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# EFFICIENT LOADING OF A Rb DARK MAGNETO-OPTICAL TRAP BY CONTROLLING CURRENT THROUGH A GETTER SOURCE

**S. Singh***, **V. B. Tiwari, H. S. Rawat**

*Laser Physics Applications Division,*
*Raja Ramanna Centre for Advanced Technology*
*452013, Indore, India*

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We report a study on the loading of a Rb dark magneto-optical trap from a current-controlled getter source. The effect of changing the temperature and number density of the background atoms on the cold atomic population in the dark state has been investigated by passing current of different magnitudes through the getter source. We observe that the dark state collection rate of the cold atoms is maximized for an optimum value of the getter current used. In our experiments, cold atoms in the dark state have been collected with the maximum collection rate $3.6 \cdot 10^7$ atoms per second and background atom collision rate $\gamma = 1.9 \pm 0.2$ s$^{-1}$ for the getter current $\sim 4$ A.

## 1. INTRODUCTION

Cold atoms free from the perturbing effects of trapping laser radiations were reported using a dark magneto-optical trap (MOT) [1], where atoms collected in the lower hyperfine ground state do not interact with the trapping lasers. Over the time, the cold and dense atomic samples from dark MOTs have been extensively used for experiments involving Bose–Einstein condensation and quantum optics experiments [2]. Recent studies using dark MOTs include compression of atoms in semidark MOTs [3], spectral characteristics and nonlinear optical recoil-induced resonances [4, 5], and lifetime measurements for different values of populations in the bright and dark hyperfine states [6]. In the experiments involving a dark MOT, it is indeed important to understand the role played by the atomic source used. Traditionally, atomic beams and ampoules have been used for loading a magneto-optical trap [7–10]. However, getters or metal dispensers are rapidly becoming popular, efficient and easy-to-handle sources of background atoms in the laser cooling experiments. For example, getter sources were recently used in the loading of alkali atoms traps such as a Na MOT [11], a Rb MOT [12], and a Cs dark MOT [13]. The operation of these getters or metal dispensers requires only a modest magnitude of getter currents of few amperes. The current passing through the getter heats it, which results in the reduction of the alkali metal salt and rapid release of the atomic vapor. Similarly, the supply of atoms can be rapidly switched off by turning down the getter current below a threshold value.

The additional advantage of these getter sources over other traditional atom sources such as a thermal atomic beam is that the trap can be efficiently loaded without involving additional complications. For example, the use of a differential pumping scheme, transverse cooling laser beams, and the Zeeman slower for efficient loading of the trap, in case of the thermal atomic beam, complicates the experimental setup. The current passing through the getter source determines the density and temperature of the background atoms used in loading the trap. The loading behavior of the normal MOT as a function of the getter current has been studied in [11, 12]. However, similar studies in a dark MOT have not been reported so far. The experimental studies in [13] were performed only for a fix value of the getter current.

In this paper, we present a systematic study to observe the effect of variation in the getter current on the efficiency of operation of a Rb dark MOT. In the steady-state condition, the efficiency of the trap increases with the collection rate and is adversely affected by the loss rate due to background atoms. We have measured the temporal evolution of the atoms collected in the dark state by measuring the absorption of

*E-mail: surendra@rrcat.gov.in

a weak probe beam passing through the center of the trap. These measurements were used to estimate both the collection and loss rates in the trap. This experimental arrangement is much simpler compared to that used in Ref. [13], where loading in the dark-state was estimated by periodic switching on and off of a "fill-up" laser beam resonant with the repumping transition.

## 2. EXPERIMENT

The dark MOT was obtained by suitably modifying our Rb MOT described in Ref. [14]. It consisted of a ten-port stainless steel vacuum chamber pumped down to the pressure $1 \cdot 10^{-8}$ Torr using a molecular turbopump and a sputter ion pump. Rb vapor was injected in the chamber by passing current through two Rb getters (SAES, Italy) fixed in series at the distance 25 cm from the MOT center. The trapping laser was kept red detuned at $\Delta L = -12$ MHz from the transition $5^2S_{1/2}(F = 3) \rightarrow 5^2P_{3/2}(F' = 4)$ of $^{85}$Rb. A hollow repumping laser beam with 5 mW power and with the frequency locked to the peak of the $5^2S_{1/2}(F = 2) \rightarrow 5^2P_{3/2}(F' = 3)$ transition was used. The hollow repumping beams are usually generated either by blocking a central part of a beam [1] or by using an expensive element such as axicons [15, 16]. We have used a simple technique to generate a hollow repumping beam with a two-lens optical setup and a dark circular spot placed near the focus of the lens system to generate a well-collimated hollow beam. In this technique, the size of the hollow laser beam was changed easily by translating the dark spot near the focus of the two lens system. Figure 1 shows a scheme of the experimental setup used for producing a hollow beam. Two converging lenses of the focal length 10 cm separated by 20 cm were used to obtain collimation of the beam. A dark spot 2.5 mm in diameter on a thin high-quality glass slide was mounted on a translation stage at a distance $z_B$ from the focus. The diameter of the dark region, $D_{dark}$, and the intensity of the hollow beam were varied by relative horizontal translation of the dark spot. This lens system was kept in the path of the repumping beam in the MOT, such that the outer region of the trap consisted of a cooling as well as a repumping laser beams. However, due to the absence of the repumping beam in the internal region, the atoms were accumulated in the "dark" hyperfine state $F = 2$.

The temperature of the background vapor was estimated from the Doppler-broadened spectra of a weak scanning probe laser beam. Further, using the probe beam, the number density of the background vapor was

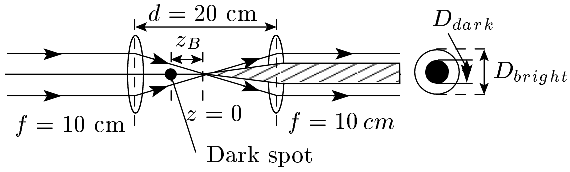


**Fig. 1.** Scheme of the experimental setup for producing a hollow beam

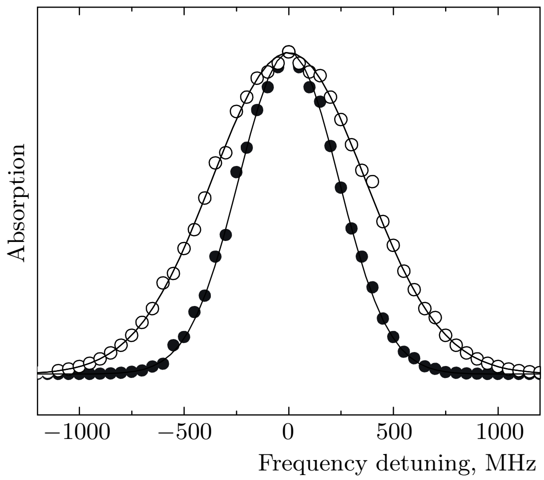


**Fig. 2.** Normalized absorption spectra for two getter currents, $I_g = 4$ A (•) and $I_g = 5$ A (◦) with the respective background vapour temperatures 400 K and 800 K. Solid lines are the theoretical fits

also estimated. The loading curves for the dark state $F = 2$ were obtained for different values of the getter current. These loading curves were used to estimate the collection and loss rates in the dark state.

## 3. RESULTS AND DISCUSSION

Figure 2 shows the typical Doppler-broadened spectra for two different values, 4 and 5 A, of the current passing through the getter. The temperature of the background vapor for these two values of currents was respectively estimated to be near 400 K and 800 K. Figure 3 shows the temperature of the background Rb vapor as a function of the getter current.

Initially, the temperature of the background vapor increases slowly with the getter current $I_g$ until $I_g = 4$ A, which is followed by a much steeper increase. The getter temperature is governed by the $I_g^2 R_g$ law, where $R_g$ is the resistance of the getter, which itself is a function of the temperature.

We have also measured the resistance of the get-

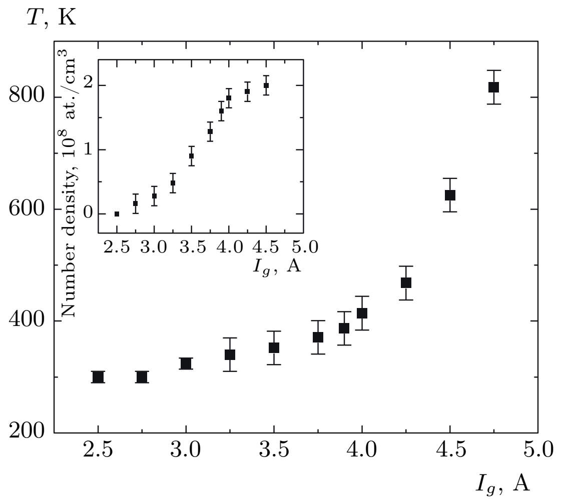


**Fig. 3.** Temperature and number density (inset) of the background Rb vapor with a getter current

ter with the current passing through it. The getter resistance decreased from 0.65 to 0.58 Ohm as the getter current was varied from $I_g = 0$ to $I_g = 5$ A. As a result, the pressure in the dark MOT chamber was also found to increase from $1 \cdot 10^{-8}$ to $2.5 \cdot 10^{-8}$ Torr. The variation in the number density of the background vapor with the getter current is shown in the inset of Fig. 3. The number density increased steadily after the threshold getter current 3.2 A and approached a nearly constant value at $I_g \approx 4$ A, possibly due to uniform heating of the whole getter material.

The laser cooling experiments can be performed in either switch-on or switch-off condition of the getters after accumulating the required number of the background atoms in the chamber. We have observed that the temperature of the background Rb atoms decreases with time after switching off the getters. For example, the vapour temperature attained the value of room temperature (near 300 K) in approximately 30 s for $I_g \approx 4$ A. However, the associated number density also decreases significantly (by an order of magnitude) during the same time intervals. We therefore performed experiments with a dark MOT using switch-on condition of the getters to ensure the sufficient background number density.

We have used the following rate equation for the collection and loss of cold atoms in the dark MOT [9]:

$$\frac{dN(t)}{dt} = C - N(t)\gamma - \beta \int n(r,t)^2 d^3r, \qquad (1)$$

where $N(t)$ is the number of cold atoms trapped at time $t$, $C$ is the collection rate of the cold atoms into the dark trap, $n(r,t)$ is the trapped atom number density, $\gamma$ is the background atom collision rate, and $\beta$ characterizes the strength of the density-dependent loss process. The solution of Eq. (1) is given by

$$N(t) = N_s\left[1 - \exp(-\Gamma_s t)\right],$$

where $N_s$ is the steady-state number of cold atoms. The first term in the total trap loss rate, $\Gamma_s = \gamma + \beta n_s$, is the collisional loss rate due to background atoms and the second term is the collisional loss rate due to trapped atoms with the spatially averaged steady-state density $n_s$.

Figure 4*a* shows the variation of the trap collection rate $C = N_s\Gamma_s$ with the getter current estimated from the measured value of $N_s$ and $\Gamma_s$. It is clear from the figure that the trap collection rate increases up to $I_g \approx 4.0$ A, which corresponds to the background vapor temperature near 400 K. We observed that the experimental values of collection rate show a dependence

$$C = Kn_s/T^{3/2}, \qquad (2)$$

which is similar to that obtained for a normal MOT [7]. Here, $K$ is the proportionality constant and $T$ is the temperature of the background vapor. Figure 4*b* shows the accompanied variation in the trap loss rate with the getter current $I_g$. It follows from Fig. 4 that the effect of the temperature increase with the getter current has a prominent effect on the trap collection rate compared to the total trap loss rate in the pressure range of our dark MOT operation. Initially, the trap loading rate increases with the increase in the background atom number density. But after the optimum value of the getter current is reached, the trap loading rate starts to decrease due to a sharp increase in the average thermal velocity of the background atoms determined by the vapor temperature (see also Fig. 2). In Fig. 4*b*, the total trap loss rate increases with the getter current. However, the slope slightly decreases at the getter current approximately 4 A, due to a smaller number of trapped atoms evident from Fig. 4*a*. These observations therefore show that the optimum loading of a dark MOT can only be achieved by properly setting the operating getter current.

To evaluate the individual collisional loss rates from the experimental results, the dependence of $\Gamma_s$ on $n_s$ in the dark state was investigated by varying the dark-spot diameter. $\Gamma_s$ was plotted versus $n_s$ for estimating the collisional loss rate coefficient $\beta$ and the background atom collisional loss rate $\gamma$. The slope and the intercept of the best-fitted data were respectively used to estimate $\beta$ and $\gamma$. The values of $\beta$ and $\gamma$ were respectively estimated to be $(4.7 \pm 0.5) \cdot 10^{-9}$ cm$^3$/s and

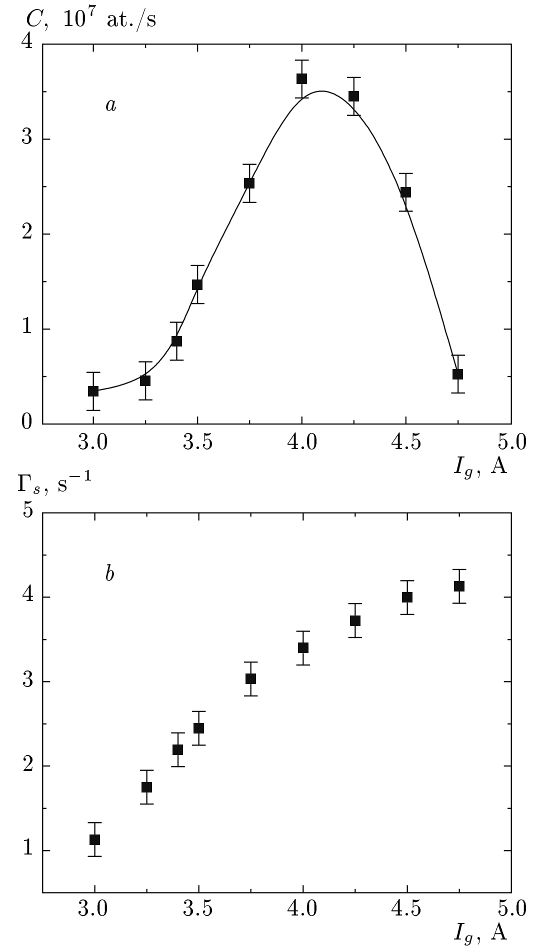


**Fig. 4.** *a*) Trap collection rate for a dark MOT with a getter current. Solid line shows the theoretical calculation using Eq. (2). *b*) Total trap loss rate $\Gamma_s$ for a dark MOT with a getter current

$1.9 \pm 0.2$ s$^{-1}$ for the background vapour temperature 400 K. The cold atom collision contribution towards the total trap loss rate was estimated to be about 30 % for $n_s = 2 \cdot 10^8$ at./cm$^3$ in the working pressure regime of our dark MOT.

## 4. CONCLUSION

We have studied the role of a getter source in optimizing the collection of cold atoms in a dark MOT using a simple experimental setup. The optimum value of the collection rate in the dark magneto-optical trap was found to depend critically on the value of the getter current used. The collection rate $3.6 \cdot 10^7$ at./s and the background atom collision rate $\gamma = 1.9 \pm 0.2$ s$^{-1}$ for the cold atoms in the dark state were estimated for the optimum getter current about 4 A. Our results clearly demonstrate that the optimized performance of the dark MOT critically depends on the value of the getter current. We believe that these results will be useful in understanding and calibrating the operation of dark MOT utilizing getters.

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