Laser cooling and trapping of atomic Ytterbium

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Recently, gaseous atomic Ytterbium (Yb) have attracted much interest in various respects, for example, an ideal sample for studying quantum optics, a test of spin statistics, an optical frequency standard, a Bose-Einstein condensation without magnetic trapping, tests of standard model of electroweak interactions [1], and so on. Motivated by these applications, we have started laser cooling and trapping of Yb atoms.

The left part of Figure 1 shows the energy-level diagram. There are two electric-dipole transition from the ground-state $^1S_0$, $^1S_0 \leftrightarrow {}^1P_1$ (the blue transition) and $^1S_0 \leftrightarrow {}^3P_1$ (the red transition), which can be useful for cooling and trapping. The blue transition provides a strong radiation force. However it was predicted theoretically that there is the branching from $^1P_1$ to some triplet states and thus this transition is not a complete two-level transition. This might cause the large loss from the MOT.

We performed the MOT of Yb atoms using the blue transition [2]. We could succeed in

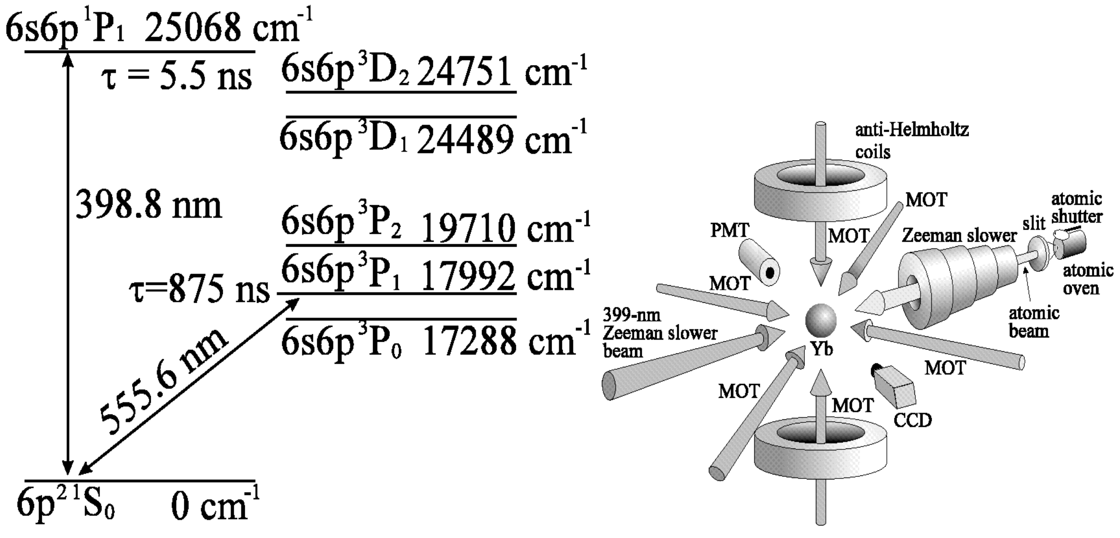

Figure 1:
(the left part) Energy-level diagram of Yb related to the cooling and trapping in this work. Several physical properties are also shown.
(the right part) Schematic view of the experimental setup of Zeeman-tuned atomic-beam slower and the magnet-optical trap of Yb atoms using the intercombination transition.

trapping Yb atoms of more than 10^6. We estimated the branching ratio of $^1P_1$ with these trapped Yb atoms. The result was consistent with the time constant of the number decay of trapped Yb atoms, about 200ms.

On the other hand, there are some favorable features of the MOT using the red transition ($^1S_0 \leftrightarrow {}^3P_1$): the Doppler limit temperature with the red transition is as low as 4.4μK whereas the one with the blue transition is 0.7mK, and there is no branching for the red transition. However there is also a difficult point in the MOT with red transition: the possibility of this intercombination transition is small, and its radiation force is weak. By designing our MOT scheme carefully, we have overcome this difficulty and succeeded in trapping Yb atoms with the MOT using this red transition [3]. The right part of Figure 1 shows the experimental setup. Yb atoms were decelerated with a Zeeman slower method using the blue transition. To prevent the effect of the radiation pressure from the light used in the Zeeman slower to the trapped atoms, the Zeeman slower in an increasing magnetic field configuration was used. The velocity of the atoms at the end of the Zeeman slower was less than about 10m/s. These slowed atoms were directly trapped with the MOT using the red transition. Thus, Yb atoms were loaded into the MOT from the Yb atomic beam continuously. The number of trapped atoms was about 10^8, the time constant of the number decay was about 3s, the density was about 10^{11} per cm^{-3}, and the temperature was about 10 μK. We also mention that we succeeded in trapping almost all stable isotopes including bosonic and fermionic ones.

In addition, we have recently succeeded in trapping Yb atoms with a dipole force trapping (DFT) method using the strong 532nm YAG laser, since the atoms in the DFT is essential for some applications. By irradiating the focused 8W laser light to atoms in the MOT with the red transition, one tenth of atoms in the MOT was re-trapped with the DFT. The number of atoms trapped with the DFT was 3×10^6, the temperature was $40 \sim 200\mu$K, and the density was estimated to be $10^{13} \sim 10^{14}$cm^{-3}. The bosonic and fermionic isotopes could be trapped with the DFT as well.

[1] Y. Takahashi, M. Fujimoto, T. Yabuzaki, Angom Dilip Singh, Manoj K. Samal, and B. P. Das, in *Proceedings of CP Violation and its Origin*, edited by K. Hagiwara (KEK Reports, Tsukuba, 1997).

[2] K. Honda, Y. Takahashi, T. Kuwamoto, M. Fujimoto, K. Toyoda, K. Ishikawa, and T. Yabuzaki *Phys. Rev. A* **59**, R934 (1999).

[3] T. Kuwamoto, K. Honda, Y. Takahashi, and T. Yabuzaki *Phys. Rev. A* **60**, R745 (1999).