Short-Term Stability Improvement of the Microwave Frequency Standard Based on Laser-Cooled $^{113}Cd^{+}$ Ions

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At Tsinghua University, we built the experimental setup to develop a microwave frequency standard with laser-cooled $^{113}Cd^{+}$ ions[1]. With this experimental setup, we measured the frequency of clock transition[2, 3]. Moreover, an ultra-stable crystal oscillator was locked to the clock transition of $^{113}Cd^{+}$ ions, and the short-term frequency stability was measured. The results is not as good as what we expected because of the low signal-to-noise ratio (SNR) of the clock signal.

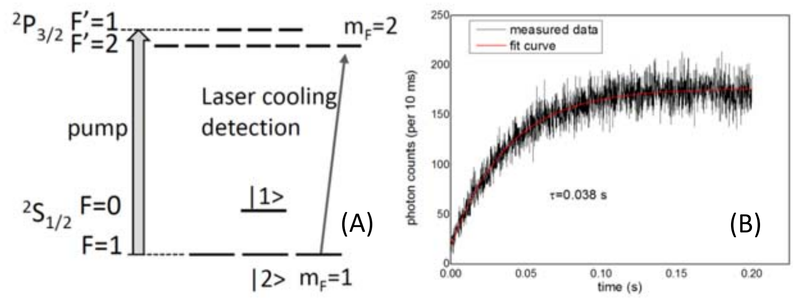

Fig. 1: (A) Schematic energy levels of $^{113}Cd^{+}$ ions (Not to scale). (B) Fluorescence decays at the beginning of detection for all ions initially populated in |1> state, and the decay time constants are 0.038 s obtained by exponential fitting (red curve).

As shown in Fig. 1 (A), the cycling transition of $^2S_{1/2}$ (F=1, m_F=1) → $^2P_{3/2}$ (F'=2, m_F=2) is driven by a circular-polarized laser for laser cooling and detection, and the transition of $^2S_{1/2}$ (F=1) → $^2P_{3/2}$ (F'=1) is resonant with another laser for optical pumping. Before applying the interrogation microwave pulses, all ions are pumped into |1>= $^2S_{1/2}$ (F=0, m_F=0) state. As soon as the microwaves interaction finishes, the cooling laser is unblocked and the fluorescence is detected simultaneously. Although the cooling laser is driving a cycling transition and the hyperfine splitting of the ground state is 15.2 GHz, the populations of ions in |1> state and |2>= $^2S_{1/2}$ (F=1, m_F=0) state were changed during detection. Figure 1 (B) shows a typical measurement result. This population decay induced by the cooling laser is one of the main limits to the SNR of the clock signal.

Here, we will discuss the reasons of the fluorescence decays during detection, and the ways to optimize SNR to improve the short-term frequency stability of the Cd^{+} clock.

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[1] J. W. Zhang, S. G. Wang, K. Miao, Z. B. Wang, L. J. Wang, "Toward a transportable microwave frequency standard based on laser cooled $^{113}Cd^{+}$ ions," *Appl. Phys. B*, DOI: 10.1007/s00340-013-5679-8, 2013.

[2] J.W. Zhang, Z.B. Wang, S.G. Wang, K. Miao, B. Wang, L.J. Wang, "High-resolution laser microwave double-resonance spectroscopy of hyperfine splitting of trapped $^{113}Cd^{+}$ and $^{111}Cd^{+}$ ions", *Phys. Rev. A*, vol. 86, p.022523, 2012.

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