Zeeman Slowing of Yb Atoms

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Ytterbium and other alkaline earth atoms have pointed out for potential use as references for optical frequency standards and next-generation primary standard clocks(1). In such applications the linewidth of clock transitions determining minimum spectral noise level of an optical standard laser and the perturbation immunity of the related states against surroundings like magnetic field are crucial points. In the case of ytterbium atoms the inter-combination transition $^1S_0$,F=1/2 - $^3P_0$,F=1/2 of a fermionic isotope ^{171}Yb has a ultra-narrow linewidth (20 mHz) and a very small Zeeman shift because the total angular momentum of the related states have only nuclear spin component, I=1/2 and J=0. Those facts encourage us to develop an optical clock based on ytterbium with the goal of obtaining 10~100 times better frequency stability and accuracy comparing with current primary time and frequency standards. Also other properties of some other transitions show favorable aspects for laser cooling and trapping, which is important for isolating the system from the surroundings. For example, $^1S_0$ - $^1P_1$ transition at 399 nm is a strong transition, the linewidth is 28 MHz, so that heavy ytterbium atoms can be decelerated quickly, while having a too hot Doppler temperature limit of 700 μK. Fortunately another inter-combination transition $^1S_0$ - $^3P_1$ (556 nm) with a moderate transition rate of 180 kHz is available for such an application. When this transition is applied to magneto optical trap of Yb atoms (green MOT), they can be cooled below tens of μK with the help of a Zeeman slower. In this report we describe an experiment on Zeeman slowing of ytterbium atoms as a step prior to the green MOT being provided with Yb atoms in the form of an effusive atomic beam from an oven heated up to 370 °C.

Generally Zeeman slower(2) has two possible slowing configurations, the first termed σ+ slowing and the second σ- slowing. In our system we adapted σ- slowing with light resonant with $^1S_0$ - $^1P_1$ transition at wavelength of 399 nm because the configuration gives a better design for preventing Zeeman cooling laser from pressing and heating the trapped Yb atom (Figure 1). In the experiment we designed 30-cm long solenoid coil for generating an adequate magnetic field-gradient where Zeeman effect compensates the position-dependent Doppler effect of decelerating atoms. In Figure 2 the measured magnetic field profile almost coincides with the calculated field-gradient. For finding the optimal design of the magnetic field-gradient we simulated the motion of ytterbium atoms in the Zeeman slower under several given conditions, such as laser power, experimental space on optical table and so on (Figure 3). In our experiment the laser power for Zeeman cooling mostly restricted. our design since the available power from a diode laser (< 10 mW) is scarcely enough to cover all the atoms in the Maxwell-Boltzman velocity distribution. The maximum intensity we can use for Zeeman slower barely exceeds $0.4I_s$ (I_s=58 mW/cm^2 : saturation intensity). Our choice was to make the Zeeman slower cut off the maximum slowing velocity at 340 m/s, which means 60 % of the total atomic beam can be controlled. The motion of ytterbium atoms at 340 m/s initially is simulated to get the final longitudinal velocity of about 10 m/s in Figure 3. According to the simulation the final speed can be controlled by frequency tuning of the cooling laser to have almost zero velocity.

In our presentation we hope to demonstrate the actual performance of the ytterbium Zeeman slower by measuring the velocity distribution at the exit of the slower.

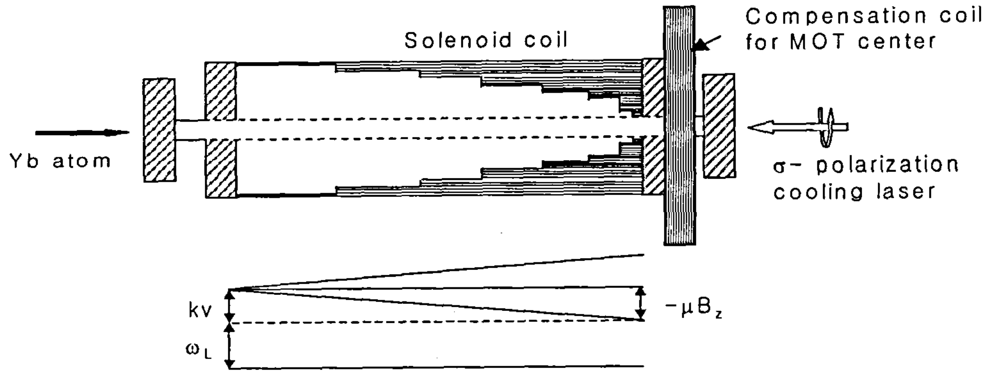

Figure 1. Top : The configuration of the Zeeman slower with σ^--polarization cooling laser where the magnetic field increases with slowing of atoms. Bttom : the relationship between the Doppler shift kv, the cooling laser frequency ω_L and the Zeeman shift $-\mu B_z$ depends on the position of Zeeman slower.

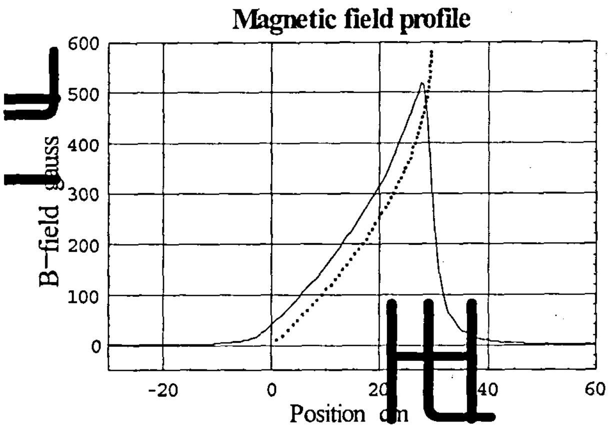

Figure 3. The measured magnetic field gradient (solid line) at 2.5-A coil current and the simulated optimal field gradient (dotted line) for 340-m/s maximum cooling velocity and 0.4Is laser intensity.

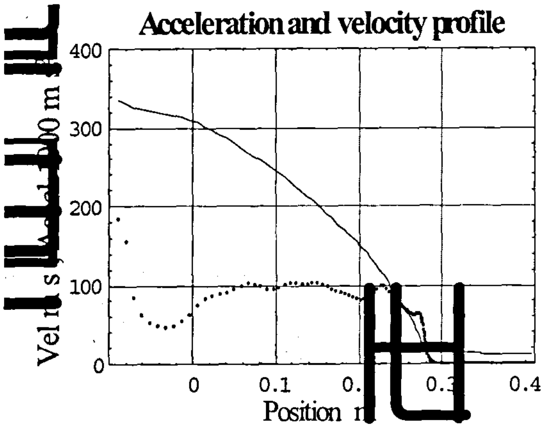

Figure 2. The simulated acceleration (dotted line, negative sign) and velocity (solid line) variation at 340 m/s initial speed and 0.4Is laser intensity.

1. J. L. Hall *et al.*, J. Opt. Soc. Am. B **6**, 2194 (1989).
2. W. D. Phillips and H. Metcalf, Phys. Rev. Lett. **48**, 596 (1982).