Constructive, destructive and differential detection of coherent population trapping resonance

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***Summary*— We propose and demonstrate a coherent population trapping (CPT) scheme, in which a CPT dark state is constructively and destructively detected by a bi-chromatic light field with proper polarization and timing setting. Electromagnetically induced transparency (EIT) and electromagnetically induced absorption (EIA) resonances are simultaneously observed in a vapor cell. A differential-CPT (diff-CPT) signal, with doubled amplitude and suppression of common-mode noise of light and of the atomic ensemble, is then obtained by subtracting EIT and EIA resonances. This approach might be of great interest for the development of high-performance atomic clocks, sensors, or high-resolution spectroscopy.**

Keywords*— coherent population trapping (CPT); electromagnetically induced transparency (EIT); electromagnetically induced absorption (EIA); differential detection

I. INTRODUCTION

Coherent population trapping (CPT) [1] is a quantum interference process that consists of making atoms interact with a dual-frequency field that connects two ground states of the atomic ensemble to a common excited state. At null Raman detuning, atoms are pumped in a so-called dark state in which electromagnetically-induced transparency (EIT) of the atomic medium is obtained.

The opposite behavior, increased absorption, can be obtained with electromagnetically-induced absorption (EIA) [2]. The latter can be observed in 3-level Λ-schemes with properly-tuned counterpropagating bi-chromatic fields such that a dark state created by a dual-frequency field is a bright state for the second field.

Best CPT clocks exhibit short-term fractional frequency stability levels in the range of a few 10^{-13} at 1 s [3-5]. In [6], an EIA clock was demonstrated with a short-term stability of 4×10^{-12} at 1 s.

While the short-term stability of CPT clocks is comparable to the one of best microwave vapor cell clocks [7], it remains about a factor 10 higher than the ultimate photon shot noise limit. When ultra-low noise local oscillators are used [8] such that the Dick effect contribution is well rejected, the short-term stability of high-performance CPT clocks is in general limited by the laser noise, especially the laser amplitude noise.

In this study, we propose and demonstrate a method for probing coherent population trapping resonances in an atomic vapor based on the simultaneous detection of mirror-images of transmission (dark state-EIT) and absorption resonances (bright state-EIA) for the clock transition, and subsequent use of a differential detection stage at the cell output [9, 10]. This technique leads to the detection of an atomic resonance with enhanced amplitude and suppressed common noise.

II. EXPERIMENTAL RESULTS

Figure 1 shows a simplified scheme of the experimental setup implemented for demonstration of the proposed method.

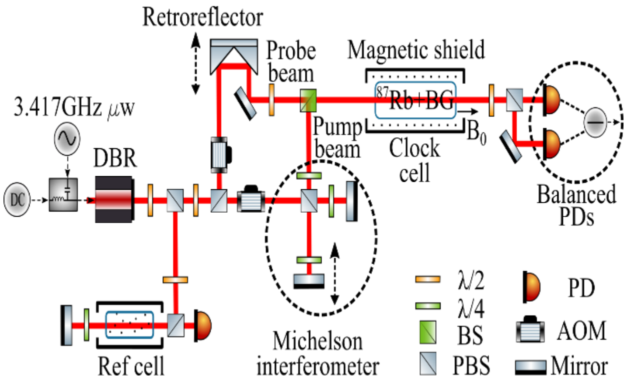

Fig. 1. Experimental setup.

Figure 1: Experimental setup.

The laser source is a distributed Bragg-resonator (DBR) laser, tuned on the Rb D_1 line, directly-modulated at 3.417 GHz for producing optical sidebands frequency-split at 6.8 GHz for CPT interaction. The laser frequency is stabilized using the dual-frequency sub-Doppler spectroscopy [11] on an evacuated vapor cell. Initially prepared into a CPT state using the push-pull optical pumping scheme [12] created with a Michelson-like system, atoms are then probed with a phase-delayed linearly polarized bichromatic probe beam, such that the initial CPT state is a dark state or bright state for respective orthogonal circularly polarized components of the probe field. EIT and EIA resonances are then simultaneously generated due to the fact that one of the electric dipole moments of the double-Λ system is of opposite sign to the three other ones. The atomic resonances are created in a buffer-gas filled Rb vapor cell, temperature-stabilized, surrounded by a static magnetic field and protected by a magnetic shield. At the cell output, opposite polarizations are separated and balanced photodiodes are used to obtain the output diff-CPT signal.

Figure 2 shows an example of EIT, EIA and diff-CPT signals detected in the vapor cell.

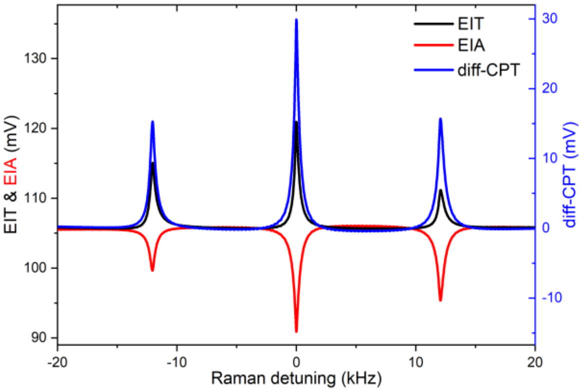

Figure 2: EIT, EIA and differential-CPT signal detected in the buffer-gas filled Rb vapor cell.

The three peaks correspond to transitions of the Zeeman spectrum, the central one being the 0-0 clock transition. The diff-CPT signal exhibits an amplitude twice higher that those of respective EIT and EIA signals, and is detected with a dc background level that is almost nulled. The linewidth of the diff-CPT signal is between those of EIT and EIA resonances. Also, we have observed common-mode noise rejection onto the diff-CPT signal.

III. CONCLUSIONS

We have proposed and demonstrated a scheme that allows the simultaneous detection of dark and bright resonances in a vapor cell that leads, through the use of a differential detection stage, to a resonance signal with doubled amplitude and reduced common-mode noise. These ingredients might be the basis for the demonstration of a CPT clock with improved short-term fractional frequency stability.

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