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ULTRA STABLE COHERENT SOURCES BASED ON INJECTION LOCKED DFB FROM A FEMTOSECOND FIBER LASER COMB

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Abstract − We propose ultra stable coherent laser sources based on optical injection locked single mode of the femtosecond fiber laser comb. The source is discretely tunable coherent optical sources by two DFB lasers, which are injection-locked to a respective single mode of the fiber laser comb with the frequency difference of 500 MHz, that is exactly twice of the comb repetition frequency.

Keywords: injection locking, fiber laser comb, DFB laser

1. INTRODUCTION

The optical frequency comb generator (OFCG) has revolutionized the field of optical frequency metrology over the past decade by providing an absolute frequency ‘ruler’ [1, 2]. Although the OFCG has a possibility as optical sources for the optical communication and for the high-resolution spectroscopy, it has been used in these applications only in limited cases due to the low power of each comb mode and the narrow mode-spacing. The recently-developed comb injection locking technique [3-6] has solved these problems by extracting a single comb mode and amplifying its mode power. This technique has been applied to the absolute frequency measurements utilizing the enhanced signal-to-noise ratio of the heterodyne beat between the comb and the laser to be measured [7, 8]. Some experimental results of high resolution spectroscopy with this technique have also been reported [9, 10]. The beating signal between the selectively injection locked DFB lasers from modes of OFCG can be used as frequency synthesizer. In this paper, we select a desired single mode from a fiber femtosecond laser comb with a very narrow spacing of 250 MHz and demonstrate ultra stable coherent optical sources by using two injection locked DFB lasers at the desired comb mode of an OFCG based on a fiber femtosecond laser.

2. EXPERIMENTAL SETUP

Figure 1 shows a schematic of the experimental setup for

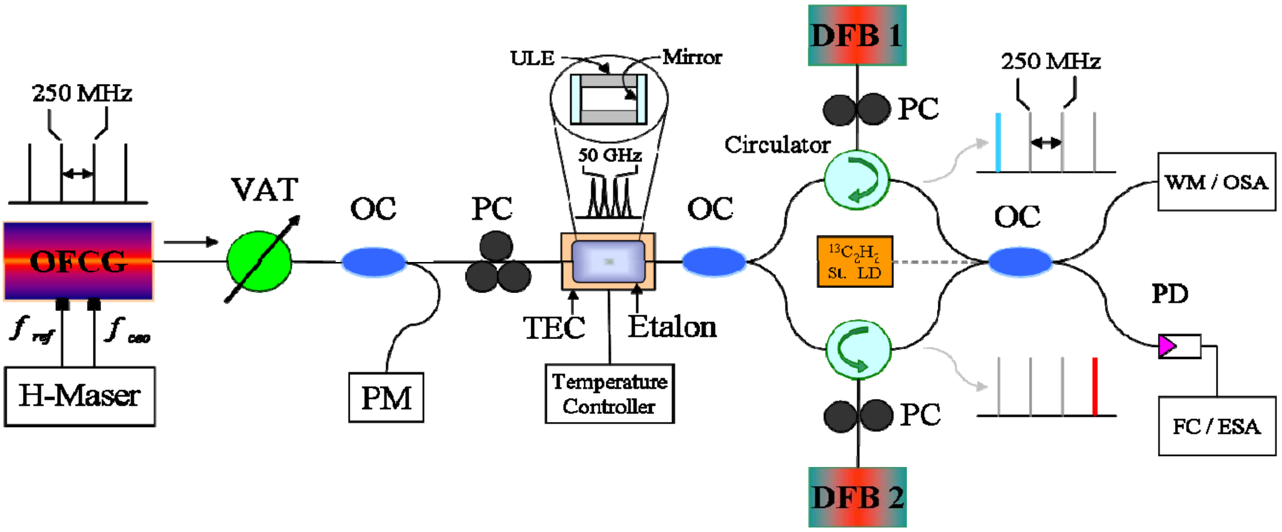

Fig. 1: Experimental setup for ultra stable coherent laser sources based injection locked two DFB lasers. The optical frequency comb generator (OFCG) was used for the injection seeding. VAT: variable attenuator, OC: output coupler, PM: power meter, PC: polarization controller, PD: photo detector, OSA: optical spectrum analyzer, WM: wavelength meter, FC: frequency counter, ESA: electrical spectrum analyzer

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ultra stable coherent laser sources using OFCG. The OFCG was stabilized to two degrees of freedom of a comb with a repetition rate of 250 MHz and a carrier envelope offset (CEO) frequency of 20 MHz, as determined using the f-2f technique. The total output power and center wavelength of the OFCG are 200 mW and 1560 nm, respectively. The injected power of the OFCG was adjusted through a variable attenuator (VAT). An output coupler (OC) was used to monitor the comb power entering the DFB laser by a power meter. After passing through the output coupler, the optical comb enters the polarization controller (PC). An etalon filter was used to filter the desired bandwidth of the optical comb. The mode filtered combs were injected into the DFB laser through the circulator. In order to inject the comb modes into the DFB laser, a DFB laser module without an isolator was installed behind the PC. The center wavelength of two DFB laser is 1542.72 nm at an output power of 20 mW and can be tuned by adjustment of current and temperature for selecting of different frequency comb components. The beat frequency between the two injection locked DFB lasers were detected by a photo detector (PD) and recorded by a frequency counter synchronized to a time base obtained from the H-maser with a relative stability of 2 × 10^{-13} at 1s.

3. RFSULTS

Figure 2 shows the transmittance spectrum of etalon filter before to DFB laser. The free spectral range (FSR) and finesse of the etalon filter are 50 GHz and 60, respectively. The mode filtered combs with 250 MHz spacing can be seen in insert figure 2. The number of comb modes can be limited to approximately 1 GHz by the etalon filter. The maximum side mode suppression ratio was more than 25 dB .The filtered comb components were injected into the DFB lasers.

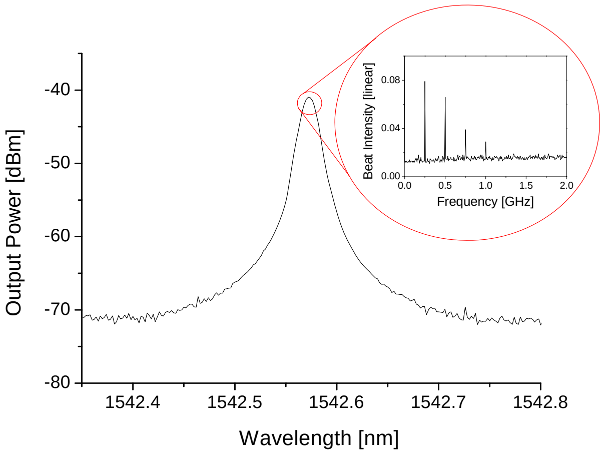

Fig. 2. The transmittance spectrum of etalon filter with 50 GHz spacing. The insert is RF spectrum of optical comb after filtered by the etalon filter.

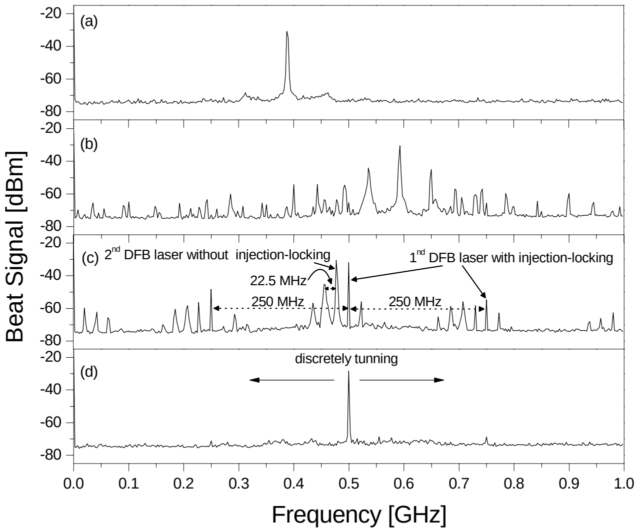

Fig. 3. The beat signals between the two DFB lasers illustrating the injection–locking process for the ultra stable coherent optical sources. (a) without the OFCG-injection to both lasers, (b) with the OFCG-injection to both lasers without the injection-lock, (c) when one of the laser is injection-locked to the OFCG, while the other is not, (d) when both of the lasers are injection-locked to a respective single mode of the OFCG, with the frequency difference of 500 MHz.

We used another DFB laser to demonstrate the convenient frequency selection of ultra stable coherent optical sources. After injection-locking the first DFB laser, the frequency selection and the injection-locking of the second DFB laser can easily be performed by using the first DFB laser as a reference. Figure 3 shows the injection–locking process for the two DFB lasers. The beat signal between the two DFB lasers without the injection of the comb to both of the lasers is as shown in Fig. 3(a). Figure 3(b) shows the beat signal between the two DFB lasers when the comb was injected to both lasers, however the injection-locking is not established for either laser. The spectrum of the beat signal in this case shows a very complicated structure, which consists of the beat frequency between the two DFB lasers, the fundamental and the harmonics of the OFCG repetition rate, the harmonics of the beat signal between the OFCG and the first DFB laser or the second one, and the electrically mixed signals between all of these. By finely adjusting the current of the first DFB laser, we could select out a desired single frequency comb mode. Figure 3(c) shows the beat signals between the two DFB lasers in this situation, where the first DFB is injection-locked to a single mode of the OFCG and the second one is not injection-locked yet. It should be noted that this is the start point for the frequency selection of the second laser, if we have already stabilized the first laser frequency by an OFCG injection-locking, as explained in the last paragraph with the monitoring by an acetylene-stabilized laser. In Fig. 3(c), the signals at the multiples of 250 MHz are made from the beat between the first injection-locked DFB laser and the amplified comb modes in the second DFB laser, which is not injection-locked yet. The signal at 477.5 MHz is the beat signal between the first DFB laser and the second one, and other beat frequencies with 22.5 MHz spacing are attributed to the harmonics and the electronic mixing of these signals. The frequency offset of the second laser from the first one can easily be tuned by varying the current of the second laser. We can confirm the injection-lock of the second DFB laser by observing that only one tooth of the beat signal is dominant and stable in its frequency as in Fig. 3(d). As we increased the comb injection power from 40 to 200 μW, the locking range also increased. However, at higher power, the injection lock had a tendency to be unstable due to the_nearest side mode amplification. Thus, the experimental results in this letter were obtained under the condition of the injection power level of 140 μW, when the locking range was more than 100 MHz. The side-mode suppression ratio was more than 40 dB as can be seen in Fig. 3(d). The linewidth of the beat signal between the two injection–locked DFB lasers was less than the resolution bandwidth limit (10 MHz), which indicates the phase-coherence between the comb modes.

4. CONCLUSIONS

We have demonstrated the ultra stable coherent laser sources using a selected mode by DFB laser from an optical frequency comb generator (OFCG) with high stability. The injection locking schemes of a DFB laser consist of components based on fiber that is compact and easily aligned. The frequency difference of the two injection-locked lasers is only limited by the electronic bandwidth including the photodetector and the total number of the injection-locked lasers is not limited in principle. The ultra stable coherent sources with injection locked DFB lasers are expected to be adopted as a light source that can be used for the absolute frequency reference (AFR) of ITU-T grids, THz sources and high-resolution coherent spectroscopy in the optical communications field.

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