency fiber laser [4,5]. Traveling-wave laser cavity is employed. This cavity involves un-pumped erbium-doped fiber (EDF) as a saturable absorber. The lasing wavelength is roughly determined by a band-pass filter (BPF) of 0.6 nm band-width. The gain and absorption peak wavelengths of the employed EDF amplifier (EDFA) and un-pumped EDF are around 1560 nm. The laser cavity length is 18.2 nm. The measured line-width the fiber laser is approximately 4 kHz. At the wavelength of 1560 nm, the slope efficiency and the oscillation threshold without the external light injection are 18.56 % and 11.23 mW, respectively. To optimize the interference between the oscillation and external lights in the saturable absorber, the polarization controller (PC) is employed to adjust to the state of the polarization of the oscillation light.

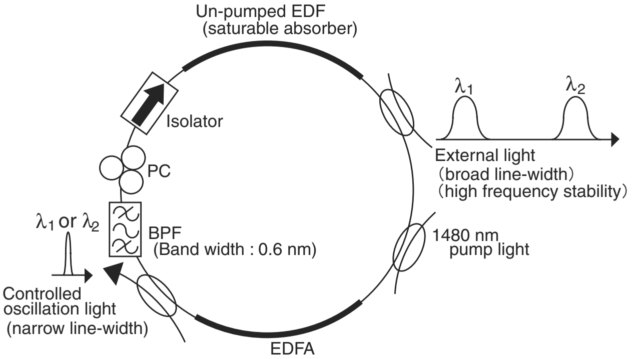
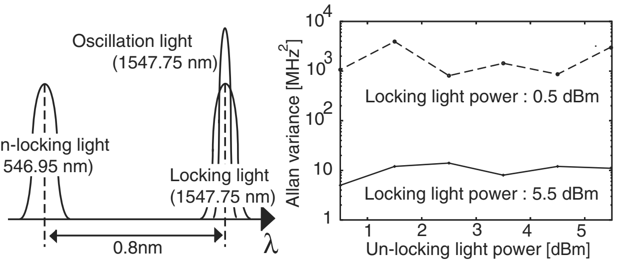


Figure 1: Setup of a single-frequency fiber laser

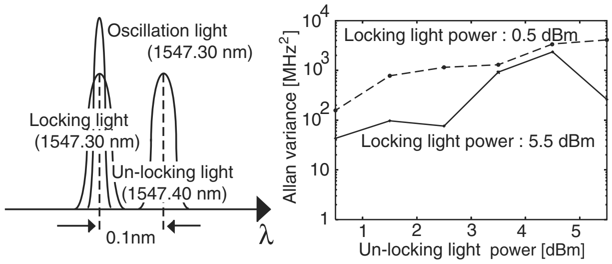
When the wavelength difference between oscillation and external lights is large, the oscillation frequency is not locked to the external light. On the other hand, the frequency can be locked as the oscillation wavelength is close to the wavelength of the external light. Such frequency control is achieved by cooperatively induced spatial hole-burning (SHB) of the absorption formed by the lasing and the external lights in the saturable absorber [4, 5]. Previously, we demonstrated the frequency control of the single-frequency fiber laser using an external light. In this work, we employed a dual-wavelength external light source whose wavelength spacing corresponds to the frequency grid of ITU-T. By tuning the BPF in the cavity, the oscillation light can be frequency-locked to one of the external lights. We investigate the frequency stability of the fiber laser for various injected powers and wavelength spacings of the two external lights.

Experiment and results

To investigate the performance of frequency locking of the proposed method, we measured the frequency stability with changing the wavelength spacing between the two external lights. The frequency stability is quantitatively estimated by employing Allan variance [6, 7]. For example, Allan variance of the fiber laser at free-running operation is in order of several hundreds MHz^2, whereas the value of the employed external light source is about 10 MHz^2.



(a) In the case of 0.8 nm wavelength spacing



(b) In the case of 0.1 nm wavelength spacing

Figure 2: External light power dependence of Allan variance

If the BPF is tuned to one of the external light wavelength, the frequency of the fiber laser is locked to the external light. Figure 2 shows Allan variance of the fiber laser controlled by the dual-wavelength external light as the function of the injected powers of the external lights. In the case of 0.8 nm wavelength spacing, the wavelength of the injected external lights are 1546.95 nm and 1547.75 nm, respectively. In Fig. 2 (a), the oscillation wavelength of the fiber laser is locked to the longer wavelength external light. When the injected power of the shorter wavelength external light (un-locking light) is changed, no remarkable change of the frequency stability is observed. On the other hand, it can be clearly seen that the power of the locking light strongly affects the stability. Moreover, we obtain similarly high stability for wavelength spacing above 0.2 nm. On the other hand, for the wavelength spacing of 0.1 nm, good frequency stability is not obtained regardless the injected powers of the locking and un-locking lights. We believe that this behavior is due to broad bandwidth of the employed BPF (0.6 nm) in the cavity. Further improvement of the stability will be possible using BPF with a narrower bandwidth.

Figure 3 shows Allan variance of the fiber laser when the oscillation wavelength is tuned in the range of 1546.94 nm to 1547.26 nm by the BPF. The wavelengths of the external lights are 1547.00 nm and 1547.20nm, respectively. These injected powers are set to 5.5 dBm. As shown in Fig. 3, the lasing frequency is successfully locked to either of the external light with high frequency stability when the oscillation wavelength of the fiber laser is close to the corresponding external light wavelength.

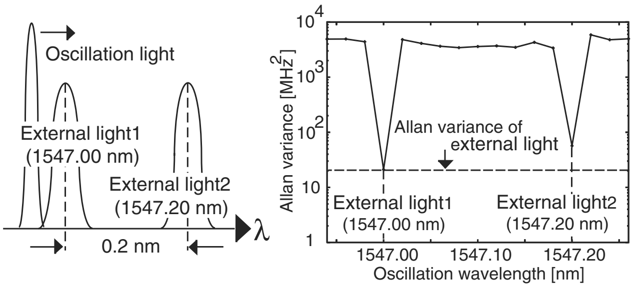


Figure 3: Allan variance with tuning the oscillation wavelength of the fiber laser

Conclusion

We proposed and demonstrated a frequency locking with dual-wavelength external light injection and investigated the frequency control characteristics. The oscillation frequency was successfully locked to the frequency of the external light with high frequency stability for the external wavelength spacing above 0.2 nm. If external light sources with the ITU-T grid are employed, the proposed single-frequency fiber laser will be applicable to a narrow line-width operation corresponding to the ITU-T grid. Such light source will be useful for future DWDM transmission systems.

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