量子光学学报 4(4):229～235,1998
Acta Sinica Quantum Optica

Magneto-Optical Trap Loaded from an Ultrahigh-Vacuum Vapor Cell of Cesium Atoms*

Wang Junmin　Zhang Tiancai　Yang Weidong　He Lingxiang
Liu Haifeng①　Xie Changde　Peng Kunchi
(*Institute of Opto-Electronics, Shanxi University, Taiyuan, Shanxi* 030006)

Abstract　Using two narrow-linewidth diode lasers as trapping and repumping laser sources we realized cesium magneto-optical trap (MOT) in an ultrahigh-vacuum vapor cell of cesium atoms. The numbers, average atomic density and temperature of trapped cesium atoms are estimated to be 2.8×10^{8}, 3.9×10^{10} atoms/cm^{3} and 300μK, respectively.

Key Words　Laser cooling and trapping, Magneto-optical trap (MOT), Cesium vapor cell, Narrow-linewidth diode laser, Off-set locking

Classification Code of Chinese Literatures　O431

0 Introduction

Research works of laser cooling and trapping of neutral atoms are very active in last decades. Magneto-optical trap (MOT) [1] is one kind of very important techniques for laser cooling and trapping of neutral atoms. There are two common methods for loading a MOT, one is with precooled atomic beam [1], and other one is that neutral atoms are trapped in the low velocity tail of Maxwell velocity distribution directly from dilute atomic vapor cell at room temperature without precooling step [2]. The latter greatly simplifies MOT technique and the experimental

---

* Supported by the National Natural Science Foundation of China (Project No. 19774039), Shanxi Provincial Science Foundation for Youth (Project No. 971012) and Shanxi Provincial Research Funds for Returned Students Abroad.

① Shaanxi Astronomical Observatory, Chinese Academy of Science, Xi'an, Shaanxi 710600.

Received: August 25, 1998

system, hence promotes the development of MOT technique. In fact, MOT of neutral atoms is becoming of prevalent equipment in physical labs. Cold atoms in MOT, as a kind of special nonlinear optical media, have been used in many fields, such as quantum state generation [3] , quantum nondemolition (QND) measurement [4], interaction between atoms and optical field [5], etc. The experiments of Bose-Einstein condensation (BEC) [6] and "atoms laser" [7] are also based on MOT technique.

In our country, Peking University [8] and Shanghai Institute of Optical and Fine Mechanics, Chinese Academy of Science [9] have made good progress in atomic MOT at 1996. Recently a setup of cesium MOT has been established in our institute [10~11]. Our aim is to investigate the properties of the interaction between cold atoms and light fields, including classical and nonclassical light. In this paper, we report the preliminary experimental results of our cesium MOT based on two-laser optical system. It is shown that about 2.8×10^8 cesium atoms with temperature of about 300μK were loaded into the MOT directly from a stainless-steel ultrahigh-vacuum cesium vapor cell.

1 Experimental system arrangement of our vapor-cell MOT

The basic idea of the vapor-cell MOT is to use the radiation pressure from six circularly polarized red-detuned trapping beams which are orthogonally-intersected in the dilute atomic vapor cell and the damped harmonic potential produced by a weak gradient magnetic-field in conjunction with the radiation pressure to trap low-speed atoms from background atoms with a Maxwell velocity distribution. More details for the principle of cooling and trapping in vapor-cell MOT can be found in references [2][12~14].

The nuclear spin of cesium atom is 7/2. Relevant energy levels of cesium atoms are shown in Fig. 1. The transition between hyperfine level $F = 4$ of ground state $6S_{1/2}$ and $F' = 5$ of excited state $6P_{3/2}$ (D_2 line) is the so-called cooling cycling transition. Frequency of trapping laser is tuned to the red end of the cooling cycling transition, that is required by the cooling and trapping mechanism of MOT. Repumping laser tuned to the $6S_{1/2}F = 3 \rightarrow 6P_{3/2}F' = 4$ hyperfine transition is used to prevent the atoms from accumulating in the $6S_{1/2}F = 3$ ground state which due to the effect of optical pumping.

Experimental set-up is shown sketchly in Fig. 2. The cesium vapor cell is a vertical cylinder of stainless steel with eight quartz windows. A specially designed stainless cylinder which contains a cesium reservoir is connected to the vapor cell. The vapor cell is connected with a vacuum pump system consisting of ion pump, molecular pump, vane rotary pump, and a ionization-type vacuum gauge. Vacuum degree in the vapor cell is about 2.0×10^{-7}Pa ($\sim 1.5 \times 10^{-9}$ Torr) and cesium vapor in it is far from saturation. A quadrupole magnetic field is provided by a pair of anti-Helmholtz coils which are fixed on the main cylinder. A gradient of 0.48-mT/cm on axis of the coils is generated at the center of the quadrupole magnetic field. The corresponding current of each coil is about 2 A.

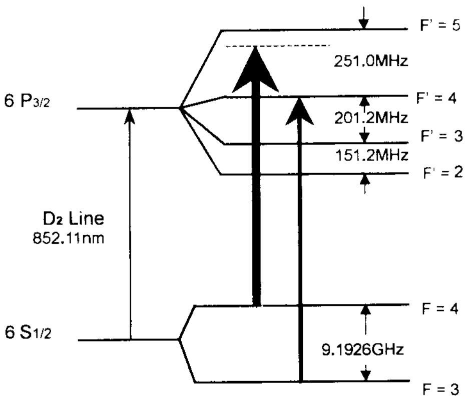

Fig. 1 Hyperfine levels of cesium atoms (D_2 line). The large arrow and the small arrow indicate the positions of trapping laser and repumping laser for the trap.

For obtaining cold atoms the trapping laser should have narrow linewidth comparable with natural linewidth of the cooling cycling transition (4.9MHz) and good frequency stability to ensure reliable operation of MOT. We used two narrow-linewidth diode lasers as trapping laser source and repumping laser source. The trapping laser is a 500-mW single-frequency diode laser with linewidth of 200 KHz (SDL-TC40 of SDL Inc.). A 40-dB optical isolator is used to avoid optical feedback. A beam of about 5 mW split by a $\lambda/2$ -waveplate and a cube polarizer (P_1) is employed for frequency stabilization. It is frequency-shifted to $\nu_0 - 2\Omega$ by a double-pass acousto-optical frequency-shifting system consisting of a cube polarizer (P_2), two apertures, two thin lens with 145-mm focal length, an acousto-optical shifter ($\Omega = (60\pm10)$MHz) , a $\lambda/4$ — waveplate and a retroreflecting mirror. Adjusting the $\lambda/4$ —waveplate before the retroreflecting mirror we make the frequency-shifted beam be reflected out from cube polarizer P_2 and then injected into the device of cesium saturation absorption spectra (Cs-SAS1) for frequency discriminating. Another small part split from main output beam is injected into Cs-SAS0 to monitor the frequency of main output beam without frequency-shifting. The typical saturation absorption spectra with Doppler background from Cs-SAS0 and Cs-SAS1 are shown in Fig. 3. When the frequency $\nu_0 - 2\Omega$ (Cs-SAS1) is swept through the crossover of $6S_{1/2}F = 4 \rightarrow 6P_{3/2}F' = 4$ and 5, the laser frequency ν_0 (Cs-SAS0) is just on the red end of the cooling cycling

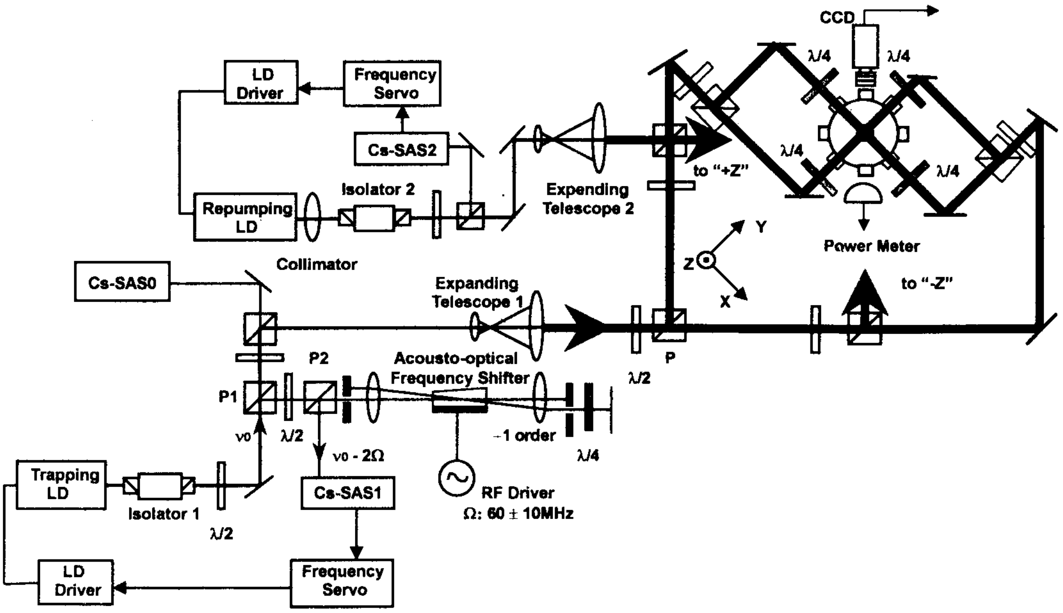

Fig. 2 Experimental arrangement of our vapor cell MOT of cesium atoms.

transition with detuning $\Delta = \nu_5 - \nu_{45} - 2\Omega = 125.5\text{MHz} - 2\Omega$. During the experiment the trapping laser is off-set locked on the cooling cycle with 15-MHz detuning (corresponding to $\Omega = 55.25\text{MHz}$). The detuning can be adjusted from 0 to 25MHz conveniently by tuning the operating frequency of the acousto-optical shifter. With this configuration the propagating direction of the frequency-shifted beam remain fixed while the detuning Δ of the trapping laser is adjusted. An additional advantage of this configuration is that the needed operating frequency of acousto-optical shifter is much lower than that for single pass system.

The main output beam of the trapping laser is expanded and collimated to 20-mm diameter by a expanding telescope, then split into six linearly polarized beams. The polarization states of the beams are changed to required circular polarization by six quartz $\lambda/4$-waveplates with diameter of 30 mm. The six trapping beams with power of 12.5mW in each one intersect orthogonally in the cesium vapor cell. The repumping laser is a 100-mW distributed-Bragg-reflector (DBR) diode laser with linewidth of 3MHz (SDL-5712-H1 of SDL Inc.). It's output beam is collimated by a collimating lens with N. A. of 0.30 (Model 4017 of ILX Lightwave

Corp), and locked on the $6S_{1/2}F=3 \rightarrow 6P_{3/2}F'=4$ hyperfine transition by the technique of saturation absorption spectra. This beam is expanded to about 20-mm diameter and superimposed on the trapping beam along upward direction. A CCD camera and an optical power meter with a measuring range of 10pW ~2mW (Model 1815C of Newport Corp) are used to observe the fluorescence of trapped cesium atoms in the MOT.

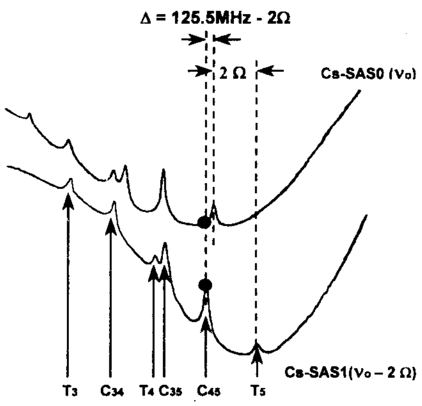

Fig. 3 The saturated absorption spectra with Doppler backgound recorded with and without the acousto-optical frequency shift ($6S_{1/2}F=4$ ◊ $6P_{3/2}$ $F'=3, 4, 5$).

2 Experimental results

When the detuning of the trapping laser is adjusted between 2 and 20MHz (~ 15MHz is optimal), a bright fluorescence cloud of trapped atoms appeared in the center of the vapor cell. The bright fluorescence cloud disappeared rapidly if the repumping beam was blocked. The diameter of the trap measured with the CCD camera is about 2.4 mm and the number of cesium atoms in MOT estimated by measuring power of the bright fluorescence is about 2.8×10^8 while the detuning is kept on 15MHz. The average atomic density of MOT is about 3.9×10^{10} atoms/cm^3. The temperature of the trapped cesium atoms estimated from the spring constant of the MOT is about 300μK.

In summary, sample of ultra-cold cesium atoms are observed in our vapor cell MOT. About 2.8×10^8 cesium atoms with temperature of about 300μK were loaded into MOT directly from a stainless-steel ultrahigh-vacuum cesium vapor cell. High stability and reliability are the preferable advantage of the designed system.

References

1 Raab E L, Prentiss M , Alex Cable, Steven Chu, Pritchard D E. Trapping of neutral atoms with radiation pressure. *Phys Rev Lett*, 1987, **59**(23): 2631~2634

2 Monroe C, Swann W, Robinson H, Wieman C. Very cold trapped atoms in a vapor cell. *Phys Rev Lett*, 1990, **65**(13):1571~1574

3 Lambrecht A, Courty J M, Reynaud S, Giacobino E. Cold atoms: a newmedium for quantum optics. *Appl*

Phys B, 1995, **60**(2):129～134

4 Roch J -F, Vigneron K, Grelu Ph, Sinatra A, Poizat J -Ph, Grangier Ph. Quantum nondemolition measurements using cold trapped atoms. *Phy Rev Lett*, 1997, **78**(4):634～637

5 Grison D, Lounis B, Salomon C, Courtois T Y, Grynberg G. Raman Spectroscopy of cesium atoms in a laser trap. *Europhys Lett*, 1991, **15**(2):149～154

6 Anderson M H, Ensher J R, Matthews M R, Wieman C E, Cornell E A. Observation of Bose-Einstein condensation in a dilute atomic vapor. *Science*, 1995, **269**(5221):198～201;

Davis K B, Mewes M -O, Andrews M R, Druten N J van, Durfee D S, Kurn D M, Ketterle W. Bose-Einstein condensation in a gas of sodium atoms. *Phys Rev Lett*, 1995, **75**(22):3969～3973;

Bradley C C, Sackett C A, Hulet R G. Bose-Einstein condensation of lithium: observation of limited condensate number. *Phys Rev Lett*, 1997, **78**(6):985～989

7 Mewes M -O, Andrews M R, Kurn D M, Durfee D S, Townsend C G, Ketterle W. Output coupler for Bose-Einstein condensed atoms. *Phys Rev Lett*, 1997, **78**(4) :582～585

8 Gan Jianhua, Li Yimin, Chen Xuzong, Liu Haifeng, Yang Donghai, Wang Yiqiu. Magneto-optical trap of cesium atoms. *Chinese Physics Letters*, 1996, **13**(11): 821～824

9 Liu Xunming, Lin Yueming, Zhou Shanyu, Huo Yunsheng, Wang Yuzhu. Laser cooling and trapping of sodium atoms in magneto-optical trap. *Chinese Journal of Lasers*, 1996, **B5**(6):511～515

10 Wang Junmin, Zhang Tiancai, Yang Weidong, He Lingxiang, Liu Haifeng, Xie changde, Peng Kunchi. Realization of laser cooling and trapping of cesium atoms at Institute of Opto-Electronics of Shanxi University. *Acta Sinica Quantum Optica* (in Chinese), 1998, **4**(3):148

11 Wang Junmin, Zhang Tiancai, Yang Weidong, He Lingxiang, Liu Haifeng, Xie changde, Peng Kunchi. Cooling and trapping of cesium atoms using the technique of vapor-cell magneto-optical trap. *Acta Optica Sinica*(in Chinese), 1998, **18**(12) (accepted for publication)

12 Dalibard, Cohen-Tannoudji C. , Laser cooling below the Doppler limit by polari-zation gradients: simple theoretical models. *J Opt Soc Am B*, 1989, **6**(11):2023～2045

13 Weiss D S, Riis E, Shevy Y, Ungar P J, Chu S. Optical molasses and multilevel atoms: experiment. *J Opt Soc Am B*, 1989, **6**(11):2072～2083

14 Cohen-Tannoudji C C, Phillips W D. New mechanisms for laser cooling. *Physics Today*, 1990, **43**(10):33～40