External Cavity Laser for Chip-Scale Atomic Clock

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***Abstract*—In this paper we report a new coherent population trapping (CPT) atomic clock based on external cavity laser. Unlike usual CPT atomic clocks, where used the vertical cavity surface emitting laser (VCSEL), we combine the external cavity laser (ECL) with CPT atomic clock to improve the stability. Compared with VCSEL, the ECL has higher laser power of 10 mW and narrower linewidth of 0.8 MHz, meaning that the signal-to-noise ratio of clock can be further improved.**

Keywords—CPT; atomic clock; chip scale; ECL.

I. INTRODUCTION

As the development of atomic clock technology, the chip-scale atomic clock is a crucial research direction and can be applied in many fields such as time keeping Navigation system [1-2], secure communications, time synchronization, precise timing in portable military equipment, and artificial intelligence [3-5]. The combination of atomic clock and coherent population trapping (CPT) has become the key scheme of chip-scale atomic clock as the CPT signal with small linewidth and the simplicity of clock system [6-7]. The CPT atomic clocks' performance mainly depend on four components including laser, mechanical design, control system and electronic circuits, in which the laser's performance is one of the crucial factors [8]. Now CPT chip-scale clock mainly uses the vertical cavity surface emitting laser (VCSEL) to generate the light corresponding to the atomic transition. The signal to noise ration of the clock transition spectrum depends on the laser's linewidth and power. Compared with VCSEL, the external cavity laser (ECL) can be used to realize the more superior performance with narrower linewidth and higher laser power.

In this paper we realized the ECL with 10 mW laser power, 0.8 MHz linewidth and size of 1.6 cm×0.8 cm×0.9 cm. Based on it, we propose a new scheme to construct the CPT chip-scale atomic clock through the combination of ECL and CPT atomic clock. Due to the improvement of the signal-to-noise ratio, the stability of the chip-scale atomic clock also has high potential to be improved in the future.

II. EXPERIMENTAL SETUP

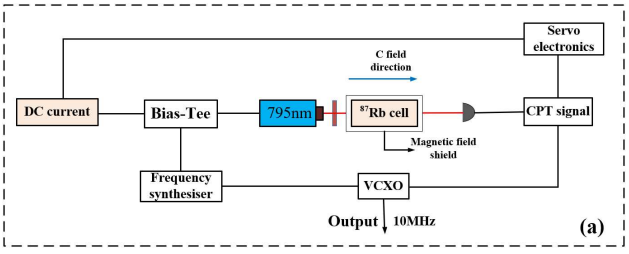

Fig. 1. The scheme of CPT atomic clock

The basic principle of CPT atomic clock as shown in Fig. 1, the wavelength of ECL we realized is 794.98 nm corresponding to the D1 line of ^{87}Rb atoms as shown in Fig. 2. And the internal layout of ECL is shown in Fig.3(b), which consist of diodes, mechanical structure, and optical elements.

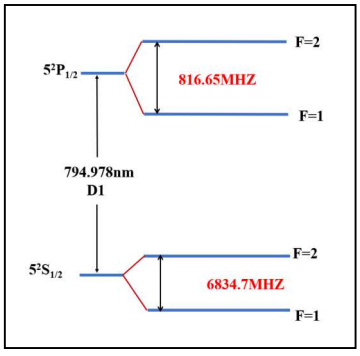

Fig. 2. Hyperfine structure of D1-line of ^{87}Rb.

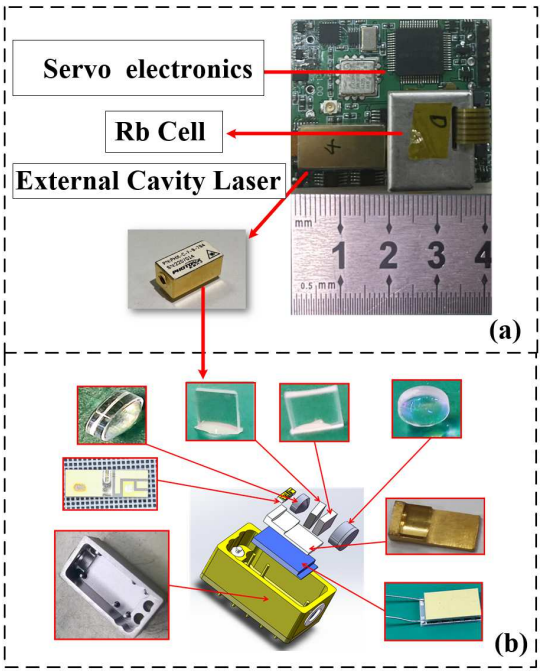

Fig. 3. The layout of ECL including diodes, mechanical structure and optical elements.

We have constructed the chip-scale atomic clock based on the CPT principle as shown in Fig.3(a), more details are omitted because it is still in test stage. In which the ECL used in our laser system is shown in Fig.3(b). Experimentally we realize CPT atomic clock prototype system by using ECL with size of 1.6 cm×0.8 cm×0.9 cm.

III. RESULTS

The key performances of the laser applied in CPT chip-scale atomic clock as shown in Fig.4:

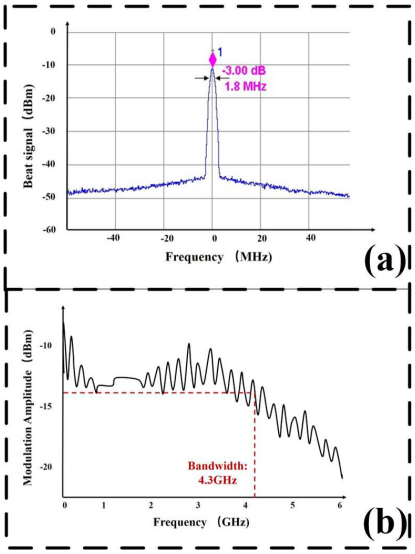

Fig. 4. The key performance of the laser in CPT chip-scale atomic clock , including linewidth of 0.9 MHz as shown in Fig. 4(a) and response modulation bandwidth of 4.3 GHz.

In summary, the ECL in chip-scale optical clock performance at 794.98 nm can achieve a power output of 10 mW, a linewidth of 0.8 MHz, and a modulation response bandwidth of 4.3 GHz. In addition, its side-mode-suppression ratio (SMSR) is larger than 35 dB.

IV. DISCUSSION

Compared with VCSEL in CPT chip-scale atomic clock, the ECL's output power 10 mW is much larger than the laser power conventionally used in VCSEL ~0.5 mw. Furthermore, the ECL has a narrower line width~0.8 MHz than the VCSEL~100 MHz.

The optimization of laser power and linewidth will enhance the signal CPT spectrum signal-to-noise ratio to improve the stability of chip-scale atomic clock in the future.

V. CONCLUSIONS

This report propose a new scheme to realize CPT chip-scale atomic clock by changing the conventional laser- VCSEL to the ECL to improve the performance of chip-scale atomic clock , we have realized the ECL with higher laser power and narrower linewidth.

In the future, we will apply the ECL in the CPT atomic clock to realize the CPT chip-scale microwave clock with high stability. This work will improve the CPT atomic clock' usability and make CPT chip-scale atomic clocks easily applied in the certain military and civilian fields.

REFERENCES

[1] J.H. Won, D. Dominik, E.Bernd, "Performance comparison of different forms of Kalman filter approaches for a vector-based GNSS signal tracking loop," Navigation, vol.57, pp. 185–199, June 2010.

[2] M. Lashley, D. M. Bevly, "Vector delay frequency lock loop implementation and analysis," Proc. of the 2009 Int. Technical Meeting of the Institute of Navigation, 2009, pp.1073–1086.

[3] H. Sun, Q. Sun, S. Biereigel et al. "A radiation tolerant clock generator for the CMS endcap timing layer readout chip", J. Instrum. , Vol. 17, C03038, March, 2022.

[4] R. Lutwak, D. Emmons, W. Riley, et al. "The Chip-Scale Atomic Clock Coherent Population Trapping Conventional Interrogation", Proceedings of the 34th Annual Precise Time and Time Interval Systems Applications Meeting Reston, Virginia December 3-5, 2002.

[5] J. Vanier, A. Godone and F. Levi, "Coherent population trapping in cesium: dark lines and coherent microwave emission", Phys. Rev. A vol. 58, pp. 2345-2358, September, 1998.

[6] A. Godone, F. Levi and J. Vanier, "Coherent microwave emission in cesium under coherent population trapping", Phys. Rev. A vol. 59, pp. R12-R15, January, 1999.

[7] J. E. Kitching, H.G. Robinson, and L. Hollberg, "Compact microwave frequency reference based on coherent population trapping", Proc. of the 6th Symp on Freq. Stands. and Metrology, pp. 167-174, 2001.

[8] St Andrews, Scotland, P. Gill, editor, World Scientific, London; J. Kitching, S. Knappe, and L. Hollberg, "Performance of small-scale frequency references", Proc. of the IEEE Int. Freq, Cont. Symp. May 29-31, 2002.

[9] E. Arimondo, "V coherent population trapping in laser spectroscopy", Prog. Optics, vol. 39, pp. 257- 354, 1996.