Coherent Population Trapped Spectrum Based on Chip-scale External Cavity Diode Laser

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***Abstract*—This article reports a scheme for obtaining coherent population trapping (CPT) spectrum based on a chip-scale external cavity diode laser (CECDL). The CPT spectrum linewidth is 680Hz. Compared to the scheme using vertical cavity surface emitting laser (VCSEL), CECDL has a comparable small volume and higher laser power of 14mW and narrower linewidth of 270kHz. This is beneficial for improving the frequency stability performance of CPT chip-scale atomic clocks.**

***Keywords*—CPT, atomic clock, external cavity laser, chip scale**

I. Introduction

The coupling of two ground states to a common excited state by means of two coherent radiations leads to interference effects in the excitation process, a phenomenon that has been called coherent population trapping (CPT) [1]. CPT chip scale atomic clocks have the advantages of small size, low power loss, and good stability. With the rapid development of atomic clock technology, CPT chip scale atomic clocks have been applied in many fields, such as navigation and positioning, secure communication, time-frequency synchronization, portable military equipment, etc. The laser source commonly used in CPT chip-scale atomic clocks is VCSEL [2]. But its linewidth is wide, usually several tens of MHz. Compared to the VCSEL, the linewidth of external cavity diode lasers is usually narrower in 100 kHz level. However, classical external cavity lasers usually have large size and limited modulation bandwidth, making it difficult to be used for CPT chip-scale atomic clocks.

II. Experimental Setup and Result

The chip-scale external cavity diode laser (CECDL) we utilized weighing 4.062g and having a volume of 0.896cm³, with a modulation bandwidth of more than 4GHz. ^{87}Rb atoms are filled into a cube vapor cell with a volume of 0.216cm³. The CECDL and atomic vapor cell are shown in Figure 1 (a) and (b).

In this experiment, the laser frequency was tuned to the ^{87}Rb atom $5^2S_{1/2}$, F=1, F=2 → $5^2P_{1/2}$ transition line, and the energy level structure of the 87Rb atom D1 line is shown in Figure 1(C). Due to the narrow continuous mode free range of external cavity lasers, it is difficult to directly observe all the complete absorption spectra. So we observe the laser wavelength by a wavelength meter at first. By changing the current and temperature values, the wavelength can be stabilized at 794.977nm.

By adding 3.417GHz microwave modulation to the laser, changes of the laser cavity mode can be observed on an oscilloscope. By gradually increasing the power of the

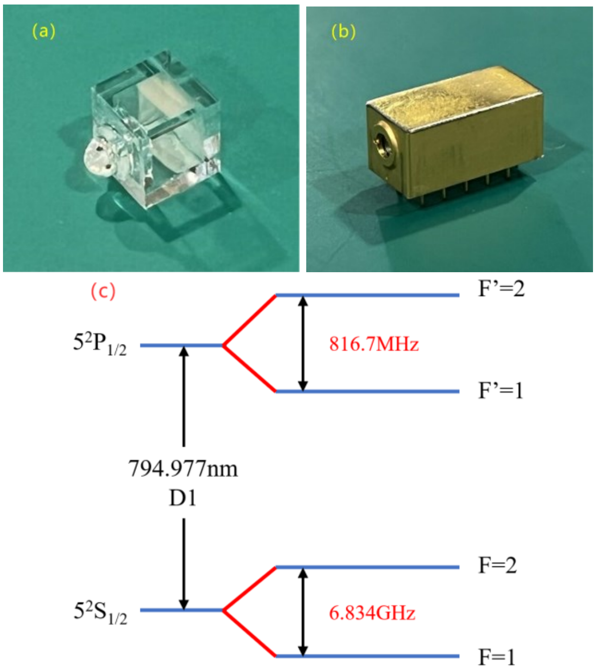

Fig. 1. (a) ^{87}Rb vapor cell. (b) Chip-scale external cavity diode laser. (c) Hyperfine structure of D1-line of ^{87}Rb.

3.417GHz microwave signal, the laser ±1st order sideband gradually increases. According to the experimental results, the absorption spectra shape is optimal when the ±1st order sideband is 1/4 of the signal intensity of the 0th order sideband. The ratio of ±1st order sidebands to the 0th order cavity mode of the laser is shown in Figure 2. As shown in the figure, the interval between the ±1st and 0th order sidebands of the laser is 3.417GHz. The sum of the two intervals is 6.834GHz. This corresponds to the frequency interval between the $5^2S_{1/2}$, F=1 → $5^2S_{1/2}$, F=2 energy levels in the ^{87}Rb atomic energy level structure.

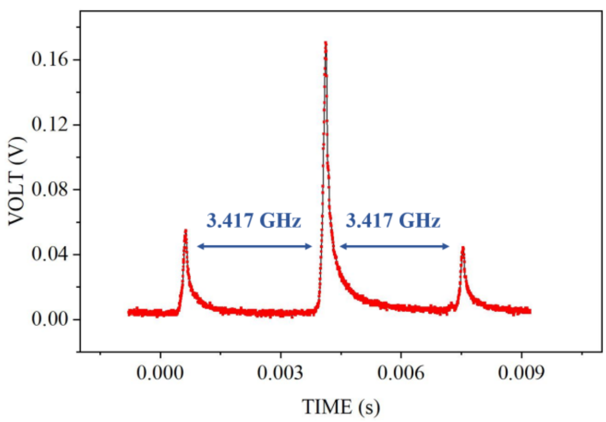

Fig. 2. Laser cavity mode spectrum after microwave modulation.

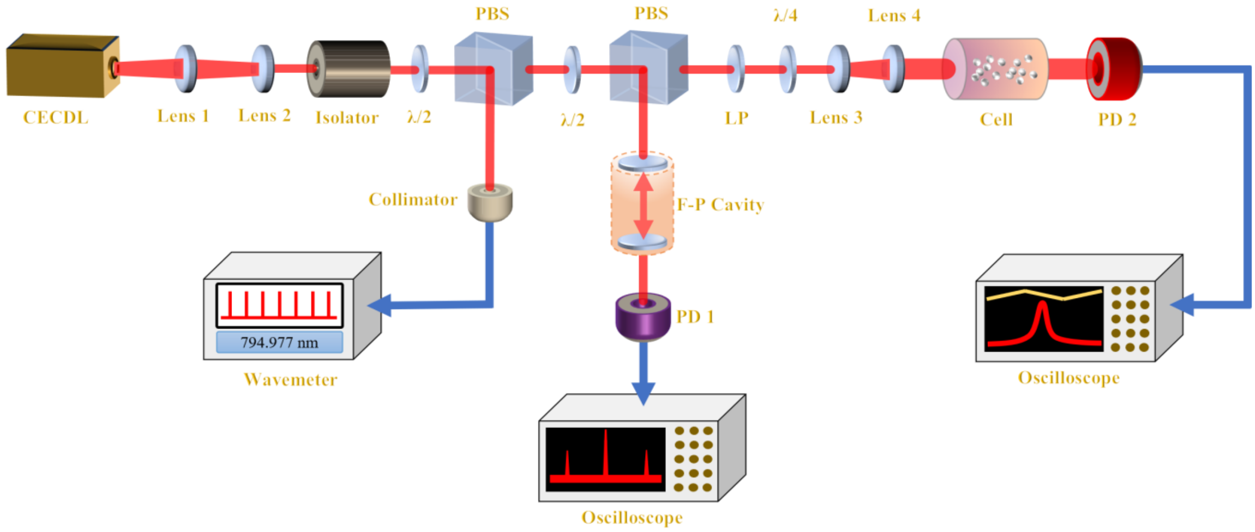

Fig. 3. Experimental optical path diagram. CECDL, chip-scale external cavity diode laser; Lens 1 and Lens 2, collimator lens; λ/2, halfwave plate; PBS, polarization beam splitter; LP, linear polarizer; Lens 3 and Lens 4, expander lens; PD 1 and PD 2, photo-electric detector.

As shown in Figure 3, the laser generated by the chip-scale external cavity diode laser (CECDL) is divided into three paths through two polarization beam splitters (PBS). The first path is injected into a wavelength meter for detecting the wavelength. The second path is injected into the F-P resonant cavity to observe the cavity mode spectrum of the laser directly modulated by 3.4GHz microwave signal. The last path passes through a linear polarizer, a λ/4 wave plate, and two beam expander lenses before being directed into an atomic vapor cell. Two expander lenses are used to expand the laser beam, allowing the laser to fully interact with ^{87}Rb atoms in the vapor cell. Finally the laser will be detected by a photo-electric detector (PD). Coherent population trapping (CPT) spectrum can be observed through an oscilloscope.

In the experiment , we lock the wavelength at 794.977nm

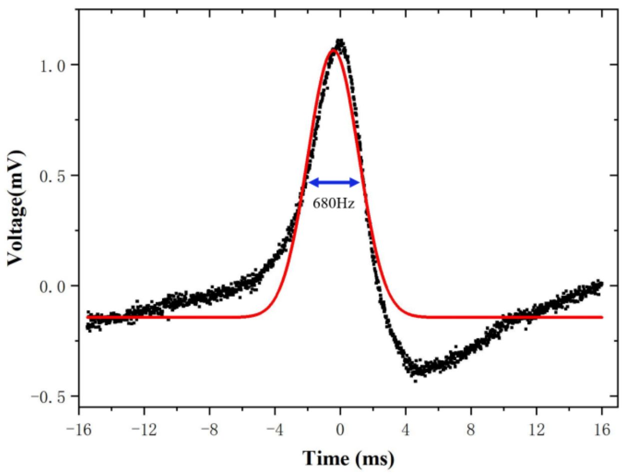

Fig. 4. Coherent population trapping spectrum obtained by chip-scale external cavity diode laser.

by adjusting the current and temperature of CECDL. And then, turn on the microwave signal scanning and apply microwave modulation to the CECDL through a bias-tee module. The frequency of microwave signal is 3.417GHz. By fine-tuning the microwave intensity and frequency, coherent population trapping (CPT) spectrum can be observed. Heating current can provide an undesired magnetic field for atomic vapor cell while controlling temperature. So we optimized the structure of temperature controller and magnetic field of the vapor cell. Finally, the obtained CPT linewidth is 680Hz, which is basically consistent with the test results by VCSEL. The compact external cavity laser we used in the experiment has a linewidth of 270kHz, which is two levels narrower than VCSEL. The CPT spectrum are shown in Figure 4. Due to the measurement of data is in Alternating Current mode, the spectrum is asymmetric. Due to the linewidth of the external cavity laser is narrower, which is beneficial for increasing the signal to noise ratio of the CPT clock.

III. Conclusions

This article proposes a new scheme for obtaining CPT spectrum using a chip-scale external cavity diode laser. The linewidth of CPT spectrum is 680Hz, which is basically consistent with the test results by VCSEL. However, the linewidth of the external cavity laser is narrower, which is beneficial for increasing the signal to noise ratio of the CPT clock. The results of this experiment will contribute to achieve a more stable CPT chip-scale atomic clock.

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