Push-pull optical pumping with mode-locked laser

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Coherent population trapping (CPT) resonance in alkali-metal has been studied for frequency standards. A narrow dip in absorption/fluorescence, dubbed 0-0 resonance, is achieved in a cell with a buffer gas or an anti-relaxation coating. Developed by Jau and Happer[1], the push-pull optical pumping (PPOP) technique improves the 0-0 signal by using a pump field with alternating circular polarization between right (RCP) and left (LCP), with a proper delay. When a delay between the two polarizations is half the atomic oscillation period, a large population is synchronously pumped into the 0-0 superposition. Similarly, a mode-locked laser that produces a frequency comb composed of equally phase coherent modes (> 10^4 modes) will produce an 0-0 resonance when the mode spacing is an integer fraction of the ground-state splitting, as we demonstrated in the case of ^{87}Rb [2]. We present here the enhancement of the 0-0 CPT resonance excited by a frequency comb, using push-pull optical pumping. A train of ps mode-locked pulses from a Ti:sapphire laser is sent into a Michelson interferometer with a sequence of wave plates, in order to generate a train of pulses with alternating circular polarizations with adjustable delay. The laser repetition rate is set near a sub-harmonic of the ground state splitting of rubidium-87. The rubidium cell, placed in a static longitudinal magnetic field and heated to 40° C, contains approximately 25 Torr of nitrogen molecules. A high contrast (~30 %) 0-0 CPT (Fig.1) resonance is observed when both the repetition rate and the inverse of the delay between RCP and LCP pulses are a sub-harmonic of the ground state splitting. The resonance width of 4.5 kHz at an average power of 1 mW (all modes) decreases to 1.3 kHz with a reduction of average power. The contrast and resonance width increase with average power, up to a maximum at 40 mW. The delay between RCP and LCP pulses is a critical parameter for PPOP with a mode-locked laser, When a delay between the two oppositely polarized pulses is 0 or multiples of the atomic oscillation, the CPT signal completely vanishes (Fig.2).

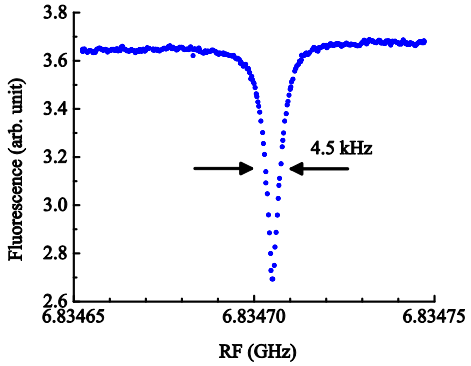

Figure 1: 0-0 CPT resonance excited by a mode-locked pulse train, using PPOP. A dip in fluorescence with 4.5 kHz width appears when 54th harmonic of the repetition rate matches the ground state hyperfine splitting of 6.834 GHz.

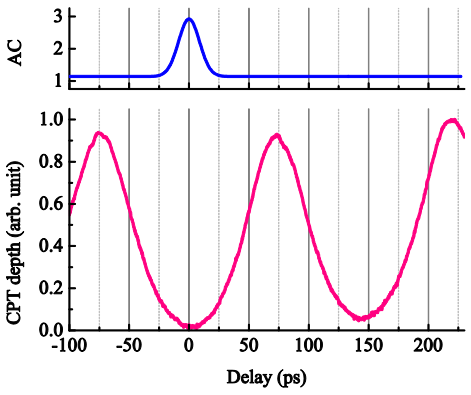

Figure 2: Depth [fluorescence (max-min)/max] of CPT resonance as a function of a delay between RCP and LCP pulses. Auto-correlation (AC) is shown as reference.

[1] Y.-Y. Jau, "Push-pull optical pumping of pure superposition states", Phys. Rev. Lett. 93, 160802 (2004)

[2] L. Arissian, "Repetition rate spectroscopy of the dark line resonance in rubidium", Opt. Comm. 264, 169-173 (2006)