CHAPTER 6

CONCLUSIONS AND OUTLOOK

In this chapter, we begin by restating briefly the whole picture of the research in the first part of Section 6.1. The crucial results in the research are pointed and summarized at the end of the section. Finally, the outlook of the research are elaborated in Section 6.2.

6.1 Conclusions

This thesis involves investigation of light-assisted collisions between cold atoms confined optically in a FORT. The research was conducted not only for extending the knowledge of the cold collisions but also for enhancing the efficiency of single atom production, one of a precursor for a neutral-atom based quantum computer. Hence the scheme of this study is to answer the following questions: (1) What are the procedural details of the cold collisions induced by light? (2) What are the best parameters that make only one atom lost from the two-body collisions and improve the single atom loading efficiency?

To respond to these questions, the experiment began with preparing the cold ^{85}Rb atoms in a MOT inside vacuum chamber while monitoring a cold-atom cloud trapped in a MOT with the fluorescence imaging. Upon realizing cMOT followed by optical molasses, a portion of the molasses cloud was loaded into a FORT (a dipole trap) where the cold collisions were studied.

In the FORT, the occupancy of ether one or two atoms could be prepared and identified. On average eighty-four cold atoms were loaded into the FORT initially. After applying the collision light, the majority of atoms were ejected until only a few atoms were left in the trap. The counting of the remaining atoms was permitted by the assistance of the imaging light pulse. We observed that the histogram of the atomic fluorescence counts was discrete in correspondence with the number of atoms in the trap. This allowed us to determine a small number of the atoms prepared in each experimental run. The number of atoms left in the trap depended on the duration of the collision light pulse; more atoms were lost when the duration was longer. Consequently an attempt was made to optimize the duration for loading either single or two atoms. The measured temperatures of the atoms after loading were 204 ± 5 μK for a single atom and 281 ± 14 μK for two atoms. The capability of preparation and recognition of both single and two atoms provided an ideal pathway to observe and study the individual collision events.

At this point, the questions stated before at the beginning are answerable by investigating the dynamics of two atoms in a FORT under the influence of the collision light pulse. Experimentally, the microscopic view of only two atoms in the trap allowed us to distinguish between the collisional two- and one-atom loss events. As a consequence of the loss, the reduction in the probability of retaining both atoms in the trap was observed while the probabilities of detecting one and zero atoms were increasing (see Figure 5.8). The experimental result was represented in the time evolution of those probabilities. By simulating the dynamic of two atoms to reproduce the evolution (see Section 5.1.1), the insight of the collisional process is revealed and providing the answer to the first question. Furthermore, the probability of a single atom loss event in the two-body collision, $P(1|2)$, was extracted from the observed evolution. The maximization of $P(1|2)$ value was studied to answer the second question.

We found that the collisions induced by the red-detuned light for most parameters investigated gave a nonzero value of $P(1|2)$. The simulation result agrees well with the experiment and also uncovers the reason of the nonzero value. Even thought the red-detuned light assisted collisions can release a high energy (as the atoms undergo the attractive excited-state curve of the semi-molecular energy level illustrated in Figure 2.11 (b)) leading to both collision partner loss but in actuality the collisions have a potential to release a lower energy with a higher probability. For collisions between the atoms with finite speed of the center of mass, it is possible to lose only one of them for a wide range of released energy. As the probability density of the released energy has a strong dependence on the detuning of the collision light, the effect of the detuning on $P(1|2)$ was also investigated. The experimental result shows that the $P(1|2)$ value rise when the magnitude of the detuning decreases (see Figure 5.10). The highest observed $P(1|2)$ value were 0.5 at the detuning of –30 MHz. However, the employment of the light with this detuning contributed to a low efficiency for generating a single atom because of the low trapping lifetime due to the near resonance pressure. The highest single atom loading efficiency of 63% was reached by using the light with the –45 MHz detuning (the other parameters were the same as used in Figure 5.8 (a)), which were the best parameters compromising between $P(1|2)$ and the trapping lifetime. To the best of our knowledge, this is the first time that the single atom loading efficiency of the red-detuned light-assisted collision exceeds the limit of 50% [9, 18-20]

In the case of collisions induced by the blue-detuned light, we found that the capability to control the released energy from the collision leaded to the observation of near deterministic $P(1|2)$ value. Experimentally, when the detuning of the collision light was set to the value corresponding to the trap depth of FORT, most of the two-atom collisions contributed only to single atom lost. As a result, we observed the highest value of $P(1|2)$ to be 0.96. The simulation was used to reveal the hidden process of this collision as mentioned in the following details. Since two atoms undergo into the repulsive quasi-molecular potential by absorbing the light, the energy released is limit at the trap depth energy. By sharing this amount of energy to both of them, it is not allowed for two-atom loss except for the collision between the high-energy atoms. After the collision, the atoms left in the trap may have a high total energy that leads to the pair loss and the short trapping lifetime. Therefore the cooling mechanism of PGC formed by the cooling/repump beams played a crucial roll for dissipating the excess energy. The cooperation between the collision light and the cooling light leads to a high $P(1|2)$ value. Consequently this provided the world high record of 91% efficiency of loading single atom.

6.2 Outlook

It would be interesting to use the others atomic species such as ^{87}Rb and Cs. Their larger hyperfine splitting would lead to the use of a deeper trap corresponding with the repump and cooling mechanism of the cooling beam. Consequently the collision beam will be set to the larger blue detuned frequency that would reduce the heating due to the radiative pressure of the beam. Furthermore the separation between the atomic ground states is bigger, that would reduce the two-atom loss from the inelastic collision induced by the cooling/repump beams. The two-atom loss from the hyperfine-changing collision may be reduced as a result of larger hyperfine splitting of the excited states. From all above reasons, the use of atomic species with larger hyperfine splitting would provide the big improvement in the efficiency of the single atom preparation by the blue-detuned light.

The other geometry of trap is interesting to be use as well. As in the case of the single atom preparation by employing the red-detuned light, the efficiency would be improved if the high collision rate of the high-energy atoms could be allowed. This may increase $P(1|2)$ with out compromising the PGC cooling rate (the intensity of the cooling/repump beams). As a consequence the left atom after the collision would have a longer trapping lifetime. It has a potential that the efficiency of loading single atom would be improve by using the tight trap under conditions.

However, with the findings in this thesis they could be applied to other applications. The capability to prepare single atoms with efficiency of 91% in the duration of 542 ms could prepare individual qubits occupied in 30-site lattice with the probability of 0.06. By using the detection light pulse to choose only the successful loading, the single atoms perfectly occupied in all sites of would be achieved in 10 s (and about one minute for the 50 sites). This could provide an infrastructure for quantum computing and information research. In addition, the foundation of nonzero $P(1|2)$ in the collisions induced by the red-detuned light could effect the interpretation of the correlated research such as cold collision study [53, 54] and parity measurements [55].