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A compact coherent population trapping clock with a short-term fractional frequency stability of $4.2 \times 10^{-13} \tau^{-1/2}$

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Abstract—Based on the constructive polarization modulation coherent population trapping, we demonstrated a cw mode CPT clock with a short-term fractional frequency stability at the level of $4.2 \times 10^{-13} \tau^{-1/2}$ up to the averaging time of 100 seconds. This high performance and compact CPT atomic clock would lead more applications which concern on both the frequency stability and the compactness.

Keywords—CPT; Atomic clock; High performance

I. INTRODUCTION

The constructive polarization modulation coherent population trapping (CPT) [1] is a promising way to implement a high performance compact CPT clock [2,3]. Here we report the our progress towards a cw CPT clock with high performance.

II. LASER POWER & FREQUENCY LOCKING

As a prerequisite for the clock application, we need firstly stabilized the laser power and laser frequency, which is depicted in Fig. 2.

Fig. 1. Setup for laser power locking and laser carrier frequency locking.

We find the DFB diode laser in our setup is quite sensitively to the back-reflections, e.g., even the coated collimated lens may introduced some intensity and frequency noise at the regime of 100Hz to 10 kHz. A very careful alignment is need to find a position to minimum the noise induced by the lens and at the same time keep the well collimated laser beam. To reduce light feedback from EOPM fiber face, a 60 dB isolator before the EOPM is also utilized. We measured the laser relative intensity noise (RIN) before and after the fiber EOPM, as demonstrated in Fig. 3. We can clearly find the fiber EOPM induced additional intensity noise

between 1Hz to 1 kHz. The relatively high intensity noisy laser need to be stabilized. With the setup shown in Fig.2, we successfully suppressed most of these noises at least 15 dB in the range of 1 Hz to 1000 Hz.

Fig. 2. The laser RIN before and after pass through the EOPM, in the latter case, the RIN with and w/o laser power locking are recorded, the detector noise and analyzer noise floor are also presented.

With a setup similar to [3,4], we observed the two-color Doppler-free spectroscopy in a pure Cesium cell depicted in Fig. 4, thus we can lock the laser carrier frequency. The frequency noise with and w/o locking are presented in Fig. 5, from which we can find the servo bandwidth is about 3 kHz.

Fig. 3. Two-color spectroscopies in reference cell (pure Cesium) and clock cell (Cesium plus buffer gas).

Fig. 4. The laser frequency noise with and w/o laser frequency locking.

Fig. 5. Main setup and components for double-modulation CPT.

The Fig. 5 presented the main setup and components in our DM CPT, more detail can be found in [5]. The main difference in this studies are following, the laser beam diameter is expanded to $9\text{mm} \times 16\text{mm}$ before the vapor cell. The cylindrical Cs vapor cell, 25mm diameter and 50 mm long, is filled with 15 Torr of mixed buffer gas (argon and nitrogen). The cell temperature is stabilized to about 35°C . In our experiment a uniform magnetic field of $3.43\text{ }\mu\text{T}$ along the direction of cell axis is applied to remove the Zeeman degeneracy.

The typical CPT signal of clock transition is present in Fig 6, with contrast $C=5.6\%$ and linewidth $\text{FWHM}=385\text{Hz}$.

Fig. 6. Typical clock signal.

With this relative high contrast and narrow linewidth CPT signal, we lock our local oscillator to the atoms ensemble, and

compare it with Hydrogen maser, a preliminary results recorded in Fig. 7 show the frequency stability reach at the level of $4.2 \times 10^{-13}/\sqrt{\tau}$ up to the 100 seconds averaging time. These short-term frequency stability performances is very close to best CPT clocks. Further study will focus on the improvement of the mid-term and long-term frequency stability.

Fig. 7. Allan deviation of our DM CPT clock.

IV. CONCLUSION

We have demonstrated a cw CPT clock with polarization modulation, a short-term frequency stability of $4.2 \times 10^{-13}/\sqrt{\tau}$ until 100 second is measured. This results clearly demonstrated the feasibility to implement a high performance and compact CPT clock based on polarization modulation.

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