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Progress towards realization of an optical frequency standard using trapped Ba+ ions

We aim at realization of an optical frequency standard with barium ion (Ba⁺). The ${}^{2}S_{1/2}$ ($F = 2, m_{F} = 0$) - ${}^{2}D_{3/2}$ ($F = 0, m_{F} = 0$) clock transition in odd isotopes ${}^{135}Ba^{+}$ or ${}^{137}Ba^{+}$ is insensitive to quadrupole electric field[1]. Therefore, it is possible to improve the frequency stability by increase of the number of ions without degradation of uncertainty.

As a first step, we are developing an optical clock referenced to the ${}^{2}S_{1/2} - {}^{2}D_{5/2}$ transition at 1.76 μ m in ${}^{138}Ba^{+}$ ions[2-5]. So far, we conducted single-ion spectroscopy of the clock transition using a linenarrowed external-cavity laser diode (ECLD) and resolved motional sidebands [6]. To accelerate the detection of the spectra of the clock transition, we employed deexcitation of the ${}^{2}D_{3/2}$ state owing to its long lifetime of 31 s. We first drove the ${}^{2}D_{5/2} - {}^{2}P_{3/2}$ transition at 614 nm by irradiating with radiation from an orange LED. The deexcitation rate was measured to be $\boxtimes 10$ s. Then, we irradiated with radiation around 614 nm from an optical frequency comb (OCF) based on a Yb:KYW laser[6] to further accelerate the deexcitation. We estimated the deexcitation time to be 200 ms, where the optical power in 30-nm bandwidth was 40 μ W. This is a similar approach to use of an amplified spontaneous-emission in a Yb-doped fiber amplifier for deexcitation of the ${}^{2}D_{5/2}$ state in Sr⁺ ions[8].

We also succeeded in laser cooling of single ¹³⁷Ba⁺ ions loaded through odd-isotope-selective photoionization[9]. We employ two-step photoionization of Ba atoms using the ¹S₀ - ¹P₁ transition at 553 nm as the first excitation. Ba atoms in the ¹P₁ state is further excited using the second radiation above the ionization potential. Radiation at 553 nm is generated using a frequency-doubled ECLD and the second radiation is generated from a laser diode (LD) at 396 nm. Radiation for the first excitation is blue-detuned by 500 MHz from the absorption line of ¹³⁸Ba⁺ ions. We laser cooled ¹³⁷Ba⁺ ions by driving the ²S_{1/2} - ²P_{1/2} transition using two frequency-doubled ECLDs at 493 nm to avoid optical pumping in the hyperfine structures. We simultaneously drove the ²D_{3/2} - ²P_{1/2} transition using three ECLDs at 650 nm. We detected the fluorescence of a photon counting rate of 700 s⁻¹ for a ¹³⁷Ba⁺ ion.

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