Imaging of single $^9Be^+$ ions in surface-electrode traps for quantum information processing

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Application Note

Introduction

In quantum logic, the basic unit of information of Boolean logic, the bit, is replaced by its quantum counterpart, the quantum bit or "qubit", a well-controlled quantum two-level system. In our experiments, two atomic hyperfine states of a $^9Be^+$ ion define the qubit. The ions are trapped in a microfabricated surface-electrode Paul trap, made of gold-plated electrodes supported on an aluminum nitride substrate. By supplying RF and DC potentials to the trap electrodes, single ions are confined 45 μm above the trap surface under ultra-high vacuum conditions. In quantum information processing with trapped ions, the joint motion of the strongly coupled charged particles in the trap serves as a quantum "bus" for exchanging information between individual qubits. This motional degree of freedom needs to be coupled to each ion's qubit degree of freedom [1]. This is typically done using tightly focused laser beams. However, scaling laser-based techniques for multi-qubit gates is a challenging task. In an alternative approach, the desired coupling is achieved by means of oscillating microwave near-field gradients created by currents in conductors embedded in a planar ion trap [2,3]. The trap that we use is an evolved version of the designs from [4]. A near-field amplitude gradient over the motional wavepacket of the ion generates the required coupling between the motional and "qubit" degrees of freedom.

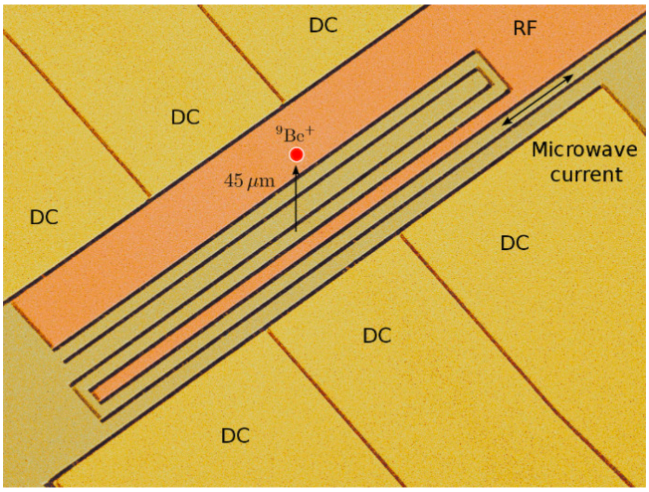

Figure 1: False colored SEM micrograph of surface-electrode ion trap used in the experiment. The ion is trapped 45 μm above the trap surface by applying DC and RF voltages to the trap electrodes. It is manipulated using microwave currents injected into a specially designed trap electrode right below the ion. The structure is made of 11 μm thick electroplated gold with 4 μm gaps (dark on the picture) between the electrodes.

Experiment

To load $^9Be^+$ ions into the trap, we hit a solid beryllium target with a single nanosecond laser pulse at 1064 nm. This releases a gas jet of neutral ^9Be atoms across the trap surface. We use a 235 nm laser to drive a resonantly enhanced 2-photon transition to the continuum, which ionizes the neutral ^9Be atoms. For detection and Doppler cooling of the $^9Be^+$ ions, we use a laser beam at 313 nm resonant with a cycling transition between states within the $S_{1/2}$ and $P_{3/2}$ manifolds of $^9Be^+$.

Fluorescence photons scattered by the ion are collected by a custom objective (magnification 13x, numerical aperture 0.41) with optical axis normal to the trap surface and placed outside the vacuum system. The lens is mounted on a 3D motorized stage which allows us to scan over the trap surface and to change the lens height to account for the different wavelengths used in our experiment. At the position of the image created by the objective, we have placed an aperture which allows us to filter away stray light from the trap surface. A second stage is realized using a microscope objective with a magnification of 3, so that the total magnification is approximately 40. In order to reduce the external stray light which might affect the image, the whole optical path is enclosed in a tube system. The light passing through the system is directed onto an iXon+ EMCCD camera (DU885 KC-VP from Andor Technology). The EMCCD camera is initially used to align the laser beams relative to the structures inside the surface-electrode ion trap. Subsequently, the beams are lifted off the surface to the position where the ion is expected, and the imaging system is shifted by the same amount. Once the trapping procedure works, the iris at the intermediate image position is reduced to further minimize stray light. Figure 2 shows a typical image of a single $^9Be^+$ ion, taken by the EMCCD camera.

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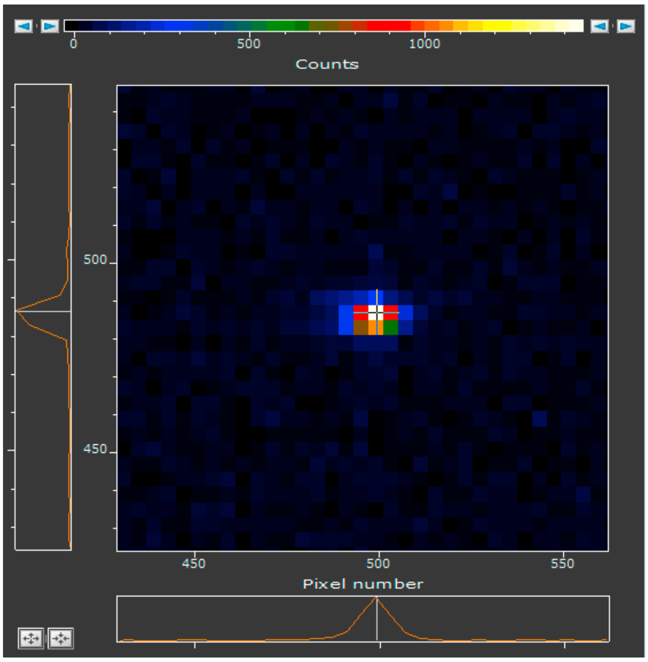

Figure 2: Resonance fluorescence from single Be^+ ion trapped in a surface-electrode trap.

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References

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