다준위 원자 포획의 포획 변수 측정

Measurement of the trap parameters of a multi-level atom trap

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We study the Doppler cooling theory for the multi-level atoms in a three-dimensional magneto-optical trap (MOT) by measuring the damping coefficient as well as the trap frequency as functions of the magnetic field gradient or the detuning. The measurement method is to detect the oscillatory behavior of atomic cloud[1]. The atomic motion in a MOT is simply given by a damped harmonic oscillator model with the damping coefficient β and the trap frequency f_0. When a uniform magnetic field (B_z) is applied at the MOT, the position of trap center is shifted by B_z/b, where b is magnetic field gradient for the z axis of MOT. When the uniform magnetic field is suddenly turned off, the atomic cloud moves to original trap center. In case of under-damped motion, we can extract the trap parameters by measuring the trajectory of atomic cloud after the uniform magnetic field is suddenly turned off. We also find that the damping coefficient is increased due to the existence of the sub-Doppler trap in the near vicinity of the magnetic field center. We explained this phenomenon by the Monte Carlo simulation. Finally we also compared the data of trap frequency with the parametric resonance method. Since our experiments were performed on low saturation parameter and for small number of atoms in the MOT we did not consider trap number dependence on the trap parameters.

We captured about 2×10^8 atoms in a standard vapor-cell MOT by using six counterpropagating laser beams with 1.5 cm of the $e^{-1/2}$ width[2,3]. When the added magnetic field is turned off fast, the atomic cloud starts to come back to original trap center. The trajectory of the center of the atomic cloud is simply given by

$$z(t) = z(0) + Ae^{-\beta t/2}\left(\cos 2\pi f_0 t + \frac{\beta}{4\pi f_0}\sin 2\pi f_0 t\right) \tag{1}$$

where f_0 is the trap frequency, β is damping coefficient, z_0 is the equilibrium position, and A is the initial displacement from equilibrium. Triggered with the turning off B_z-field, the motion of atomic cloud are recorded to the photodiode array of 16 elements with 1 mm width. Each channel detect the change of absorption of resonant probe laser that propagate perpendicular to the oscillation of atomic cloud with 1.6 cm width and 0.5 cm height.

Fig. 1(a) is the contour-plot of the typical absorption signals of 16 channels, where vertical axis is the position of photo diode array and horizontal axis is the time after switching off the magnetic field. In the picture the bright region means large absorption from large number of atoms. Fig. 1(b) shows the positions of maximum brightness as time goes and its fitted curve with Eq. (1). From the fitting in Fig. 1(b) we can obtain the trap frequency and damping coefficient. The experimental conditions and the fitted results are presented in Fig. 2 with the magnetic field gradient 10 G/cm. Fig. 2 shows the dependence of (a) trap frequency and (b) damping coefficient on the magnetic field gradient, for the detuning $\Delta=-2.7\Gamma$ and the trapping beam intensity $I_z=0.10$ mW/cm^2 (filled square), 0.13 mW/cm^2 (filled circle) and 0.17 mW/cm^2 (filled triangle), respectively. The intensities of lasers of perpendicular directions($I_x=I_y$) are 0.62 mW/cm^2. The solid, dashed, and dashed-dotted lines are the calculated results from theoretical model.

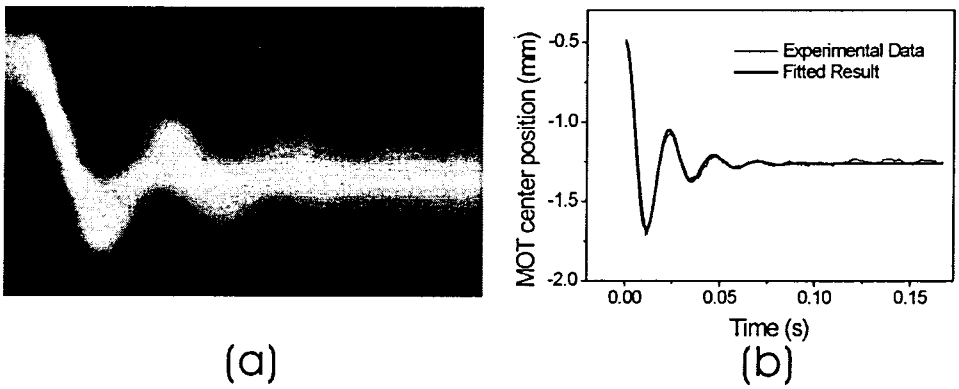

그림 1 (a) The contour plot of the signals shows the typical oscillating behavior of atomic cloud. (b) The positions of maximum brightness from (a) and the fitted curve width Eq. (1).

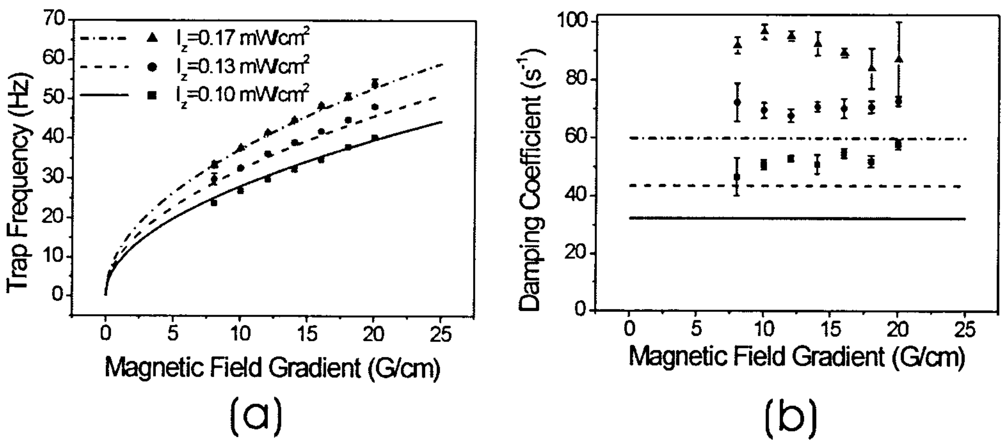

그림 2 The dependence of (a) trap frequency and (b) damping coefficient on the magnetic field gradient.

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