Single ion imaging and state detection for quantum networks

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Application Note

Introduction
Looking at the parameters of experimentally available quantum systems, trapped atomic ions provide the most advanced overall package, outperforming the competition with respect to quantum state storage time and process quality of coherent manipulation. To study few system coupling effects or to establish entangled links in a quantum network, it is desirable to be able to create networks of interacting ions. If high coupling speed or large link distances are a concern, single photons as mediator of the ion-ion interaction become the apparent choice. To enhance the light-matter interaction, high-finesse optical cavities have been successfully combined with neutral atoms, essentially providing a way to convert atomic quantum states into photonic quantum states and back again.

Experimental set-up
In our lab we are combining these techniques to create the nodes of a potential quantum network. An individual node is made up of a single trapped Ytterbium-ion placed in the waist of the mode formed inside a high-finesse fiber cavity (see Figure 1). The Paul-type ion traps we use are designed to fit inside the fiber cavities while still leaving a large portion of the solid angle surrounding the ion open for light collection and laser beam access: two sharply tipped electrodes extend into the space between the cavity mirrors, resulting in a distance of 50 µm from each tip to the trapped ion.

With laser-beams focused to a waist of 20 µm, stray-light from the outer wings of the laser beams scattered at these tips is the main contributor to background noise in ion fluorescence measurements. This requires tight control of the imaging quality of the detection system and proper stray-light filtering through means of aperture stops and spatial filtering.

We observe the ion's fluorescence with a microscope objective with magnification 10 on an EMCCD camera (Luca-R DL604M-OEM from Andor Technology) giving us a spatial resolution of approximately 1 µm. Figure 2 shows a typical image of a trapped ion. The residual aberrations visible in the image are due to the thickness of the vacuum window and have been modelled with an optical simulation.

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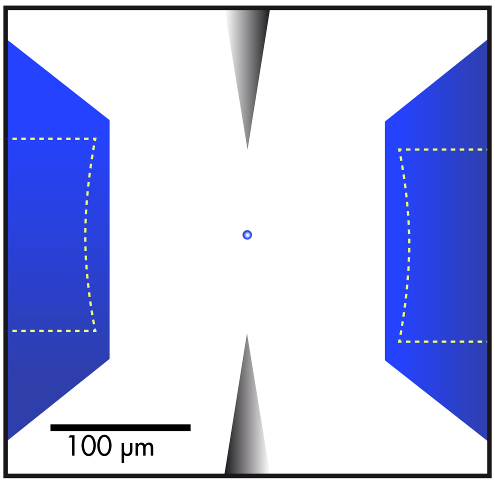

Figure 1: Schematic of the experimental set -up. The ion is trapped between two sharp tip electrodes (grey) and surrounded by the optical cavity (dotted yellow) that is housed inside conductive sleeves (blue).

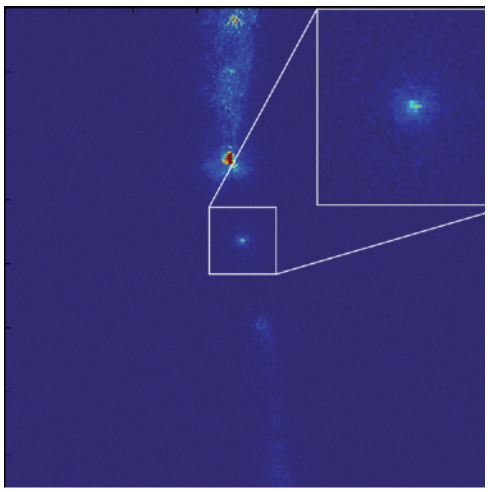

Figure 2: Example image of a trapped Ytterbium-ion. Visible in the image is the stray-light produced by the Doppler cooling laser scattered at the trap electrodes.

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