An Er:Fiber Femtosecond Optical Frequency Comb for Measurement of the D_1 Line in Cold ^{6}Li Atoms

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***Abstract*—In this paper, we demonstrate a home-made Er:fiber femtosecond optical frequency comb system. The system includes Femtosecond laser, detection and control of f_{rep} and f_{ceo}, Spectral broaden and Beat unit. By controlling the intra-cavity electro-optic modulator and piezoactuator , the f_{rep} is stabilized with high bandwidth and large range (about megahertz bandwidth and 3 kilohertz range).In-loop frequency instability of f_{ceo} and f_{rep} are $3.7\times10^{-18}/\tau^{1/2}$ and $1.8\times10^{-13}/\tau^{1/2}$ respectively. By using highly nonlinear fiber and MgO: Periodically poled lithium niobate , the Spectral range of femtosecond optical frequency comb is extended from infrared 1520-1607 nm to 671 nm.This system can be commendably used in measurement of the absolute frequency of D_1 line in cold ^{6}Li atoms.**

Keywords—optical frequency comb; femtosecond fiber laser; spectral broaden; frequency measurement

I. Introduction

Optical Frequency Comb (OFC) is a frequency-controlled femtosecond laser, which is an equally spaced frequency comb teeth in the frequency domain. As the most efficient and simple optical frequency measurement tool, OFC can convert optical frequency into radio frequency for directly frequency measurement. It is widely used in astronomical spectroscopy measurement and calibration [1-3], laser frequency measurement [4], absolute distance measurement [5,6] and precision spectral measurement [7,8]. In the precision spectral measurement, by extending the spectral range of OFC to cover the single-frequency lasers, the beat signal between OFC and single-frequency laser can be obtained. Then, the stable single-frequency laser can be obtained and measured by phase-locking the beat signal to a stable radio frequency source[9].

This paper reports a complete Er:fiber OFC system for the measurement of D_1 line in cold ^{6}Li atoms. It includes three parts: Femtosecond laser, Detection and control of f_{rep} and f_{ceo}, Spectral broaden and Beat. A nonlinear-polarization-rotation (NPR) mode-locked laser is used as the femtosecond laser, its center wavelength is 1572 nm and repetition rate is 196.5 MHz, respectively. Frequency control unit employing phase-locked system to lock the comb teeth of OFC to a stable radio frequency source. In-loop frequency instability of f_{ceo} and f_{rep} is approximately 3.7×10^{-18}@1s and 1.8×10@1s. Optical spectrum is broadened and multiplied from infrared 1520-1607 nm to 671 nm by using highly nonlinear fiber (HNLF) and MgO: Periodically poled lithium niobate (PPLN). Finally, obtaining the beat signal between the single-frequency laser and OFC about 60 dB at the resolution bandwidth (RBW) of 1 Hz .

II. Methods/Results

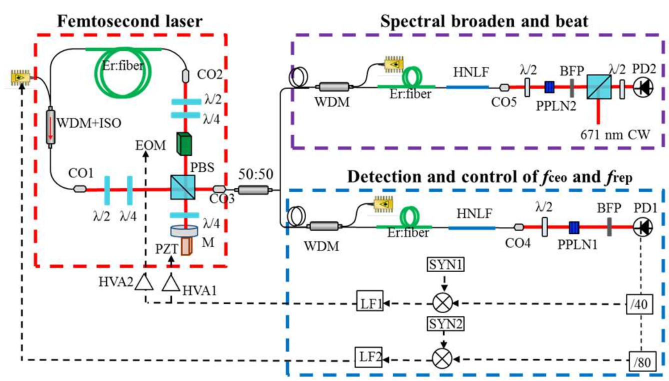

Fig. 1. Experimental setup of optical frequency comb(OFC) system.Col, collimator; λ/2, half wave plate; λ /4, quarter wave plate; PBS, polarization beam splitter;EOM, electro-opticmodulator; PZT, Piezoelectric ceramic; WDM+ ISO,wavelength division multiplexing with isolator;M, mirror; HNLF, highly nonlinear fiber;PPLN, MgO: Periodically poled lithium niobate;BPF,band pass filter;SYN ,frequency synthesizer;LF, loop filter; HVA, high voltage amplifier.Thick solid lines and curves represent opticalfibers; red solid lines represent free-space paths.

The experimental setup of the OFC system is shown in figure 1. , Including three parts: Femtosecond laser, detection and control of f_{rep} and f_{ceo}, Spectrum broaden and beat frequency unit. Femtosecond laser source is a home-made Er:fiber laser based on NPR mode-locking mechanisms. The output power of the laser is 52 mW at a pump power of 590 mW . The fundamental repetition rate is up to 196.5 MHz and the pulse width is 59 fs. Detection and control of f_{rep} and f_{ceo} unit produces a stable frequency source by phase-locking f_{rep} and f_{ceo} . f_{ceo} can be detected by f-$2f$ interference. f_{rep} and f_{ceo} are referenced to signals produced by a frequency synthesizer (SYN). The control components are the current source of the pumping laser for f_{ceo}, and a piezoactuator (PZT) and an electro-optic modulator (EOM) for f_{rep}. The wavelength of D_1 line transition frequency of Li atom is around 671 nm. Spectrum broaden and beat unit produces the spectral range of output coverd 671 nm by using spectral broaden and frequency multiplication technology. The output laser spectrum can be first expanded to 1342 nm by using HNLF, and then be doubled to 671 nm by using PPLN. Finally,PD2 detected the beat signal between OFC and single-frequency laser.

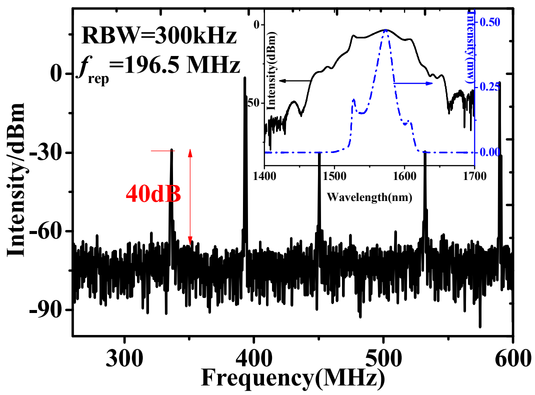

Fig. 2. RF spectrum and spectrogram of OFC

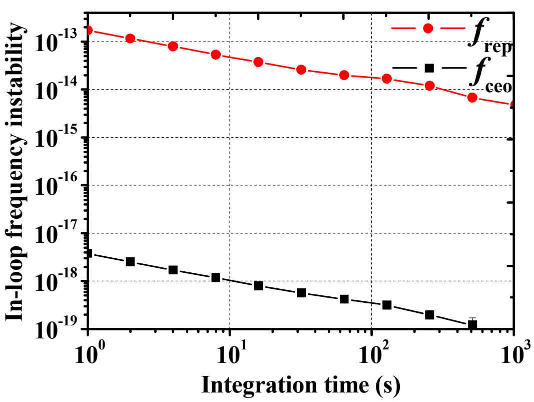

Fig. 3. In-loop frequency instability

Figure 2 shows RF spectrum and spectrogram of OFC. The insert of Figure 2 shows the optical spectrum of mode-locked laser. Center wavelength is 1572 nm ,and the spectral bandwidth at 3 dB is 35 nm. Signal Noise Ratio (SNR) of f_{ceo} is about 40 dB (RBW=300 kHz), which meets requirement for OFC locking.

Figure 3 shows in-loop frequency instability of OFC after phase-locking. In-loop frequency instability of f_{ceo} and f_{rep} are $3.74\times10^{-18}/\tau^{1/2}$ and $1.75\times10^{-13}/\tau^{1/2}$, respectively. This is much less than the frequency jitter of OFC Under the condition of free operation.

The insert of Figure 4 shows the spectrum distribution obtained after PPLN. The output power at 671nm is 0.25 mW, the spectral bandwidth at 3 dB is 0.2 nm. By simple derivation, we know that he output intensity at 671 nm is 0.681 mW /nm and the power of per mode at 671 nm is 208 nW. The power of per mode is greater than 100 nW, which meets the power required for beat with single-frequency laser. Figure 4 shows beat signal between OFC and single-frequency laser. The SNR of the beat signal is about 60 dB at the RBW of 1Hz, which can drive the commercial frequency locking servo to locking the single-frequency laser and transfer the stability of the OFC to which of the single-frequency laser.

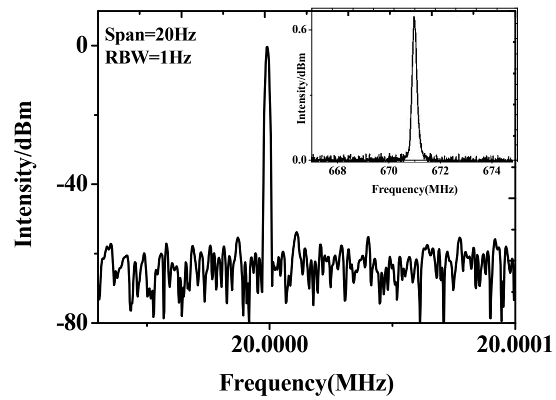

Fig. 4. Beat signal between Optical Comb and single frequency laser. Spectrum at 671nm

III. DISCUSSION/INTERPRETATION

In this paper, We demonstrate a home-made Er:fiber OFC . In-loop frequency instabilities of f_{ceo} and f_{rep} are $3.7\times10^{-18}/\tau^{1/2}$ and $1.8\times10^{-13}/\tau^{1/2}$, respectively. The instability of the f_{rep} is limited by the noise level of the counter. However, the instability of 2×10^{-14}@100s provides the accuracy of the order of 10 Hz for the frequency measurement, matching the need for the Lithium transition frequency measurement.

IV. CONCLUSIONS

An Er:fiber OFC for of the Lithium transition frequency measurement has been designed. Its In-loop frequency instability satisfied for accuracy in measurement. The optical comb and its application system described in this paper can also be extended to other wavelength range for precision spectral measurement.

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