Cooling and crystallization of trapped single 171Yb+ ion for optical frequency standard

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By measuring the frequencies emitted as atoms transition between energy levels, atomic frequency standards are among the most advanced devices available for keeping time. Here, we report our recent progress in developing an optical frequency standard based on a single $^{171}Yb^{+}$. With the laser Doppler cooling, a single ytterbium ion is cooled to crystallization and the temperature of the ion crystal is estimated to be below 1 mK. The progress reported in here is the first step of the project and paves the way for future development.

The entire system is shown in Fig. 1. The single $^{171}Yb^{+}$ ion is trapped in a linear Paul trap which consists of six electrodes. Four cylindrical electrodes act as radio frequency (RF) electrodes for radial confinement; two tapered electrodes act as endcap (EC) electrodes for axial confinement; two extra cylindrical electrodes act as compensate (CMP) electrodes for the compensation of stay electric field and reducing micromotion of ion.

Lasers are fully made in China. The 370 nm laser beam is used for Doppler cooling the $^{171}Yb^{+}$ ion. Two repump laser beams of wavelengths 935-nm and 760-nm are used to repump the $^{171}Yb^{+}$ ion from the $^{2}D_{3/2}$ and $^{2}F_{7/2}$ dark states. A 3.06-GHz and 5.2-GHz microwave sidebands are applied to the 935-nm and 760-nm laser beams by fiber electro-optic modulator (EOM) to eliminate the hyperfine dark state of the $^{2}D_{3/2}$ and $^{2}F_{7/2}$ level, respectively. Laser beam output from the fiber collimators is focused on the $^{171}Yb^{+}$ ion through lenses installed on translation stages. The waists of the focused laser beams are around $50\,\mu m$. The frequencies of laser beams are stabilized to a high-precision wavelength meter (HighFinesse WS8-2) by a proportional–integral–derivative controller. The wavelength meter can further be calibrated using an ultra-stable “clock laser”.

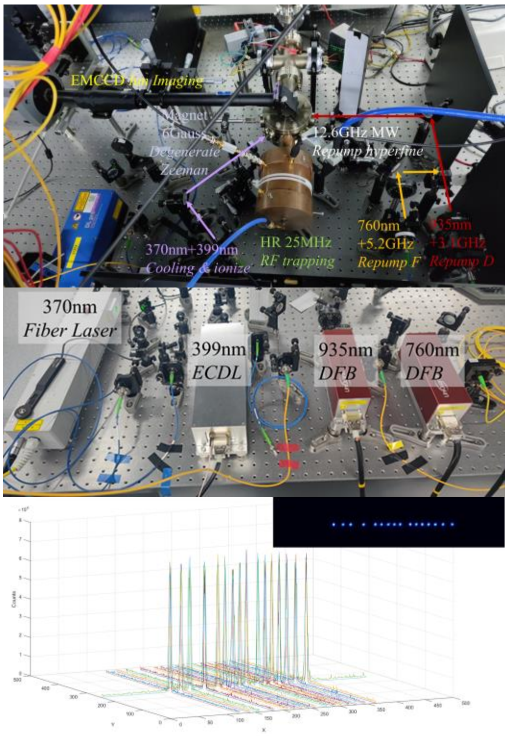

Fig.1. System, Lasers & $^{171}Yb^{+}$ ion crystal.

The temperature of the single $^{171}Yb^{+}$ ion is estimated through the EMCCD image. The image of ion is the convolution of the point-spread function (PSF) and the fluorescence of the ion [1,2]. The temperature of the single $^{171}Yb^{+}$ ion is estimated to be around 0.8 mK which close to its Doppler cooling limit. The temperature of multi $^{171}Yb^{+}$ ions is also estimated to be below 1 mK, which indicate a low heating rate of our ion trap. A low temperature of ion aiding a suppression of the second-order Doppler shift of uncertainty.

References

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