Towards an $^{27}Al^+$ ion optical clock

Zetian Xu, Xiaoyi Zeng, Xiaohui Shi, Huang Che, Ke Deng, Jie Zhang, Zehuang Lu

MOE Key Laboratory of Fundamental Quantities Measurement, School of Physics,

Huazhong University of Science and Technology, Wuhan, P.R. China

Email: zehuanglu@mail.hust.edu.cn

Al^+ optical clocks based on quantum logic technique currently are the most accurate ion optical clock[1]. In our laboratory we are developing an Al^+ optical clock based on quantum logic technique, and $^{25}Mg^+$ has been chosen to be the logic ion. Here, we will report our progress on Raman sideband cooling of $^{25}Mg^+$, and the development of ultra-stable lasers used for Al^+ optical frequency standards.

Raman sideband cooling of $^{25}Mg^+$ to its secular motion vibration ground state is necessary before we can apply quantum logic technique. In our experiment, the cooling laser is derived from a UV FHG diode laser. The center frequency of Raman lights are red detuned 9.2 GHz relative to the $^{25}Mg^+$ transition from $^2S_{1/2}$ F=3, m_F=3 state to $^2P_{3/2}$ F'=3, $m_{F'}$=3 state. The frequency difference between the two Raman lights is about 1.789 GHz, which coincides with the ground state hyperfine splitting of $^{25}Mg^+$. Their polarizations are adjusted to be π and σ^+ respectively with an applied 6 G magnetic field. The propagation directions of the two beams are perpendicular to each other. The Doppler cooling light is obtained from the same UV FHG laser. By placing a 9.2 GHz EOM before the FHG cavity, this laser can serve the double purposes of Raman sideband cooling and Doppler cooling.

To perform Raman sideband cooling, a microwave resonance experiment was carried out to precisely determine the value of the $^{25}Mg^+$ ground state hyperfine splitting to a few hundred Hertz level. Microwave is generated by an antenna placed in the vacuum chamber. In the experiment all lights are switched by AOM, and the pulse sequences are generated by a FPGA card. By applying 9.2 GHz detuned Raman lights during the interaction time we further measured the AC Stark shift induced by the two Raman beams. To ensure efficient Raman sideband cooling, the secular motion frequency of $^{25}Mg^+$ is tuned to be 952 kHz where the corresponding Lamb-Dicke parameter is 0.42. Finally, we will discuss our latest results on Raman sideband cooling.

Al^+ optical clock requires a sub-hertz linewidth laser as the clock laser, and a 100 Hz linewidth laser as the shelving laser. Two diode lasers are stabilized to two similar 10 cm ultra-stable cavities through Pound-Drever-Hall (PDH) locking. The FHG of these two diode lasers will be used as the shelving laser and the clock laser, respectively. The ultra-stable cavities are made of ULE materials with near 25 ℃ zero-crossing temperature of CTE, and are installed in two vacuum chambers. The linewidth of the beat notes of the two stabilized lasers when they are tuned to the same wavelength is around 1 Hz, and the Allan deviation is 6.5×10^{-15} at 1 s. The noise contribution factors and further improvement to this result will be discussed.

---

[1] C. W. Chou *et al.*, "Frequency Comparison of Two High-Accuracy Al^+ Optical Clocks", Phys. Rev. Lett., vol. 104, 07082, 2010.