TEMPORAL VARIATION OF LOCAL DENSITY OF Cs ATOMS IN MOT

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ABSTRACT

We propose a new laser-spectroscopic method for measuring the translational temperature in a localized region of magneto-optical trap. A focused pumping pulse tuned to the Cs D_2 line irradiates a part of the MOT. Atoms in the irradiated region are accelerated by the radiation pressure and ejected from the trap. Temporal variation of the local number density is monitored by a probe beam. An anomalous transient absorption was observed just after irradiation of the pumping pulse. We conclude that the transient signal reflects the motion of the atoms in a localized region of MOT.
Keywords: magneto-optical trap, radiation pressure, Cs

1. INTRODUCTION

The magneto-optical trap (MOT) is one of the most useful techniques for producing cold atoms. This trap is used in many experiments such as atomic fountain clock, production of Bose-Einstein condensation, and atom interferometer. In the fountain clock, atoms once trapped in a MOT are further cooled down by the polarization gradient cooling (PGC), and then launched for measurements of the Ramsey signals [1]. The velocity distribution realized in a finite PGC time depends on the initial conditions of the MOT [2, 3]. Therefore, it is important for evaluation of clock quality to clarify dynamic properties of atoms in the MOT.

There are several methods of measuring the velocity distribution of cooled atoms [4]. The release and recapture method and the time-of-flight (TOF) method are generally used to measure the velocity distribution. These methods, however, do not provide detailed information on local parameters in the MOT such as temperature gradient. Analysis of the stimulated optical Compton scattering gives data of atom velocity in a limited region [5]. This works well at velocities near 1 cm/s, and is insensitive to light shifts.

In this paper, we propose a new laser-spectroscopic method for measuring the translational temperature in a localized region of MOT. Our method uses pump and probe laser beams: cw probe laser site-selectively monitors the temporal variation of the population density in the MOT after ejection of atoms by a pulsed pump light.

2. EXPERIMENT

Our experiment is performed on Cs atoms trapped in a diode-laser MOT. The trapping laser beams are delivered from an extended cavity diode laser (ECDL). The frequency is red-detuned from that of the F=4–F'=5 transition of the Cs D_2 line at 852 nm by –15 MHz. The laser power is 3 mW for each axis and the beam diameter is 12 mm. A focused pumping pulse tuned to the Cs D_2 line irradiates a part of the MOT. Atoms in the irradiated region are accelerated by the radiation pressure and ejected from the trap. Chopping cw radiation with an acousto-optic modulator forms the pump pulse. The pulse width is changed from 50 µs to 500 µs. The laser pulse hits the atom cloud on its beam waist of 100 µm, and ejects atoms from the small region in the MOT. The power of the ejecting beam is 2 mW. After the irradiation of the pump pulse, the surrounding atoms drift into the ejected region to recover its density. The recovering time reflects the velocity distribution of these atoms.

The temporal variation of the local number density is monitored by a probe beam. The probe beam is also focused on the MOT. Its intensity is kept sufficiently low so as not to affect the motion of atoms. Temporal variation of the probe laser power transmitted from the MOT is recorded and stored in PC.

The pump pulse and probe beam are delivered from another ECDL. These beams pass through double-pass AOMs and their optical paths don't shift even when the AOM frequency is changed. The frequency of the pump beam is stabilized to the absorption peak of the trapped atoms on the F=4–F'=5 transition. The frequency of the probe beam changes from –20 MHz to +20 MHz around the resonant frequency. The angle between the pump beam and the probe beam is 108 degree. The signal-to-noise ratio of the probe absorption is sensitive to the frequency stability of the trap beam and the probe beam.

3. RESULTS AND DISCUSSION

Figure 1 shows a typical profile of the transmitted power of the probe beam. Transmission of the probe beam increases

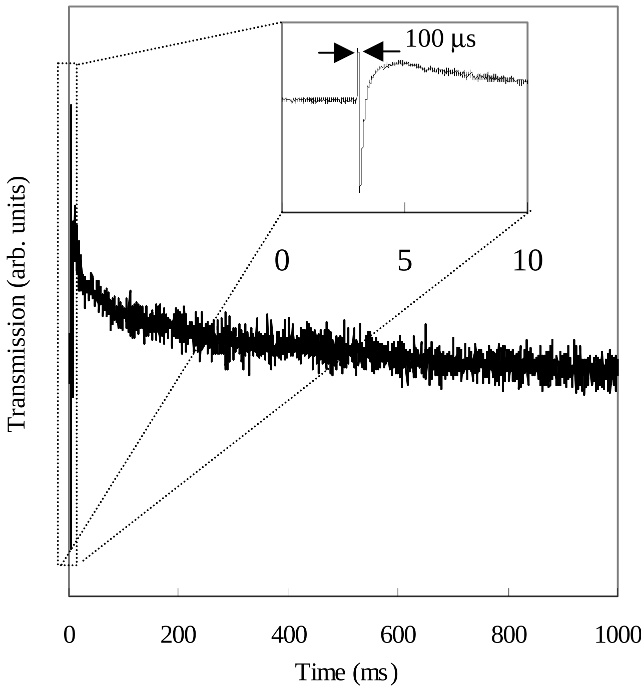

Fig. 1: Temporal variation of the transmitted probe laser intensity. The width of the pump pulse is 100 µs.

during the 100 μs pump pulse. Just after this pulse is terminated, an anomalous transient signal is observed. The transmission of the probe beam instantaneously decreases below its equilibrium value within a few milliseconds. Then, the transmission overshoots its original level and gradually decays to the equilibrium state with a time constant of several hundred milliseconds.

The increase of the transmission during the irradiation of the pump pulse can be explained partly by the saturation of the probe absorption due to the pump pulse. The slow decay of the transmitted power after the overshooting is reasonably understood as the process of loading Cs atoms to the MOT from ambient gases. The transient decrease of the transmission just after the pulse termination and the following overshooting signal seem to reflect the local dynamics induced by the pump laser. So, we focus our attention on these anomalous transient signals.

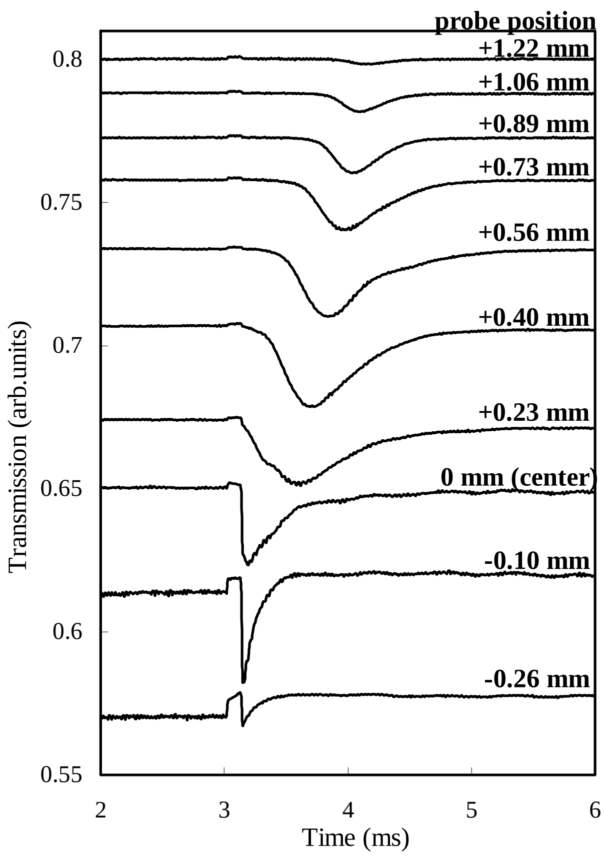

Fig. 2: Dependence of the transient transmission signal on the position of the probe beam.

Figure 2 shows how the temporal variation of the transmitted probe laser intensity depends on the position of the crossing point between the pump and probe beams. The pump beam passes in the center of the MOT. By shifting the path of the probe beam, we can move the crossing point from upstream to downstream of the pump beam. The probe beam monitors outside of the atom cloud when the crossing point is over 0.5 mm away from the trap center. It is observed that as the probe beam goes downstream, the transmission dip arrives later. This suggests that atoms accelerated by the pushing pulse come to the probed region and absorb the laser light for a certain period of time. The intensity of the TOF signal gradually decreases as the crossing point goes further away from the trap center in the downstream direction. This is because the accelerated atoms are diffused. The width of the TOF signal doesn't depend much on the flight time because the original velocity distribution is very small. The average velocity of the ejected atoms is estimated from the peak shift of the TOF signal to be 1.5 m/s.

It should also be noted that the overshooting signal occurs only when the upstream of the pump pulse is probed. Local number density of Cs atoms increases downstream and decreases upstream. The radiation pressure of the pushing pulse carries atoms in the irradiated region to downstream of its propagation.

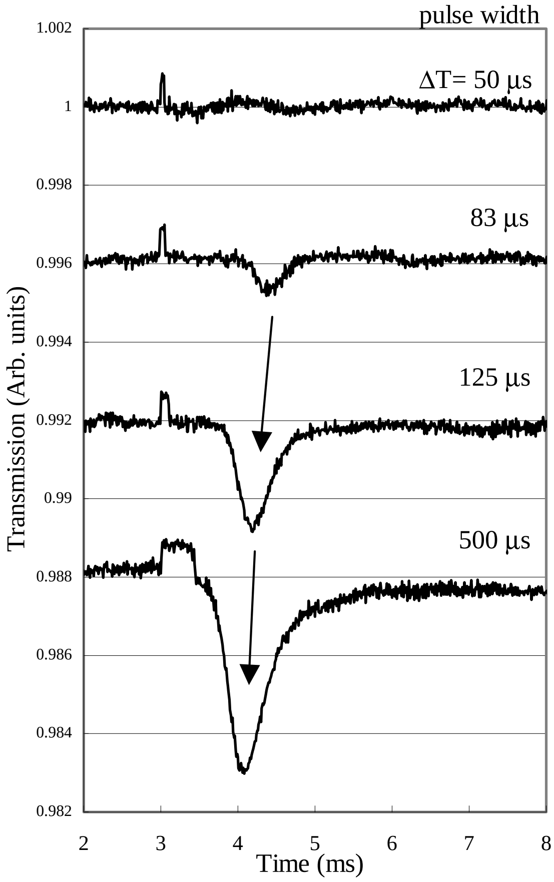

Fig. 3: Dependence of the TOF signal on the width of the pump

Figure 3 shows observed dependence of the transmission signal on the width of the pump pulse. The position of the probe beam is 1 mm downstream from the center of the MOT cloud. The observed dips correspond to the TOF signals of the atoms ejected by the pump pulse. The signal intensity becomes larger with an increase in the pulse width. The peak of the TOF signal arrives earlier for longer pulse. With the 50 μs pulse, the impulse is not large enough to accelerate atoms beyond the trapping barrier. These observations again show that the transient decrease of the transmitted probe power is due to the absorption by accelerated atoms.

Figure 4 shows the probe-frequency dependence of the transient signal. The probe beam crosses the pump beam in the center of the atom cloud. The pulse width is 125 μs. The detuning Δ is the difference between the probe laser frequency and the F=4–F'=5 transition frequency of the MOT atoms. The transient absorption after the pump pulse is largest when the detuning is –2 MHz. The most probable velocity component in the direction of the pump laser is calculated from this Doppler shift to be 5.5 m/s. This value is different from 1.5 m/s obtained from the TOF signals in Figure 2. The discrepancy may be attributed to the ambiguity in determining the line center of the trapped atoms.

As mentioned before, the short pulse synchronized to the pump pulse is caused partly by the cross saturation. It should be noted, however, that its height becomes maximum when the probe laser is blue-shifted. Absorption by the accelerated atoms is superposed on the bleaching signal and reduces its height for red-shifted frequencies.

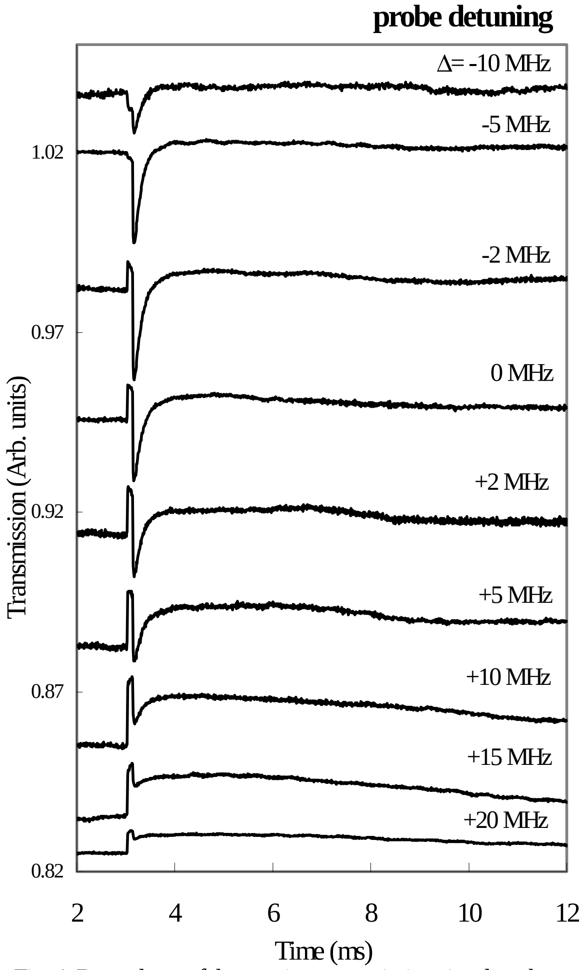

Fig. 4: Dependence of the transient transmission signal on the probe detuning

4. SUMMARY

We proposed a new laser-spectroscopic method for measuring the translational temperature in a local region of MOT. An anomalous transient response was observed in the transmission of the probe laser. It was found that the instantaneous absorption is due to the atoms in spatially restricted region accelerated by the pump beam. The most probable velocity of the ejected atoms was measured from the TOF signals and Doppler shift of the probe absorption. The transient signals also depend on diffusion process in the MOT. Further analysis on them will give us more detailed information of local population dynamics.

5. REFERENCES

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