Second Stage Laser Cooling and Optical Trapping of ^{169}Tm Atoms

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Laser cooling and trapping of neutral atoms is one of the most powerful tools for studying atomic ensembles at ultralow temperatures. Laser-cooled lanthanides are effectively used in such fundamental fields as the study of cold collisions [1], Bose-Einstein condensation [2] and ultra-precise atomic clocks [3].

We propose to use the transition at the wavelength 1.14 µm between two fine-structure components of Thulium ground-state as a "clock transition" in optical lattice clock. Narrow natural line width (1.2 Hz) and strong shielding by closed $6s^2$ and $5s^2$ shells provide high frequency stability of Thulium-based optical clocks. To load atoms in a shallow optical dipole trap or optical lattice, they should be laser cooled to temperatures as low as 1-10 µK.

Laser cooling and trapping of thulium atoms was demonstrated in our laboratory in 2010 [4]. We used a strong nearly closed transition with the wavelength of λ=410.6 nm and the natural line width of γ=9.4 MHz for Zeeman slowing and trapping of laser-cooled atoms in a magneto-optical trap (MOT). Due to similar magnetic sensitivity of the upper and lower cooling levels, sub-Doppler cooling mechanisms happened to be very efficient which allowed us to reach temperatures down to 25 µK directly in the MOT. In fact, this temperature is enough to re-capture atoms from MOT in a dipole trap formed by a tightly focused few-watt laser beam. This regime would be unfavorable for optical clock applications due to a strong dynamic Stark shifts from the trap field and low re-capturing efficiency due to tight focusing. To reach more favorable regime further cooling is required.

For this purpose we have implemented second stage cooling of ^{169}Tm atoms using closed transition $4f^{13}6s^2(J = 7/2) \rightarrow 4f^{12}5d_{5/2}6s^2(J' = 9/2)$ with the wavelength of λ=530.7 nm and the natural line width of γ=360 kHz. The Doppler limit in this case is lower than 9 µK. For cooling and trapping we used the second harmonic of semiconductor laser with a spectral line width about 1 MHz. Due to broad laser spectrum only MOT with large red light detuning can be realized. However in this regime the Doppler limit isn't attained. So the obtained temperature was in the range 20-30 µK. To decrease temperature of atoms we plan to narrow the laser spectral line width by locking it in an external optical cavity.

References:
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