High sensitivity spectroscopy of cold atoms, in a single beam, dark optical trap

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Cold atoms confined in far off-resonant optical dipole traps are useful for precision spectroscopy and for the study of quantum collective effects. To reduce interaction of the atoms with the trapping light, traps in which repulsive light forces confine atoms mostly in the dark were developed [1]. These dark optical traps enable long coherence times of the trapped atoms combined with tight confinement, and therefore high atomic densities. However, most schemes for dark optical traps require a combination of several laser beams, and this experimental complexity limits their wide use. Hence, single-beam dark traps are of a great interest.

We have recently demonstrated single beam dark optical traps for cold atoms based on two different schemes. In the first scheme [2] [3], the trap is formed using a binary phase element (BPE) that consists of equal-width rings, with a π radians phase difference between subsequent rings. When a beam that passes the BPE is focused, destructive interference between adjacent rings ensures a dark region around the focus, which is surrounded by light in all directions. Long spin-relaxation times of 100-1000 ms were measured in such a trap, indicating that the atoms were exposed on the average to as small as 1/700 of the maximal trapping light intensity [2].

In the second scheme, we used a rapidly rotating (up to 400 KHz) and tightly focused laser beam for the formation of a dynamic dark optical trap [4]. The laser beam was rotated using two perpendicular acousto-optic scanners with a radius of rotation 2-6 times larger then the beam waist, so that a dark volume completely surrounded by light was obtained. We verified experimentally that for high rotation frequency the optical dipole potential can be precisely described by an effective time-averaged quasi-static potential. We demonstrated dynamic changes of the potential by trapping 10^6 atoms in a large radius trap, and then adiabatically decreasing the rotation radius. This compression resulted a 350-fold increase in the atomic density, to $5X10^{13}$ atoms/cm^3, where elastic collision rate of 100 sec^{-1} was measured. A 4 times adiabatic increase in the peak phase-space density was also obtained due to the change in the functional shape of the trap potential.

The low interaction of atoms with the trapping light, the high number of atoms and tight confinement achieved, make these optical traps useful for spectroscopic research of weak atomic transitions. This was demonstrated by performing two-photon electron-shelving spectroscopy of the $5S_{\frac{1}{2}}F=2 \rightarrow\ 5D_{\frac{5}{2}}F'$ transition in ^{85}Rb [5]. The strongly confined atoms in the trap were exposed to an additional, strongly focused laser beam, which scanned its frequency over the two-photon transition (around 778 nm). The atoms in the trap were initially pumped into the F=2 hyperfine level. Since the detuning of the the trapping beam was very large - 10 nm, spin relaxation times due to spontaneous Raman scattering from the trapping beam were very large. Therefore, the rate at which atoms were transferred into the F=3 hyperfine level were mainly determined by the two-photon absorption rate. The normalized F=3 population fraction was measured from the resonance fluorescence of the strong cycling transition $5S_{\frac{1}{2}}F=3 \rightarrow 5p_{\frac{3}{2}}F'=4$ yeilding up to 10^7 quantum amplification of the weak transition rate.

Figure 1, shows the F=3 population after 0.5 sec as a function of the two-photon beam frequency. The measured line hight and frequency differences are in very good agreement with the theoretical calculations. A transition rate as low as 0.1 $\sec^{-1}$, with an extremely weak laser intensity of only 25 μW, was measured this way.

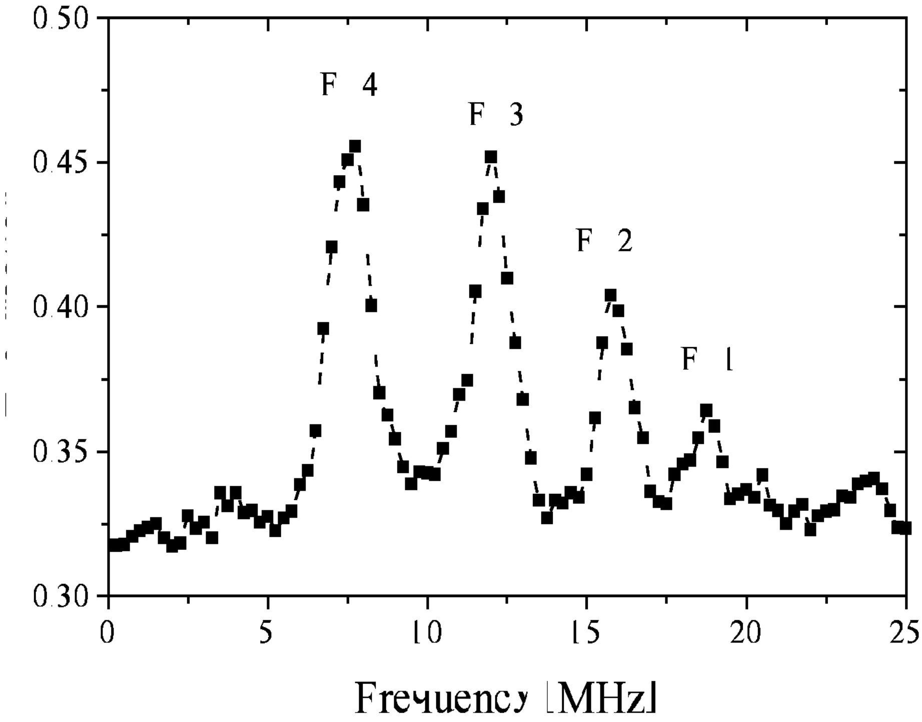

Figure 1: Measured two-photon spectrum of the $5S_{\frac{1}{2}}F=2 \rightarrow\ 5D_{\frac{5}{2}}F'$ transition in ^{85}Rb.

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