A Novel Scheme for Noise Suppression of CPT Resonance

Qinglin Li[1, 2], Tenghui Yang[1, 2], Peter Yun[1, 2, *]
[1]National Time Service Center, Chinese Academy of Sciences, East Shuyuan Road, Lintong, Xi'an, 710600, Shaanxi, China
[2]University of Chinese Academy of Sciences, Beijing 100049, China
*yunenxue@ntsc.ac.cn

***Abstract*—We proposed and demonstrated a continuous wave (CW) version of constructive, destructive & differential detection (CDD) of coherent population trapping resonance (CPT), in which we simultaneously observed electromagnetically induced transparency (EIT) and absorption (EIA) resonances with counterpropagating pump and probe bichromatic light beams. A differential CPT signal is also obtained with doubled amplitude and suppressed common-mode noise. The enhanced signal-to-noise ratio (SNR) of CPT resonance with one order of magnitude in this novel scheme could beneficial to implement high-performance CPT atomic clocks, as well as atomic sensors, and high-resolution spectroscopy.**

Keywords—coherent population trapping (CPT); electromagnetically induced transparency (EIT) and absorption (EIA); differential detection; common mode noise rejection.

I. Introdution

Coherent population trapping (CPT) is a quantum interference phenomenon widely studied in quantum state manipulation, high-resolution spectroscopy [1], atomic clocks [2], etc. Common-mode noise in CPT-based vapor cell atomic clocks, such as the laser amplitude modulation-amplitude modulation (AM-AM), frequency modulation-amplitude modulation (FM-AM), and photodetector noise, is one of the critical limitations to its short-term frequency stability. Based on our previous configuration [3], i.e., constructive, destructive & differential detection (CDD) of CPT with copropagating pump and probe light in pulse-mode, we further present a differential detection scheme for CPT atomic clocks designed to suppress noise. In this configuration, a pump bichromatic light interacts with the atomic ensemble, then the transmission light is reflected as a probe light and illuminates the atomic system again. With the proper polarization setting of the pump and probe beams, EIT and EIA signals are observed simultaneously. A differential CPT (diff-CPT) signal with medial linewidth but doubled amplitude is obtained by subtracting the EIT and EIA signals.

II. Experimental setup

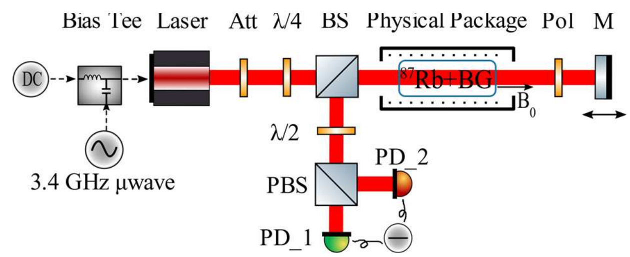

Fig. 1. The main experimental setup.

The experimental setup is depicted in Fig. 1. Similar to our previous demonstration [4], a distributed Bragg reflector (DBR) laser is adopted, which emits a 795 nm laser beam corresponding to the D_1 line of ^{87}Rb. The bichromatic light is split into two beams, one sent to a reference cell for laser frequency locking (not shown in the Fig.1). Another beam is sent to a clock cell for CPT experiments. In the scheme, a circularly polarized pump beam first prepares the atomic ensemble into a CPT state. Then the transmitted light is linear polarized and reflected as a probe beam to interrogate the atomic ensemble again. The two counter-rotating circular polarization components of linear polarized probe beam can be constructive or destructive to the previous CPT state according to their Raman phase relative to the pump beam. The probe light passes through a half-wave plate and a polarizing beam splitter (PBS) to complete polarization separation, then an EIT and EIA signals are observed by balanced photodetectors, and a diff-CPT signal also obtained by subtracting the two signals.

In contrast to previous Ref. [5], a smaller-sized cylindrical vapor cell is employed in this study. The vapor cell, with a length of 10 mm and a diameter of 10 mm, is filled with ^{87}Rb and 25 Torr buffer gas mixture of Ar and N_2 (with a pressure ratio of 1.6), and its temperature is stabilized around 68 °C. A static magnetic field of 1 μT was applied along the axial direction of the vapor cell to provide a quantized axis and remove the Zeeman degeneracy. Two layers of permalloy surround outside of the vapor cell as a magnetic shield to prevent the disturbance of the ambient magnetic field.

III. Results

Typical Zeeman spectra of EIT, EIA and diff-CPT signals are shown in Fig. 2(a), where the central peak, called the "0-0" clock transition, is shown in Fig. 2(b).

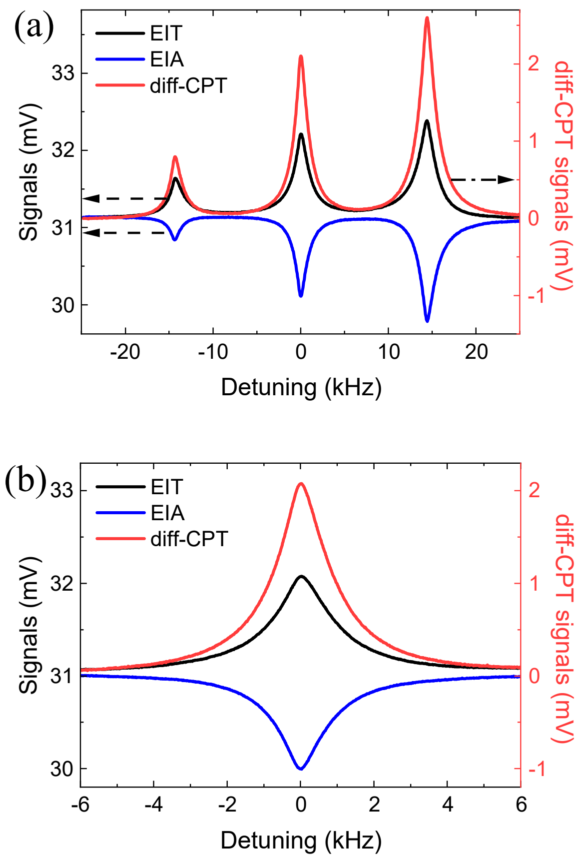

Fig. 2. Experimentally obtained typical Zeeman spectrum D_1 line of ^{87}Rb (a). The central peaks are the clock transition for different signals, which is zoomed in (b).

As shown in Fig. 2(a), the EIT and EIA signals almost exhibit opposite behaviors on the lineshape, which is responsible for the strong transmission and strong absorption experienced by the two, respectively. Fig. 2(b) shows the "0–0" clock transitions of EIT, EIA and diff-CPT signals. The linewidth of the three is almost the same, about 1.7 kHz. The amplitude of the diff-CPT signal is about 2 mV, almost twice that of the EIT and EIA signals, which is beneficial to improve the short-term frequency stability of the CPT atomic clock.

At a laser power of $P_L = 102$ μW, and with the microwave frequency tuned to the full width at half maximum at resonance for each of the EIT, EIA, and diff-CPT signals, the power spectral density (PSD) of these signals was measured using a spectrum analyzer (Stanford Research Systems SR785). The results are shown in Fig. 3.

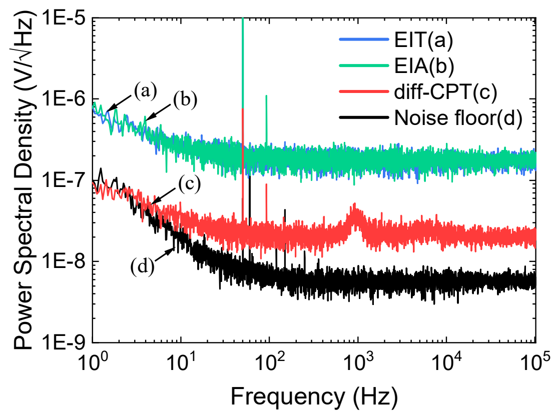

Fig. 3. Noise spectra.

In Figure 3, (a), (b), and (c) show the PSD of the EIT, EIA, and diff-CPT signals, respectively. The noise floor of the SR785, also shown in (d), serves as a reference for measuring the noise levels. At the Fourier frequency of 125 Hz, which is a typical modulation frequency used in CPT atomic clock to generated an error signal, the noise levels of the EIT and EIA signals are roughly the same, at about 1.8×10^{-7} V/√Hz, while the noise of the diff-CPT signal is significantly reduced to 2.0×10^{-8} V/√Hz, resulting in SNR improvement of approximately 12 dB. Except a spike around 1 kHz, which is believed due to the inherent noise of the differential channel of the balanced detector (Thorlabs, PDB210A), the noise levels of the diff-CPT signal is about one order of magnitude lower than that of EIT or EIA signals in the while studied frequency range.

IV. Conclusions

We propose and demonstrate a continuous wave (CW) version of CDD CPT with doubled amplitude and suppressed common-mode noise, where the interaction of counterpropagating bichromatic light fields with alkali metal atoms creates simultaneous EIT and EIA resonances. The diff-CPT signal based on this scheme has a higher SNR, and effectively suppresses the common mode noise of the system, especially AM-AM, FM-AM noise, etc. This scheme is suitable for compact high-performance CPT atomic clocks with sub-centimeter scale vapor cell.

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