Characteristics of single-atom trapping in a magneto-optical trap with a high magnetic-field gradient

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Abstract. A quantitative study on characteristics of a magneto-optical trap with a single or a few atoms is presented. A very small number of $^{85}$Rb atoms were trapped in a micron-size magneto-optical trap with a high magnetic-field gradient. In order to find the optimum condition for a single-atom trap, we have investigated how the number of atoms and the size of atomic cloud change as various experimental parameters, such as a magnetic-field gradient and the trapping laser intensity and detuning. The averaged number of atoms was measured very accurately with a calibration procedure based on the single-atom saturation curve of resonance fluorescence. In addition, the number of atoms in a trap could be controlled by suppressing stochastic loading events by means of a real-time active feedback on the magnetic-field gradient.

1. Introduction
There has been a considerable interest in trapping and manipulating individual neutral atoms since a single atom itself is a good quantum system applicable to basic studies on atomic physics and quantum optics [1, 2]. Moreover, its combination with an optical cavity serves as a novel tool for quantum information applications, e.g. generating triggered-single photons [3]. Nowadays, laser cooling and trapping of neutral atoms have made it possible to generate reliable atomic samples for these kinds of experiments.

Since the first observation of discrete steps in fluorescence signals from individual trapped neutral atoms [4] in a standard magneto-optical trap (MOT) [5], the MOT has become a standard starting point for trapping single or a small number of neutral atoms. There has been extensive progress in trapping single atoms with a MOT [6, 7, 8, 9, 10] or a dipole trap [11, 12, 13, 14] in the last decade. Furthermore, several groups have recently demonstrated that individual atoms can be loaded into an optical dipole trap or into optical cavity deterministically from a MOT containing a small number of atoms [15, 16].

One of the simple idea for trapping single or a small number of atoms in a MOT is to decrease the roading rate of the trap by employing a high magnetic-field gradient as devised and implemented first by several German groups [6, 7]. In this report we present the detailed study on the characteristics of a microscopic MOT with a small number of atoms based on the high magnetic-field gradients MOT [7]. The purpose of this report is to find optimum conditions

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1 Present address: National Institute of Metrology, Beijing, China
for a single-atom trap under a high magnetic-field gradient. The number of trapped atoms and the trap size under various experimental parameters, such as the magnetic-field gradient, the intensity and the detuning of the trapping laser, has been investigated. Particularly, we measured the averaged number of atoms very accurately by employing a calibration procedure based on the single-atom saturation curve of resonance fluorescence.

This paper is organized in the following way. We first present a description of our experimental setup for trapping a few atoms in a MOT with high magnetic-field gradients in Sec. 2. The experimental results on the dependence of the number of atoms on various experimental parameters such as the magnetic-field gradient, the trapping laser intensity and detuning is presented in Sec. 3. We discuss the time traces of fluorescence signal and the images of trapped atoms in Sec. 4. A brief discussion on optimal bin time for unambiguous determination of the instantaneous atom number from these fluorescence traces is presented in this section. The atom-number feedback technique that we have recently demonstrated is reviewed in Sec. 5. Finally, we discuss the calibration procedure for the atom number based on a fluorescence saturation curve of a single atom in Sec. 6, followed by a summary in Sec. 7.

2. Experimental Setup

2.1. High magnetic-field gradient MOT

Our experimental setup for single-atom traps is basically based on a MOT with high magnetic-field gradients [7]. We used a typical configuration of MOT, loaded from a vapor, with three orthogonal pairs of cooling laser beams counter-propagating with $\sigma^+$ and $\sigma^-$ polarizations, for trapping a small number of $^{85}$Rb atoms. A cw Ti:sapphire laser and a diode laser were used as a cooling and a repumping laser, respectively. The frequencies of the two lasers are locked at proper atomic transition lines (D2-line) by frequency-modulation locking method. The intensity and the frequency of the trapping laser were varied by an acousto-optic modulator (AOM).

The number of trapped atoms and the shape of the atomic cloud are quite sensitive to the alignment and the intensity balance of the trapping laser beams, so we used individually-adjustable six laser beams rather than retro-reflected three pairs of laser beams. The power of each laser beam was varied independently in order to make the atomic cloud take place at the center of the magnetic field. Additional coils which generate a DC magnetic field were introduced to compensate for a background DC magnetic field.

The base pressure of ultrahigh vacuum chamber was maintained in the range of $10^{-11}$ Torr by employing both an ion pump and a titanium sublimation pump. A current-driven rubidium dispenser as a rubidium atomic source was mounted about 3 cm away from the MOT center and turned on with a constant current before each experiment in order to keep the rubidium partial pressure in the chamber at the same level during the experiments. The current applied on the dispenser was normally fixed to a value between 1.7 A and 2.1 A. We could estimate the rubidium partial pressures using the observed loading rate of atoms, which was measured by counting individual loading events as reported in Ref. [17]. When the current on a dispenser was set to 1.9 A, the calculated rubidium partial pressure was about $10^{-15}$ Torr. Two water-cooled electromagnets in anti-Helmholtz configuration were employed to generate a high magnetic-field gradient up to 600 G/cm in the center of the trap.

2.2. Detection system

Fluorescence lights emitted from the atomic cloud were collected through an objective lens with a numerical aperture of 0.24 (corresponding to a solid angle of 0.17), which was mounted inside the vacuum chamber. In order to measure the number of trapped atoms and the size of the atomic cloud, the fluorescence images of the atomic cloud were taken with a digital charge-coupled-device (CCD) camera. After passing through a focusing lens and an optical bandpass filter centered at 780 nm with a bandwidth of 10 nm, the collected fluorescence light
was imaged during a proper shutter exposure time. The optical resolution of our imaging system was measured to be 2.5 \( \mu \text{m} \) in FWHM and the total detection efficiency, including the solid angle factor, light propagation losses, and the quantum efficiency of the digital CCD camera, was about 0.4%.

3. Characteristics of a Single-Atom MOT

In this section, we report the experimental results on the dependence of the averaged number of atoms \( N \) and the size of atomic cloud \( \Delta z \) on the magnitude of the magnetic-field gradient and on the intensity and detuning of the trapping laser in a high-field gradient regime. Before we discuss these results, let us first examine how we determine \( N \) experimentally.

3.1. Measurement of the number of trapped atoms

In order to measure the number of trapped atoms in an atomic cloud, we take a fluorescence image of the atomic cloud with a digital CCD camera. The total number of scattered photons \( N_p \) is then obtained for various experimental parameters by integrating the number of photons registered on all pixels in the fluorescence CCD images. Consequently, the averaged number \( N \) of atoms in the atomic cloud can be deduced from

\[
N_p = \eta_D \frac{\Omega}{4\pi} \frac{I/I_s}{1 + I/I_s + 4(\Delta/\Gamma)^2} \frac{\Gamma}{2} N, \tag{1}
\]

where \( I \) is the total intensity of the six trapping laser beams, \( \Delta \) is the trap laser detuning, \( \eta_D \) is the detector efficiency, \( \Omega \) is the detection solid angle, \( \Gamma/2\pi = 5.9 \text{ MHz} \) is the full natural linewidth of D2 transition line of \(^{85}\text{Rb} \), and \( I_s \) is the saturation intensity averaged over the ground state magnetic sublevels for \(^{85}\text{Rb} \) atom. The averaged saturation intensity of the transition \((5S_{1/2}, F_g=3 \rightarrow 5P_{3/2}, F_e=4) \) of \(^{85}\text{Rb} \) is about 3.78 mW/cm\(^2\) [19].

In order to obtain \( N \) accurately from the Eq. (1), one should know the exact values of involved parameters, \( \eta_D \), \( \Omega \), and \( I \). Measuring these parameters individually is very difficult and thus impractical. For example, it is almost impossible to measure the exact local intensity \( I \) of the trapping lasers that the atoms actually experience since the alignment of the six Gaussian-shaped laser beams is not perfect in practice and since we often do not know exactly where the MOT takes place in advance.

For accurate measurements of the number of trapped atoms, we take the following calibration procedure. We first trap exactly only one atom, not on average, using the technique to be discussed in Sec. 5 for a given set of \( \eta_D \), \( \Omega \), and \( \Delta \). In this way, we can completely eliminate the uncertainty in the atom number in Eq. (1). We then measure the fluorescence saturation curve as a function of the uncalibrated intensity \( I_0 \) of the trap laser. By fitting the observed single-atom saturation curve with an effective intensity \( I_{\text{eff}} = \alpha I_0 \) in the place of \( I \) in Eq. (1), where \( \alpha \) is fitting parameter, we can determine the proportionality constant between \( N_p \) and \( N \) in Eq. (1). Once it is determined, we can then measure arbitrary \( N \) from the observed values of \( N_p \) by using Eq. (1) with \( I_{\text{eff}} \) derived from \( I_0 \). Throughout this paper, \( I_{\text{eff}} \) is used to calculate \( N \) from the measured fluorescence signal. The details of the measurement of the single-atom saturation curve and its fitting and calibration procedure will be presented in Sec. 6.

3.2. Number of atoms vs. field gradient

There have been many reports of experimental measurements and theoretical analysis of the number of trapped atoms as function of trapping parameters [20, 21, 22].

In a typical MOT with a weak magnetic-field gradient, Zeeman shifts of atomic energy levels are usually smaller than the detuning \( |\Delta| \) of the trapping laser. In one-dimensional model, a condition, \( \mu_B \mu_B z \lesssim \hbar|\Delta| \) is satisfied in the entire region of the trapping laser beam. Here \( \mu_B \) is
the Bohr magneton and $b = \partial B/\partial z|_{z=0}$ is the magnetic-field gradient, a derivative of magnetic field $B$ at position, $z = 0$. In this limit of weak field gradient, a light restoring force exerting on the atom by two counter propagating laser beams is almost proportional to the atomic position $z$ for the entire region of the laser beam. Thus the trap potential is mainly determined by a radius $L$ of the trapping laser beam.

If we increase the magnetic-field gradient $b$ while maintaining the above condition, $b \lesssim \hbar |\Delta|/\mu_B L$, both the trap depth and the capture velocity are increased. Consequently, an increase of magnetic-field gradient causes increases in the loading rate of the MOT and the number of trapped atoms.

If the magnetic-field gradient is increased further so that the Zeeman shifts of atomic energy levels at the edge of the laser beam can become larger than the laser detuning, the restoring force of the trap is maximized at the position, $z_{\text{max}} = \pm \hbar |\Delta|/\mu_B b$ inside the laser beam and tends to decrease to zero outside the region of $|z| > z_{\text{max}}$. In this regime, as the magnetic-field gradient increases, the trap potential becomes steeper but shallower and thus the number of trapped atoms decreases [20, 23], contrary to the weak-field gradient limit. Höpe et al. [24] observed that the increase in the magnetic-field gradient lead to a rapid decrease in the roading rate of the MOT, which results in decreasing the number of trapped atoms.

The experimental result of the dependence of average numbers of trapped atoms on the magnetic-field gradient $b$ is summarized in Fig. 1 for a fixed set of laser detuning and intensity. The total intensity of six trapping laser beams was fixed to $I_{\text{eff}} = 6.7I_s$ and the 1/e diameter of the laser beam was about 3 mm.

As the field gradient increases, the average number of atoms increases in the weak magnetic-field regime and has a maximum value at a certain field gradient $b_{\text{max}}$ for which the averaged Zeeman shift of the atomic energy levels approximately equals the detuning $|\Delta|$ of the trapping laser, $b_{\text{max}} \approx \hbar |\Delta|/ (\mu_B L)$. As the laser detuning becomes larger, $b_{\text{max}}$ becomes higher. Further increase of the magnetic-field gradient, however, makes the number of atoms start to decrease rapidly.

We observe $b_{\text{max}}$ appearing around 45 G/cm for $\Delta = -2\Gamma$ and around 60 G/cm for $\Delta = -3\Gamma$, respectively. When the detuning of the laser was $\Delta = -1\Gamma$, $b_{\text{max}}$ is smaller than 30 G/cm, and thus the maximum position is not seen in Fig. 1. In this case, the Zeeman shift of atomic energy levels already exceeds the detuning of the laser at the edge of the laser beam, so the number of atoms only decreases under this experimental conditions. This results are remarkably consistent with previous finding in earlier works [20, 21, 22].

![Figure 1. Average number of trapped atoms as a function of the magnet-field gradient when the laser detuning is -1Γ(■), -2Γ(♦) and -3Γ(▲). Each data point represent the average of the several measurements and the error bar shows the statistical error. The solid line is a spline fit for visual aid.](image-url)
3.3. Number of atoms vs. detuning

Figure 2 summarizes the averaged number of atoms observed as the detuning of the trapping laser at three different magnetic-field gradients. The total intensity of six trapping laser beams was fixed at $I_{\text{eff}} = 6.7 I_s$. The laser detuning was controlled by changing the modulation frequency applied to the AOM. The general trend of the number of atoms agrees well with the results in Ref. [20].

3.4. Number of atoms vs. intensity

We also measured the number of atoms as a function of trapping laser intensity. The experimental data in Fig. 3 show how the averaged number of atoms depends on the laser intensity. The magnetic-field gradient was fixed at 60 G/cm and the laser detuning was $-\Gamma$. The trap depth and the damping force of a MOT are proportional to the intensity of trapping laser when the laser intensity is weak. Figure 3 shows that the number of atoms increases approximately linearly as the laser intensity is increased. A weak trapping laser intensity always results in trapping a small number of atoms. Even at a weak field gradient, we could observe single or a few atoms in a trap by lowering the intensity of trapping laser well below the saturation intensity. However, in this case, the trap depth becomes very shallow, and therefore the size of the atomic cloud becomes quite large. In addition, the intensity of the fluorescence light emitted from the trapped atoms becomes so dim that the observation of the loading and loss events of individual atoms in a trap becomes very difficult.
3.5. Trap size vs. field gradient

When the number of trapped atoms is small and the atomic density is low, the atomic spatial and momentum distributions are approximately Gaussian and thus they can be characterized by a deviation $\Delta z$ of the spatial distribution and a temperature $T$ of the trapped atoms. The size of the atomic cloud or the deviation $\Delta z$ is dependent on the temperature. From the equipartition theorem we have the relation, $\frac{1}{2} \kappa \Delta z^2 = \frac{1}{2} k_B T$ with the spring constant $\kappa$ of the MOT. The $\kappa$ is linearly proportional to the magnetic-field gradient $b$, therefore the size of the atomic cloud $\Delta z$ is proportional to the inverse square root of $b$ in the temperature limited regime [18]: $\Delta z \propto b^{-1/2}$.

The size of the atomic cloud was measured from the fluorescence CCD images. Figure 4 shows the experimentally observed dependence of the trap size on the magnetic-field gradient. For this, the total intensity of six laser beams was set to $I_{\text{eff}} \sim 7 I_s$ and the detuning was $-1\Gamma$.

The square dots in Fig. 4, which is drawn in log-log scale, represent experimental results and the solid line is a power-law fit. The fitting result is $\Delta z \propto b^{-0.55\pm0.01}$. It is consistent with the results of prior works [6, 22]. When the magnetic-field gradient was as high as 500 G/cm, the size of the atomic cloud was measured to be about 8 $\mu$m in 1/e diameter.

4. Single-Atom Trap

Reducing the loading rate is a key idea to trap only single or a few atoms in a MOT [6, 7]. Increasing the magnetic-field gradient enables one to reduce a loading rate and thus to lower the average number of atoms down to one atom. Alternatively, one can reduce a laser intensity...
Figure 5. Fluorescence images of trapped atoms taken with a digital CCD with an exposure time of 2 seconds when the number of atoms was exactly one, two, three, four and five. The magnetic-field gradient was set to 360 G/cm. The laser intensity and detuning were about $I_{eef}/I_s = 17$ and $\Delta/\Gamma = -1$, respectively.

Figure 6. (a) Typical time trace of fluorescence signal from the trapped atoms measured by an APD with a bin time of 100 ms, and (b) the corresponding histogram of signal levels. The magnetic-field gradient was set to 180 G/cm. The time averaged number of trapped atoms was 1.0 and the trap lifetime for single atom was measured to be 158 seconds.

or increase a detuning greatly instead of employing a high magnetic-field gradient in order to decrease the loading rate. As discussed above, these alternative approaches result in an extremely weak fluorescence signal and a large atomic cloud, both of which are not desirable for addressing and manipulating single atoms.

In this experiment, in order to trap only a few atoms, we increased the magnetic-field gradient to 180 G/cm with the laser intensity fixed at $I_{eef} = 15I_s$ and the detuning at $\Delta = -1\Gamma$. Figure 5 shows the fluorescence images of atomic clouds taken by a digital CCD camera with an exposure time of 2 seconds when the number of trapped atoms were exactly one, two, three, four and five.

The measured size of the atomic cloud or the size of an optical image of the time-averaged spatial distribution of a few trapped atoms in a more precise sense, was about 10µm in 1/e diameter for these images, and thus the density of our MOT is in the order of $10^9$/cm$^3$. We could not observe any significant changes in the size of atomic cloud for different numbers of trapped atoms in Fig. 5.

When we measured the time variation of the fluorescence of the trapped atoms with an avalanche photo diode (APD) in a photon-counting mode with a time bin of 100 ms, we obtained a step-wise time sequence such as the one shown in Fig. 6(a). The photon detection efficiency of the APD with a detection area of $\sim 170 \mu$m in diameter is about 45 % at wavelengths around 780 nm. The fluorescence signal as shown in Fig. 6(a) represents abrupt changes in the actual number of atoms in the trap as individual atoms enter and leave the trap. The histogram or
the number of occurrences of the fluorescence signal levels, shown in Fig. 6(b), corresponds to a time-averaged atom number distribution in the trap. The time-averaged number of atoms in this case was 1.0.

The step-wise time trace of the fluorescence signal is directly related to the instantaneous number \( N_i \) of atoms in the trap, and thus one can identify individual loading and loss events occurring in the trap by the abrupt changes in the fluorescence time trace. By the direct counting method described in Ref. [25], we could measure the trap loading rate \( R \), the one-atom loss rate \( L_1 \) due to collisions with background molecules and the intratrap two-atom loss rate \( L_2 \). A trap lifetime or decay time, \( \tau_1 \), of single-atom trap, which is defined as \( \tau_1 = 1/(R+L_1+L_2) \), is the average time during which the atom number in the trap remains as one. The measured trap lifetime \( \tau_1 \) of our single-atom trap was about 158 seconds, limited by the collisions with background gas molecules and by loading of another atoms into the trap.

In order to observe the step-wise fluorescence signal that can be unambiguously related to the instantaneous number of atoms in the trap, the binning time for photon counting detection has to be properly chosen. In choosing the bin time, an important time scale is the trap decay time \( \tau \). If we choose a bin time much shorter than \( \tau \), the peaks in the fluorescence-level histogram tend to overlap due to poor signal-to-noise ratio and thus introduce errors in determining the atom number. If we employ a bin time much longer than \( \tau \) on the other hand, the atom number can change during the bin time, and therefore we cannot associate any definitive atom numbers to the observed peaks in the histogram. Between these two limits, there exist an optimal size of bin time which minimizes the probability of indeterminate atom numbers. This optimal bin time depends on the photon counting rate for a single atom and the loading and loss rates. In our experiments, the optimal bin time for resolving atom numbers accurately was about 100 ms. A detailed analysis of the optimum bin time can be found in Ref. [26].

5. Atom-Number Feedback

Because of the stochastic nature of the loading and loss events, a ultra high vacuum system is essential for trapping a single atom with a relatively long trap lifetime. An extremely low
loading rate is also necessary for suppressing random multi-atom loading events. Under these conditions, single-atom trapping events are rare, and thus a long waiting time is needed to load one and only one atom in the trap.

In this section, we briefly discuss an atom-number feedback technique [10] in a vaper-cell-type MOT with which we can control the number of atoms by suppressing the random loading and loss events.

The procedure of the atom-number feedback is as follows. At first, a desired number of atoms are loaded into the trap at a relatively low magnetic-field gradient and thus with a relatively high loading rate. After having loaded atoms the number of which we want to preserve, the field gradient is instantaneously increased to a high value in order to reduce the loading rate greatly and thus to prevent more atoms from entering the trap. Once the field gradient is increased to the high value, only stochastic collisional loss events occur since the loading rate is too small to load another atoms. If atoms leave the trap and thus the fluorescence signal falls below a preset feedback level, the field gradient is decreased to the low value again in order to load the atoms. After waiting for a desired number of atoms having been loaded, the field gradient is rapidly set back to the high value again.

In this experiment, the response time of feedback was limited to 100 ms by a rise/fall time of the magnetic field gradient and the loading rate $R_L$ at the low field gradient, typicaly set to about 1/600 ms$^{-1}$. In practice, because of the finite response time for the feedback, sometimes more atoms than a target atom number can be loaded at the low field gradient. If that happens, we then empty the trap by turning the magnetic field off and reload new atoms into the vacant MOT. These unexpected overloading events make a feedback time longer especially for a large target atom number. In order to increase the feedback efficiency in the case of the target atom number of five, the feedback process was modified slightly. If the trap is overloaded with more than five atoms, we instead wait until overloaded atoms escape spontaneously from the trap by the background gas collisions or the intratrap two-atom collisions.

With this active feedback on magnetic-field gradient, we have succeeded in controlling the atom number with a resulting time trace of fluorescence and a corresponding histogram shown in Fig. 7. The observed single-atom occupation probability was measured to be as high as 99 % with the average trap lifetime of about 82 seconds. More detailed discussions on the magnetic-field gradient feedback are presented in Ref. [10].

6. Saturation Curve of Single-Atom Resonance Fluorescence

As discussed in Sec. 3, we can measure the number of atoms in the trap accurately once we calibrate the fluorescence signal of the trapped atoms with respect to that of a single atom. In this section, we describe the measurement of the fluorescence saturation curve of a single trapped atom.

We measured the fluorescence photon counts of a single trapped atom as a function of the total intensity $I_0$ of the six trapping laser beams for a constant detuning, $\Delta = -1\Gamma$. The results are shown in Fig. 8. The photon count rate ranged from about 10 kcps (kilo counts per second) at an intensity of $I_s$ to as high as 66 kcps at $22.5I_s$. We then fit the experimental data with the following formula:

$$N_p = \frac{\eta_{\text{tot}} \Gamma}{2} \frac{\alpha I_0/I_s}{1 + \alpha I_0/I_s + 4(\Delta/\Gamma)^2},$$

where $\eta_{\text{tot}} = \eta D\Omega/4\pi$ is the total detection efficiency in our experiment, $\alpha$ is a parameter used for intensity calibration. Here, the two parameters, $\eta_{\text{tot}}$ and $\alpha$ are fitting parameters whereas $I_0$ is an independent variable. The detuning is -1$\Gamma$ and the averaged saturation intensity is $I_s = 3.78$ mW/cm$^2$. The solid curve in Fig. 8 represents the fit result with $\eta_{\text{tot}} = 0.0043$ and $\alpha = 1.27$, both values being consistent with our estimates.
Figure 8. Observed photon count rate of single-atom fluorescence as a function of total intensity of six trapping laser beams. The detuning was -1Γ. The solid line represents a fitting curve given by Eq. (2) with \( \eta_{tot} = 0.0043 \) and \( \alpha = 1.27 \).

Once the fitting parameters \( \eta_{tot} \) and \( \alpha \) are known, we can determine any averaged number of atoms in our trap from the observed fluorescence counts and the measured values of \( I_0 \) by using Eq. (1) with \( I_{\text{eff}} = \alpha I_0 \) in the place of \( I \). Of course, the detuning \( \Delta \) has to be fixed at -1Γ and the measurement geometry should be the same as that used in the calibration.

In the fitting of the single-atom saturation curve, we neglected the Zeeman shifts of the atomic energy levels since they are much less than \( \Gamma \). In our experiment, the six trapping laser beams were carefully aligned and the each beam intensity was adjusted independently in order to create the atomic cloud in the center of the quadratic magnetic field. Since the size of the atomic cloud was the order of 10\( \mu \)m at a magnetic-field gradient of 100 G/cm, the Zeeman shifts of atomic energy levels due to the magnetic field within the atomic cloud are less than 1 MHz, far less than the natural linewidth of the trap transition, and therefore the influence of the magnetic field on the fluorescence saturation curve of a single atom can be neglected.

7. Summary
We trapped a few \(^{85}\text{Rb} \) atoms in a MOT and analyzed proper conditions for trapping single atoms by investigating how the number of atoms and the size of MOT change as functions of various experimental parameters. Particularly, we could measure the averaged number of atoms very accurately by employing a calibration procedure based on the single-atom saturation curve of resonance fluorescence. The measurement of the fluorescence saturation curve of a single atom and its application to atom number calibration is reported for the first time in the present work to the best of our knowledge.

In addition, we have succeeded in controlling the number of trapped atoms by means of the real-time active feedback on the magnetic-field gradient. The number of atoms in the trap was maintained at any specific number, from one up to five atoms, with its high occupation probabilities.

The present report is a comprehensive compilation of experimental details of a single-atom trap based on a MOT with a high-magnetic field gradient. We hope that it can serve as a guideline for researchers who want to build their own single atom traps for various applications in quantum optics and atomic physics.

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