Spectroscopy measurements of $^{40}Ca^{+}$ Ions in a surface ion trap

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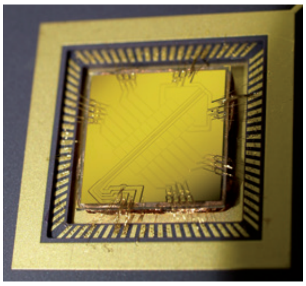
Application Note

Introduction

We trap $^{40}Ca^{+}$-Ions in a planar Paul trap with integrated, surface-mounted, micro-structured wires W1 and W2 (see Fig. 1). By sending an electric current through these we can produce a strong magnetic field gradients. The trap is fabricated by state-of-the-art micro processing technologies and consists of gold electrodes evaporated onto a sapphire substrate [1]. The trap is wire bonded to a ceramic chip carrier and the latter glued onto a PCB low-pass filter.



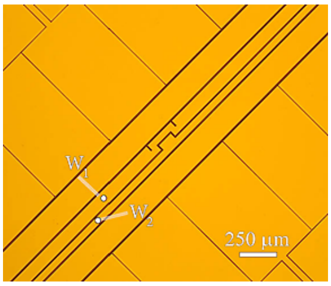


Figure 1. a) Planar ion trap glued and wire bonded to chip carrier, b) Photo micrograph of the region capable of producing the strongest magnetic field gradients.

Trap Apparatus and Fluorescence Detection

The confinement in axial and radial direction is generated by a combination of static and dynamic electric fields. A magnetic field is generated by sending oscillating or static currents through wire W1 or W2. When applying an oscillating magnetic field, the qubit state of the $^{40}Ca^{+}$ ions, which are encoded in the $S_{1/2}$ ground state, can be coherently controlled. The qubit state can be measured by fluorescence detection on the $S_{1/2} \leftrightarrow P_{1/2}$ electric dipole transition at 397 nm. Prior to measurement, one of the qubits states is transferred to a long lived $D_{5/2}$ state.

We employ the Andor iXon3 DU897-ECS-BBB to distinguish between the "dark" state, in which the ion has been excited from $S_{1/2}$ m= -1/2 to the metastable state $D_{5/2}$, and the "bright" state $S_{1/2}$ m=+1/2. For the distinction to work, prior to each measurement, a photon-counting threshold value has to be calculated, distinguishing fluorescence counts from background photons.

To obtain a reasonable estimate for this threshold, 100 measurements are taken with the ion prepared in a bright or dark state, respectively. The dark state is mimicked by omitting a repump laser during detection, such that the ion falls into a dark state and does not scatter any photons. We select a region of interest around each ion and sum up the number of photon counts for each measurement. After 100 experiments with bright and dark ions we build a histogram of all occurrences. Two Poissonian distributions can be seen (see Fig. 2), corresponding to the Dark state and the bright state. The threshold is calculated from the geometrical mean of the average values of both distributions respectively [2]. The detection time in our measurements is three to four milliseconds, using an EM gain of 300.

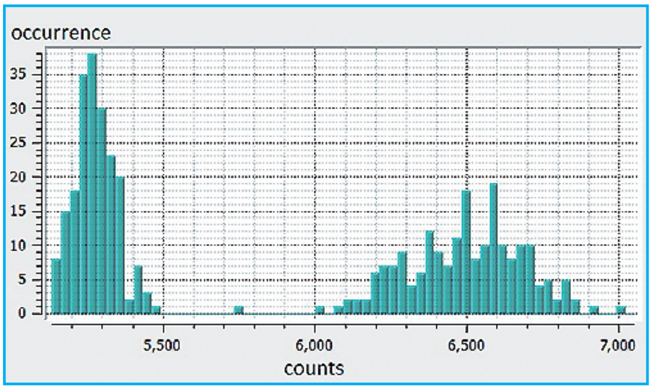


Fig. 2: Histogram of fluorescence for "bright" and "dark" state of a trapped ion where sigma = 5800.

In order to minimize the influence from other light sources, we equipped the iXon3 with an additional bandpass filter (Semrock FF01-377/50-25) around 397 nm. The camera is mounted so that it records a picture perpendicular to the trap surface (see Fig. 3). A custom made objective lens of NA~0.27 collects the ion fluorescence. Each pixel in the image corresponds to about 1.2 µm determined by comparing the inter-ion distance in a two-ion crystal with theory.

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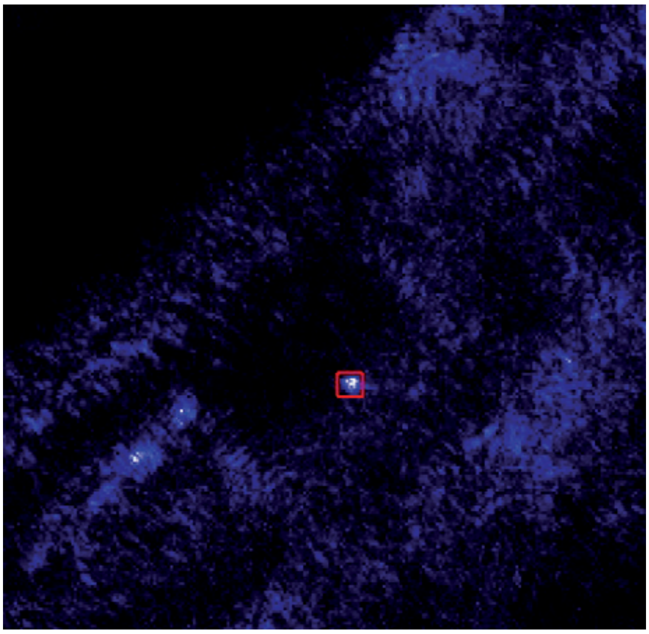

Fig. 3: Ion trapped above the wire pattern. The gaps between the wires are clearly visible due to stray light reflecting from them, although they are out of focus. The focal plane is 160 µm above the surface, where the ion is trapped.

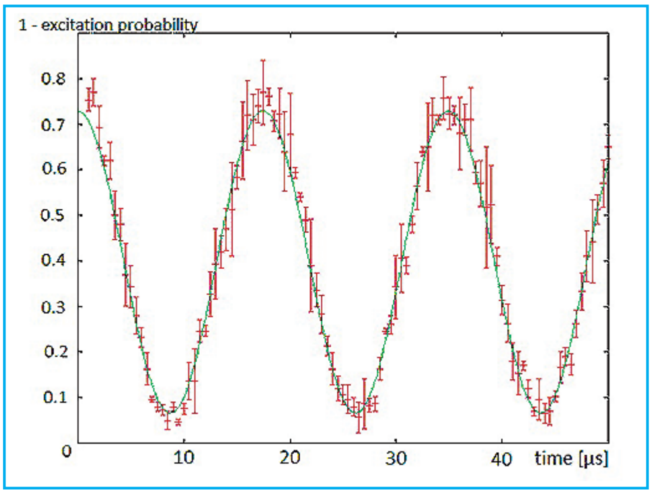

Fig. 4: Measured Rabi oscillation on carrier of Zeeman transition, where "1" means the ion is in the dark state and "0" in the bright state.

The camera control relies on a library written in the group by Alex Wiens [3], based on Andors Software Development Kit (SDK), allowing to fully integrate it into our group-intern control program for the experiment. The full width of the camera covers about one segment of the trap (around 600 µm). To reduce noise, which typically comes from insulating material in the trap setup which is exposed to our laser at 397 nm, and to speed up the charge read-out speed, we carry out spectroscopy measurements in the sub-Image mode already provided on the Andor SDK.

Measurements

Spectroscopy measurements between the two Zeeman sub levels haven been performed by applying an oscillating current to wire W1 in the RF regime. A scan with varying pulse length shows the oscillatory behavior (Rabi flop) of the 1-excitation probability, expected in a two level system (see Fig. 4).

References

[1] J. Welzel, A. Bautista-Salvador, et al., Eur. Phys. J. D 65, (2011)
[2] C. Roos, Dissertation "Controlling the quantum state of trapped ions", (2000)
[3] A. Wien, Diploma thesis "Detection of Qubit Registers in a Micro Trap", (2011)

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