Chip-Scale Optical Clock Scheme Based on Dual-Wavelength Modulation Transfer Spectroscopy

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***Abstract*—In this paper we propose a new scheme to realize the chip-scale optical clock by using a dual-wavelength modulation transfer spectroscopy (DWMTS). The electro-optical modulator (EOM) and isolator in conventional modulation transfer spectroscopy which is complicated to be built on chip can thus be avoided. We remove the EOM and isolator at the price of an extra laser, which perform the volume optimization of the entire optical system, making the optical clock based on DWMTS to be a competitive candidate.**

Keywords—optical clock; modulation transfer spectrum; chip-scale; frequency stability.

I. INTRODUCTION

Since the development of the atomic optical clock, optical clocks have been widely used in precise measurement and fundamental physics, such as length metrology, relativistic geodesy, gravitational-wave detection [1-4]. Due to high stability and accuracy of optical clock, the chip-scale optical clock also has been a key system for the implementation of high-coherence applications including data transmission, highly optical physical sensor [5-7]. Now the chip-scale optical clock mainly used two-photon spectroscopy to stabilize the laser frequency on the optical transition line due to its commercial-availability and narrow linewidth [8-10]. Similarly, the optical clock based on Modulation Transfer Spectroscopy (MTS) has been realized with high stability and accuracy [11]. However, The MTS with high performance is complicated to realize the chip-optical because of its optical complexity.

In this paper, we propose a new scheme to obtain the atomic dual-wavelength modulation transfer spectroscopy (DWMTS) by removing the electro-optical modulator (EOM) and isolator at the price of an extra laser. The simplicity of laser-integration makes it easier to realize the chip-scale optical clock.

II. EXPERIMENTAL SETUP

The optical path of the standard 780 nm MTS and DWMTS is shown in Figure 1. Here we compare the standard MTS optical path and DWMTS optical path. We can find that the EOM and isolator are necessary in the standard optical path, the EOM is used for the modulation of 780 nm laser, and the isolator protects 780 nm laser from the optical reflection.

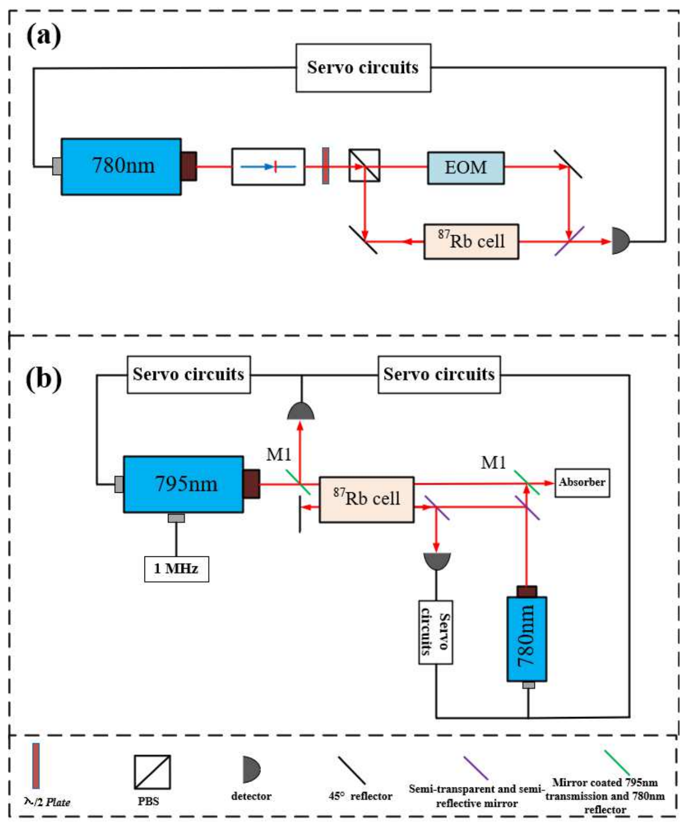

Fig. 1. The comparision of standard MTS optical path and MTS optical after optimization. (a) The standard optical path of 780 nm MTS with isolator and EOM. (b) The MTS optical path after optimization with removing the EOM and Isolator.

In the standard MTS optical path, the 780 nm laser is divided into two beams by a polarization beam splitter (PBS). One of the beams is modulated by an EOM, the other one as a probe light is detected to obtain the MTS of 780nm. Finally, we can get the discriminant signal to stabilize the frequency of the laser by the servo circuits.

As Figure 1(b) shown in the DWMTS, firstly the 795 nm modulation signal is generated by the internal 1 MHz electrical modulation, which allows EOM to be removed. Secondly, a 780 nm laser as a probe light is used to obtain the DWMTS. One of the 780 nm optical path is used to perform the pre-stabilization, which makes the laser frequency to be resonant with zero-velocity atoms. Another optical path of 780 nm is coincident with 795 nm laser to obtain DWMTS.

Similarly, we can perform the stabilization of the 795 nm laser. And the absorber is used to absorb the useless light. Since the dual-wavelength laser 780nm and 795nm lasers in this system can be distinguished by the optical coating of lens M1, so that the 780 nm detection light is completely reflected to the detector without injecting into the 795 nm laser to cause light feedback, and no isolator is required in the optical path to protect the 795 nm laser.

III. RESULTS

1. The standard saturation spectroscopy of 795 nm laser.

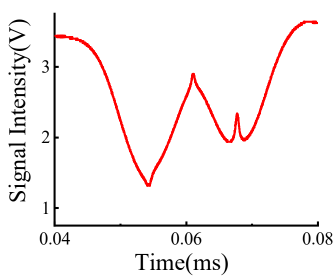

Fig. 2 The standard saturation spectroscopy of 795 nm.

The standard saturation spectroscopy of 795 nm laser as shown in Figure 1. There are three transitions peaks in the spectroscopy: transition peak of $5S_{1/2}$(F=2)—$5P_{1/2}$(F'=1); cross peak of $5S_{1/2}$(F=2)—$5P_{1/2}$(F'=1,2); transition peak of $5S_{1/2}$(F=2)—$5P_{1/2}$(F'=2).

2. The stabilization of 780 nm probe light

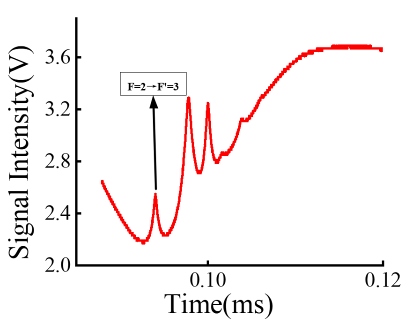

Fig. 3 The Saturation spectroscopy of 780 nm. The transitition line F=2→F'=3 is the lock point of 780 nm laser.

Fig. 3 shows the saturation spectroscopy of the 780 nm, there is high signal-to-noise ratio in the peak of $5S_{1/2}$(F=2)—$5P_{3/2}$(F'=3) for the saturation spectroscopy and MTS, which is suitable to perform the pre-stabilization of the frequency of 780 nm laser. Firstly, the 780 nm laser is stabilized on the $5S_{1/2}$(F=2)—$5P_{3/2}$(F'=3) transition line. Which meaning that 780 nm laser only interacts with zero velocity atoms.

3. The 780 nm probe light signal and comparison of standard MTS and DWMTS.

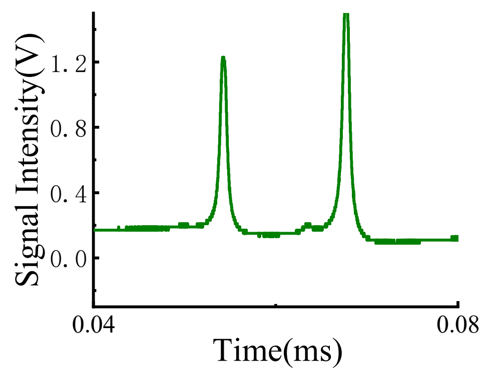

Fig. 4 The spectroscopy of 795 nm probe light in DWMTS.

Firstly, the 795 nm laser is modulated by an electric modulation signal of 1 MHz, the 795 nm as pump light interacts with atoms and the 780 nm laser of pre-stabilization as a probe light to detect atoms. The pump light is swept with triangle signal, and the probe signal as shown in Fig.4.

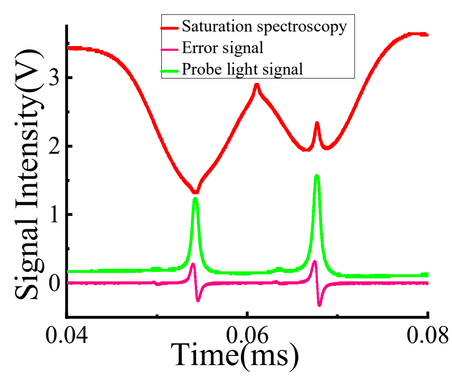

Fig. 5 The comparison of standard saturation spectroscopy and the 780 nm probe spectroscopy in DWMTS.

We compare the standard saturation spectroscopy of 795 nm and the spectroscopy in DWMTS as shown in Fig. 5. When the 795 nm laser is swept, the zero velocity atoms are quickly consumed in the ground state of ^{87}Rb atoms. Which is the reason that two transparent peaks are generated in probe light signal. Based on the spectroscopy, the error signal is produced by the process of modulation and demodulation as shown in Fig. 5.

IV. DISCUSSION

Here we demonstrate the feasibility of DWMTS. The removal of EOM and isolator has greatly eliminated the complexity of the MTS optical path, making DWMTS easier applied to realize the chip-scale optical clock.

V. CONCLUSIONS

This paper propose a new scheme to realize optical chip-scale atomic clock by introducing the DWMTS. The maturation of MTS makes it easy to improve the stability of optical chip-scale clock. Our work solves the problems in the conventional MTS to realize the chip-scale optical clock. It can be applied in different fields including optical communication and precise measurement.

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