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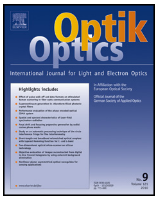

Accurate measurements of cold atomic cloud with area fit method

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ABSTRACT

We propose a scheme for accurately determining the number and the temperature of cold atomic cloud by the area fit, which is more accurate than former Gaussian fit method and can be used mostly when the cloud takes a shape that cannot be accurately captured using common Gaussian fit. We have realized measurements of cold atomic cloud with area fit. The number of trapped atoms is about 10^8 and the temperature estimated with the analysis is about 328 μK after 2 s loading.

The concept of the magneto-optical trap (MOT) was first suggested by Jean Dalibard [1], when pioneers of the field such as Pritchard and Chu were still struggling with dipole trapping of neutral atoms [2–5]. The MOT was shown to be able to trap a much higher number of atoms (on the order of 10^7 [3]), making it a preferred choice as a source of cold atoms. The two properties of the MOT cloud that we are most interested in are the number and the temperature and how they behave in different regimes.

To measure these properties, we need methods to measure the cloud size, the number of atoms, and the expansion of the cloud. The most common method is using another weak laser beam as a probe which aligned to pass through the cloud and collected on a photodiode [6].

Here we propose the area fit method for accurately determining atom number and the temperature, which can be used mostly when the cloud takes a shape that cannot be accurately captured using former common Gaussian fit method [7]. Moreover it is more accurate than Gaussian fit method.

To estimate the temperature and the number of the trapped rubidium atoms in MOT, the light of 780 nm is switched on, and the slope of the B field is set to 50 G/cm. In order to enhance the signal-to-noise ratio 780 nm light locked to $5^2S_{1/2}$,F = 2–$5^2S_{3/2}$,F = 3 transitions of rubidium is used to probe the MOT atoms, shown in Fig. 1 [8]. The diameter of the probe beam is expanded to be about 10 larger than the atomic cloud, which is covered by probe beam fully. And the light pulse is generated by controlling the on and off of AOM with the help of a time sequence controller.

Camera shutter is opened in advance, and the total exposure time of the CCD camera, usually, has been set at 200 microseconds. When the external trigger pulse from the time sequence controller has arrived, it will start the exposure of

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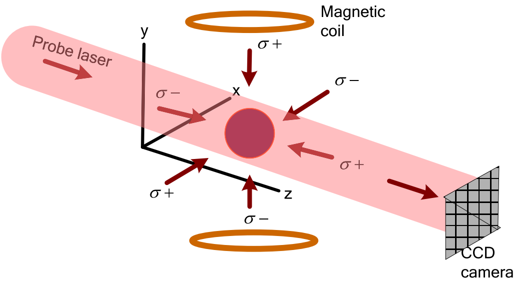

Fig. 1. Schematic of magneto-optical trap. The bronze rings represent the magnetic field coils in an anti-Helmholtz configuration. The red ball in the middle represents the atomic cloud. The pink arrows are the laser beams arranged in counter-propagating pairs of mutually orthogonal polarization. The pink beam is probe laser which radiates on CCD camera for measurements. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

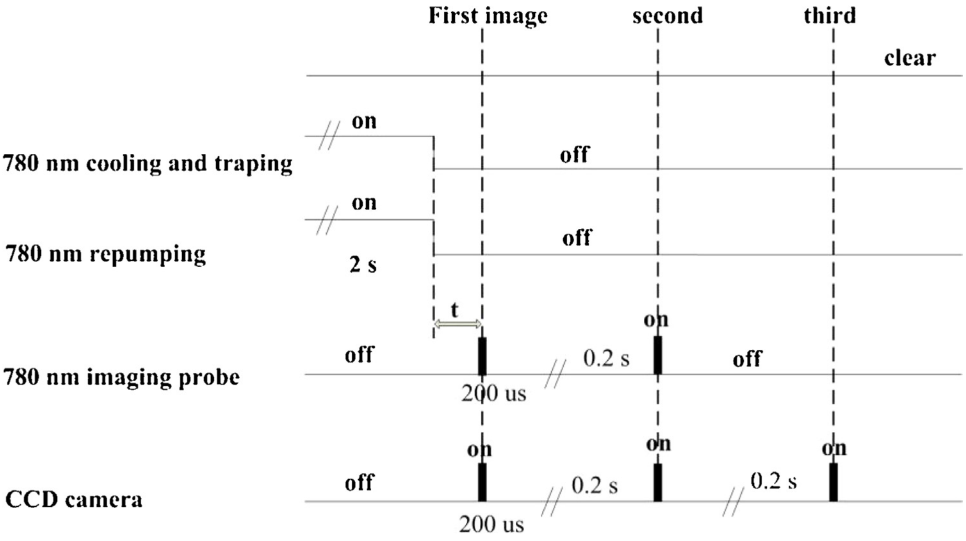

Fig. 2. Time sequence for atoms number and temperature measurements. Images are taken 3 times for subtracting the background.

the CCD. The diagram is illustrated in Fig. 2. The in-trap atoms cloud images can easily be taken by switching on the resonant probe light pulse at any time expected. In order to take the time of flight (TOF) image, atoms are released from the trap, and freely expand for period t.

We take Photos 3 times for images with background. The first image is TOF signal with CCD and probe laser background. The second is CCD and probe laser background. And the third is only CCD background. For images with background patterns, the image of the background is taken separately and subtracted from the cloud image before analysis. The center of the cloud is determined by summing up each column (for finding the center in the horizontal dimension) or row (gravity dimension). The expansion is recorded by taking pictures of the cloud after it is allowed to expand for a set period of time. We set expansion period t of TOF to 100 μs, 200 μs, 300 μs, 400 μs, 500 μs, 600 μs, 700 μs, 800 μs, 900 μs, 1 ms, 2 ms, 3 ms, separately. For better understanding, hence also we can take different period t as the processing moment of TOF.

We choose 5 moments of TOF process as a research, 0, 600 μs, 1 ms, 2 ms, 3 ms respectively, which are shown in Fig. 3(a) where the first figure is the beginning point before TOF. The cloud radius in x dimension and y dimension is expanding in TOF process. The data collection is controlled by a program written in LabVIEW which also controls the camera operation mode and exposure, and then handled in MATLAB by the area fit method.

The expansion of the cloud width is under the assumption that the velocity distribution is not disturbed during the expansion. Hence, the trap, meaning both the magnetic field and the trapping light, has to be shut down during the expansion. The pictures for each shutdown interval are 0.2 s. The cloud radius is measured using the area fit method, and cloud radius in x dimension (horizontal in real setup) and y dimension (gravity in real setup) are expanding for TOF reason, illustrated in Fig. 3(b).

The appropriate quantity is the optical density with is for resonant light $D = \sigma_0 \tilde{n}$. The cross section for resonant light is $\sigma_0 = 3\lambda^2/2\pi$and $\tilde{n}$ is the atomic density integrated along the propagation direction of the light [9,10]. Correspondingly we can calculate the number of atoms that is around 10^8, shown in Fig. 4.

Also the temperature of atoms is needed to be measured. Since the transverse magnetic field is azimuthally symmetric, the force on the x and y dimensions should be equal for an optimized trap and therefore the transverse velocity components