Precision determination of the ground-state hyperfine splitting in a $^{113}Cd^+$ microwave frequency standard

S. N. Miao[1], Y. Zheng[1,2], Y. T. Chen[1], W. X. Shi[1], J. W. Zhang[1], L. J. Wang[1,2]

[1]State Key Laboratory of Precision Measurement Technology and Instruments, Department of Precision Instrument, Tsinghua University, Beijing, P. R. China
[2]Department of Physics, Tsinghua University, Beijing, P. R. China

Email: msn20@mails.tsinghua.edu.cn

Microwave frequency standards have been playing an important role across many areas such as time standards, telecommunications, and deep space exploration. Those based on trapped ions have featured alternate schemes that have exploited the compactness, high transportability, and zero-gravity operating capabilities of the system. Among them, the microwave frequency standard based on $^{113}Cd^+$ offers promising performances because of its large ground-state hyperfine splitting frequency (15.2 GHz) and special energy level structure of $^{113}Cd^+$, which means only one laser at 214.5 nm suffices in realizing laser cooling, pumping, and detection. Since 2010, our team at Tsinghua University has been committed to developing a transportable high-performance cadmium-ion microwave frequency standard.

Recently, we built a highly stable and accurate microwave frequency standard based on laser-cooled $^{113}Cd^+$ ions. The ions (10^5) were trapped and laser-cooled to blew 100 mK in a linear quadrupole Paul trap. Compared with the active hydrogen clock for nearly five hours, the short-term fractional frequency stability of our system was measured to be $4.2 \times 10^{-13}/\sqrt{\tau}$, which is close to the limit imposed by the Dick effect. After careful evaluation of all of the systematic frequency shifts and corresponding frequency uncertainties, the 0-0 ground-state hyperfine splitting frequency of $^{113}Cd^+$ was determined to be 15199862855.02799(27) Hz. This result is consistent with previous measurement results, and the precision has been improved to 1.8×10^{-14}. Our measurement precision is four times better than the best result obtained to date[1], which is comparable to the performance of the mercury-ion microwave frequency standard.

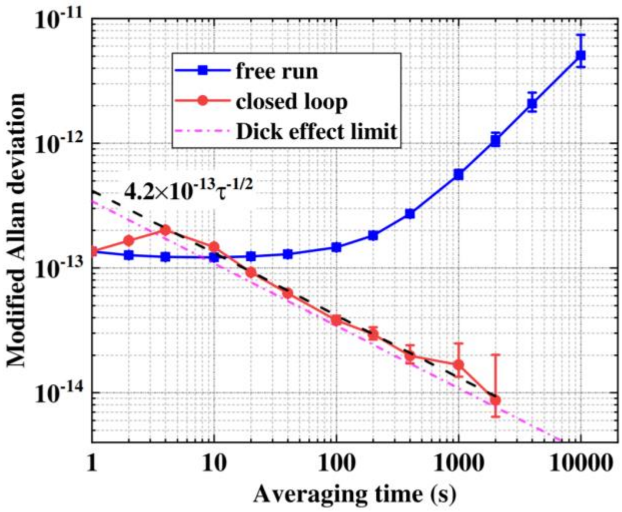

Fig. 1: Modified Allan deviations of the $^{113}Cd^+$ microwave frequency standard. The solid blue line is a fitting of data from the free-running local oscillator, the solid red line is that after closed-loop locking, and the pink dotted line signifies the Dick effect limit. The short-term fractional frequency stability of the system is estimated to be $4.2 \times 10^{-13}/\sqrt{\tau}$.

[1] K. Miao, J. W. Zhang, X. L. Sun, S. G. Wang, A. M. Zhang, K. Liang, and L. J. Wang, "High accuracy measurement of the ground-state hyperfine splitting in a $^{113}Cd^+$ microwave clock", Opt. Lett., vol. 40, p. 4249, 2015.