Dark Resonance in Bichromatic Linearly Polarized Optical Field on Cs D_1 Line

K. Watabe, T. Ikegami, A. Takamizawa, S. Yanagimachi, S. Ohshima
National Metrology Institute of Japan (NMIJ), AIST, Tsukuba, Ibaraki 305-8563, Japan

S. Knappe
National Institute of Standards and Technology, 325 South Broadway, Boulder, Colorado 80305-3322, USA†

***Abstract*—We describe a simple method for observing high-contrast coherent population trapping signals on the Cs D_1 line. The high-contrast signals were achieved by use of a bichromatic linear polarized light (lin||lin field).**

I. Introduction

Coherent population trapping (CPT) [1], [2] resonances have recently gained renewed interest, partly through the development of chip-scale atomic devices such as microfabricated atomic clocks (CSACs) [3], [4]. High contrasts and narrow resonance linewidths are important factors for the applications of CPT-based atomic frequency references [5], [6]. In the case of a conventional CPT interrogation with bichromatic circularly polarized light (σ−σ field), the signal amplitudes can be limited by the loss of atoms toward the extreme Zeeman sublevels $|F, m_F = \pm F>$ through optical pumping. The atoms that accumulate in these states contribute to neither the CPT signal nor the background absorption. In order to reach the same net absorption, the vapor temperature could be increased. In many cases, however, this is not desirable, because of increased resonance broadening through spin-exchange collisions and higher power consumption.

It has been shown that excitation of the D_1 transition instead of the D_2 transition results in both a higher resonance contrast and a narrower resonance width [7], [8]. Other approaches to increase the contrast include push-pull optical pumping with alternating circular polarizations [9], counterpropagating waves with orthogonal circular polarizations [10], interrogation with crossed linear polarizations [11], and four-wave mixing [12]. These methods excite a two-photon Λ resonance on the ground-state hyperfine sublevels with $|F, m_F = 0>$, $|F + 1, m_F = 0>$ to minimize the frequency shift due to the magnetic field.

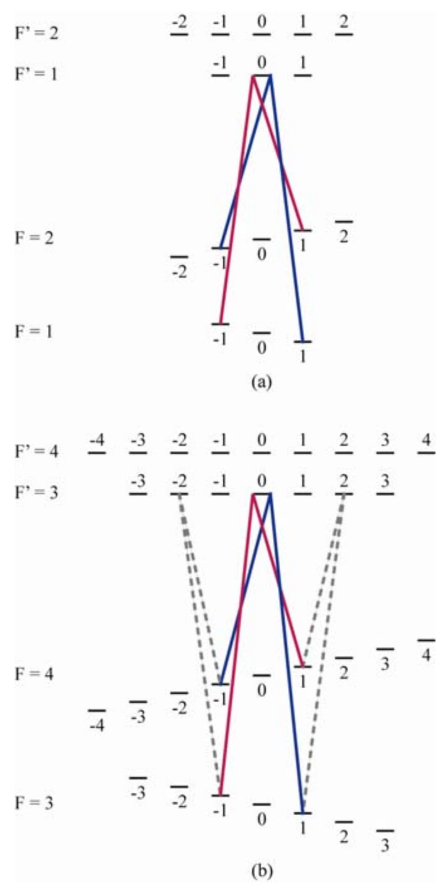

Fig. 1. Excitation scheme with a lin||lin field on the D_1 line of (a) ^{87}Rb and (b) Cs. (a) The CPT resonances in ^{87}Rb involve two pairs of ground-state hyperfine sublevels with $|F = 1, m_F = -1>$, $|F = 2, m_F = 1>$ (red) and $|F = 1, m_F = 1>$, $|F = 2, m_F = -1>$ (blue) coupled with the common excited states $|F' = 1, m_F = 0>$. (b) The CPT resonances in Cs involve two pairs of ground-state hyperfine sublevels with $|F = 3, m_F = -1>$, $|F = 4, m_F = 1>$ (red) and $|F = 3, m_F = 1>$, $|F = 4, m_F = -1>$ (blue) coupled with the common excited states $|F' = 3, m_F = 0>$. Additional single-photon resonances are possible in the case of Cs, indicated by the grey dashed lines.

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Recently, the observation of high-contrast dark resonances was reported in the most simple setup possible: Taichenachev *et al.* [13] and Kazakov *et al.* [14] proposed to measure CPT resonances with a bichromatic linearly polarized light (lin||lin field) on the D_1 line of ^{87}Rb (with nuclear spin $I = 3/2$). They demonstrated that two Λ schemes can be formed with two pairs of ground-state hyperfine sublevels simultaneously: $|F = 1, m_F = -1\rangle$, $|F = 2, m_F = 1\rangle$ and $|F = 1, m_F = 1\rangle$, $|F = 2, m_F = -1\rangle$ coupled with the common excited states $|F' = 1, m_F = 0\rangle$ (see Fig. 1a). If the contribution of the nuclear spin to the Zeeman splitting is neglected, the two-photon resonance frequencies (both $|F = 1, m_F = -1\rangle$, $|F = 2, m_F = 1\rangle$ and $|F = 1, m_F = 1\rangle$, $|F = 2, m_F = -1\rangle$) are equal to the frequency of the 0–0 resonance formed on $|F = 1, m_F = 0\rangle$, $|F = 2, m_F = 0\rangle$. This means that at least two superposition dark states exist in the case of exact two-photon resonance for fields with linear polarizations. A CPT resonance on the ground-state hyperfine sublevels with $|F, m_F = 0\rangle$, $|F + 1, m_F = 0\rangle$ is not excited in the case of the lin||lin configuration, because the different components of the circularly polarized light interfere destructively [15].

While high-contrast resonances were expected to be seen in ^{87}Rb, with nuclear spin of $I = 3/2$, this was not the case for Cs, with $I = 7/2$. The reason is that for $I = 3/2$, pure Λ systems can be formed on the $F = 1$ and $F = 2$ ground states when coupled to the excited $F' = 1$ state. This means that the ground-state Zeeman components cannot couple to any other excited states by single-photon transitions. For Cs, in contrast, this is not the case, and the ground states with $m_F = \pm 1$ can couple to other excited states. Therefore, more complicated M and W systems are possible, which usually reduce the contrast of the CPT resonance (see Fig. 1b). In this paper we compare the CPT signals for the Cs-D_1 line ($I = 7/2$) using lin||lin field excitation with those obtained in the conventional σ–σ case.

II. Experiments

The excitation scheme is shown in Fig. 1. A laser beam with a linear polarization was transmitted through a vapor of cesium atoms in a magnetic field parallel to the beam direction. Therefore, σ^+ and σ^- transitions could be excited. Two two-photon resonances of a Λ type are formed involving two pairs of ground-state hyperfine sublevels: $|F = 3, m_F = -1\rangle$, $|F = 4, m_F = 1\rangle$ and $|F = 3, m_F = 1\rangle$, $|F = 4, m_F = -1\rangle$. Both of these Λ schemes are excited through the common excited state $|F' = 3, m_F = 0\rangle$.

Fig. 2 shows the experimental setup. The two optical fields needed for the CPT signals were derived by phase modulating the output of a single extended cavity diode laser (ECDL) in the vicinity of the D_1 line of Cs ($6^2S_{1/2} \rightarrow 6^2P_{1/2}$, $\lambda \approx 894.6$ nm). A waveguide-type electro-optic modulator (EOM) modulated the phase of the optical field with a frequency around 4.6 GHz, half of the ground-state hyperfine splitting frequency of Cs. The laser frequency was tuned such that the two first-order sidebands were resonant with the transitions to the $F' = 3$ excited state. A vapor cell 25 mm in diameter and 25 mm long was used in the measurements at room temperature containing Cs and 10 Torr of N_2 buffer gas. The cell was surrounded by a magnetic shield and placed inside a solenoid that applied a longitudinal magnetic field on the order of 10 μT to lift the Zeeman energy levels' degeneracy and to separate the "clock" resonance, which has no first-order magnetic field dependence, from the field-dependent resonances. To measure the CPT resonances, the EOM frequency was scanned over a range of 10 kHz around 4.6 GHz. The measured beam diameter was 19 mm. The optical power transmitted through the gas cell was then detected with a Si photodiode.

Fig. 3 compares the CPT resonance absorption contrast of four different excitation schemes, (i) $|F = 3\rangle \rightarrow |F' = 3\rangle$, $|F = 4\rangle \rightarrow |F' = 3\rangle$ with lin||lin field, (ii) $|F = 3\rangle \rightarrow |F' = 4\rangle$, $|F = 4\rangle \rightarrow |F' = 4\rangle$ with lin||lin field, (iii) $|F = 3\rangle \rightarrow |F' = 3\rangle$, $|F = 4\rangle \rightarrow |F' = 3\rangle$ with σ–σ field, (iv) $|F = 3\rangle \rightarrow |F' = 4\rangle$, $|F = 4\rangle \rightarrow |F' = 4\rangle$ with σ–σ field. A quarter-wave plate was used in front of the Cs cell when the laser radiation was circularly polarized. The absorption contrast is defined as the ratio of the change in light absorption due to the CPT resonance to the absorption off CPT resonance. Each trace was normalized to the Doppler absorption value. The absorption contrast of about 10 % was observed in the lin||lin case with the common excited state $|F' = 3\rangle$. The linewidths of CPT resonance in the lin||lin case are slightly broader than the widths in the σ–σ case [16] because of the splitting of the two CPT resonances in the magnetic field.

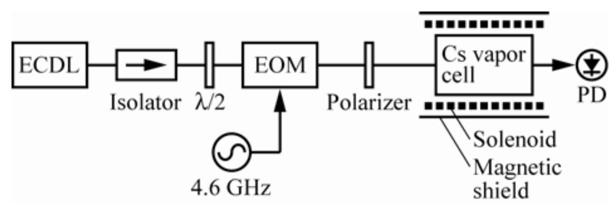

Fig. 2. Experimental arrangement used to observe the CPT phenomenon on the D_1 line of Cs atoms. ECDL: Extended cavity diode laser, EOM: Electro-optic modulator, PD: Photo detector.

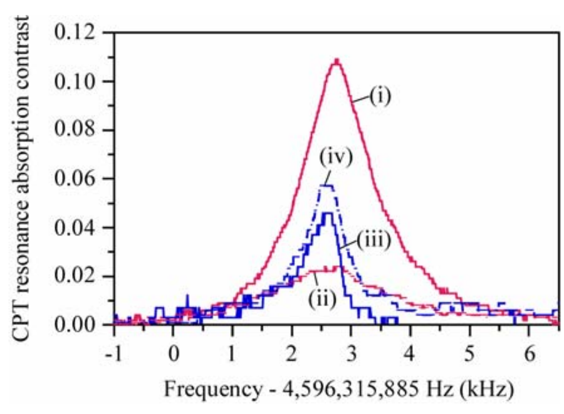

Fig. 3. CPT resonance absorption contrast with a total laser power of 2.1 mW. (i): lin||lin excitation through a common excited state $|F' = 3\rangle$, (ii): lin||lin excitation through a common excited state $|F' = 4\rangle$, (iii): σ–σ excitation through a common excited state $|F' = 3\rangle$, (iv): σ–σ excitation through a common excited state $|F' = 4\rangle$.

III. CONCLUSION

We have experimentally realized a high-contrast dark resonance using a scheme of excitation of the D_1 line of Cs with nuclear spin $I = 7/2$ for lin||lin light field. An absorption contrast of 10 % was obtained in the lin||lin case with common excited state $|F' = 3>$.

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