Ion quantum logic optical clock

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Application Note

Introduction

Techniques developed for quantum computing with trapped ions can be used to perform precision spectroscopy of ion species such as aluminum that has an ideal transition for an optical clock. In our experiment, we set up an optical clock with aluminum as the clock ion and calcium as logic ion that provides sympathetic cooling, state preparation, and internal state detection after interrogation of the clock transition.

Experiment

One of the requirements for precision spectroscopy is laser cooling. However, aluminum has no suitable transition for cooling. A potential cooling transition is at 167 nm in the vacuum ultra violet, for which currently no lasers exist. This is why we use sympathetic cooling with a second ion to achieve temperatures near 0 K. The spectroscopic readout which usually also facilitates the cooling transition is done via quantum logic.

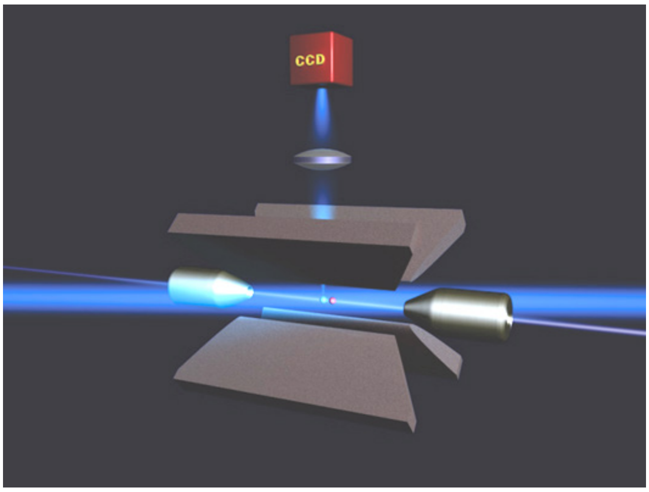

Fig. 1: Experimental setup for trapped-ion detection. The ions are illuminated by the cooling laser, the fluorescence of the logic ion is detected by an iXon3 885 EMCCD camera.

The idea is to trap a second ion of a different species, called the logic ion, together with the clock ion in the same trap. This logic ion has a better accessible cooling and detection transition than the clock ion. It cools the clock ion sympathetically via the coulomb interaction and it allows through a series of laser pulses to transfer the internal state of the clock ion after probing the clock transition onto the internal state of the logic ion where it can be read out more easily. This state projection and read out scheme is called quantum logic spectroscopy [1].

Recently we successfully trapped a Ca^+-Al^+ ion crystal as shown in Fig. 2. In the experimental setup only the fluorescence of calcium can be detected with an iXon3 885 EMCCD camera (model DU885 KC-VP from Andor Technology). This is why the presence of an Al^+ ion in the trap can only be detected indirectly. All three subfigures of Fig. 2 show the same area. In subfigure (a) a single calcium ion is loaded. Then an additional aluminium ion is loaded (b), shifting the position of the Ca^+ ion. For confirmation of the presence of an aluminium ion the two-ion crystal is shaken at the motional resonance frequency via applying a modulating electric field. On resonance, this modulation heats up the ion crystal, which can be observed through a smearing out of the Ca+ ion's fluorescence signal (c). The motional resonance frequency depends directly on the mass of the ions in the trap, from which we deduce a $^{27}Al^+$ - $^{40}Ca^+$ crystal.

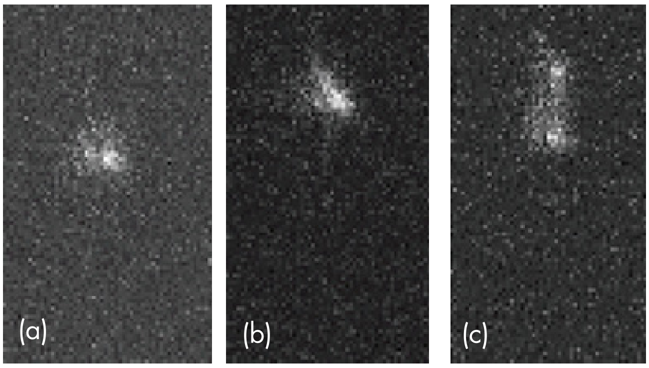

Fig. 2: Loading and confirmation of a calcium-aluminum ion crystal. Explanation of the three pictures is given in the text above.

References

[1] P. O. Schmidt et al., Spectroscopy using quantum logic, Science 309, 5735 (2005)

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