Single-ion spectroscopy of the $^{2}\text{S}_{1/2}-^{2}\text{D}_{5/2}$ clock transitions in Yb$^+$ towards search for temporal variation of the fine structure constant

Yasutaka Imai, Kazuhiko Sugiyama, Tatsuya Nishi, Shohei Higashitani, Tomoya Momiyama, and Masao Kitano

Graduate School of Electronic Science and Engineering, Kyoto University, Kyoto 615-8510, Japan

imai@giga.kuee.kyoto-u.ac.jp

Measurement of a temporal variation of the frequency ratio between two optical clocks which use different transitions as frequency references enables us to explore the temporal variation of the fine structure constant $\alpha$ [1]. A constraint on the temporal variation of $\alpha$ is preliminarily estimated to be $(-1.6 \pm 2.3) \times 10^{-17}/\text{yr}$ from the frequency ratio measurement between $^{27}\text{Al}^+$ and $^{199}\text{Hg}^+$ optical clocks [2].

We are developing optical clocks based on single Yb$^+$ ions. Yb$^+$ has three clock transitions: $^{2}\text{S}_{1/2}-^{2}\text{D}_{3/2}$, $^{2}\text{S}_{1/2}-^{2}\text{D}_{5/2}$ and $^{2}\text{S}_{1/2}-^{2}\text{F}_{7/2}$ [3, 4, 5]. We can conduct frequency ratio measurement between the different clock transitions in Yb$^+$ by using the same single Yb$^+$ ion in the same trap. This removes common-mode frequency shifts such as the gravitational red shift, and enables us to evaluate the uncertainties more precisely. Comparison between $^{2}\text{S}_{1/2}-^{2}\text{F}_{7/2}$ and $^{2}\text{S}_{1/2}-^{2}\text{D}_{5/2}$ (or $^{2}\text{D}_{3/2}$) transitions has a sensitivity approximately twice as large as that between $^{27}\text{Al}^+$ and $^{199}\text{Hg}^+$ clocks described above [6]. Conversely, comparison between $^{2}\text{S}_{1/2}-^{2}\text{D}_{3/2}$ and $^{2}\text{S}_{1/2}-^{2}\text{D}_{5/2}$ transitions vanishes the sensitivity because the two transitions have similar sensitivities [6]. This enables us to investigate whether or not other effects which cause any temporal variations exist. The isotope $^{171}\text{Yb}^+$ has magnetic-insensitive clock transitions with relatively simple hyperfine structures because of the nuclear spin $I = 1/2$.

Towards the goal of this work raised above, we conduct single-ion spectroscopy of the $^{2}\text{S}_{1/2}-^{2}\text{D}_{5/2}$ clock transition in $^{174}\text{Yb}^+$. We detected the motional sidebands as shown in Fig.1 by frequency sweep of the clock laser by 20-kHz intervals. From the relative intensity of the sidebands, we estimated the temperature of a single $^{174}\text{Yb}^+$ ion to be 2 mK. We observed a spectral width of 5 kHz by high-resolution scanning of the carrier component with 2-kHz intervals as shown in Fig.2. The width is limited by the linewidth of the clock laser of 500 Hz and the fluctuation in the ambient magnetic field. In order to remove the latter problem, we laser cooled single $^{171}\text{Yb}^+$ ions and single-ion spectroscopy of the isotope is now under preparation.