Contribution ID: **33** Type: **Talk**

Qubit addressing in a standing wave light field from integrated photonics

Monday 27 June 2022 11:00 (22 minutes)

Pairing integrated photonics with surface-electrode ion traps is an emerging technology, potentially opening the way to build novel architectures for quantum information processing [1, 2, 3]. Other than solving the scalability issues presented by individual addressing of multiple ions with free-space laser setups, it allows engineering the optical fields coupled to the ions and hence exploiting particular properties of the ion-light interaction.

Here we present a surface-electrode Paul trap where $^{40}\mathrm{Ca}^+$ ions are illuminated with two interfering beams at 729 nm forming a standing wave. The light is delivered to the trapping zone by silicon nitride waveguides, and coupled out of the chip with grating couplers. The beams intersect at $z = 50\,\mu$m above the chip, where the ions are trapped. Additional waveguides are used to send repumper light at 854 nm and 866 nm [2].

The beams are sent along the trap axis x and are linearly polarized along the orthogonal direction y. The field near the intersection of the two beams can be modeled by two interfering plane waves, $E_y(\mathbf{r}) = E_0(e^{i(k_z z+k_x x)} + e^{i(k_z z-k_x x)}) = 2E_0 e^{ik_z z}\cos(k_x x)$. This configuration modulates the field intensity along the trap axis, as well as the orientation of the electric field gradient $\partial_i E_y$. Light at this wavelength is resonant with the quadrupole transition between $|4S_{1/2}\rangle$ and $|3D_{5/2}\rangle$, whose coupling strength depends on the relative alignment between the external magnetic field and the field gradient, which then can be tuned by appropriately positioning the ion in the beam profile.

We probe the optical field with sub-wavelength resolution scanning the position of a single ion through the standing wave, and observing Rabi oscillations for transitions with $\Delta m_j = 0, -1, -2$. We measure both the Rabi frequency of the resonant optical coupling and the differential AC Stark shift induced by off-resonant coupling to other transitions, for both the carrier and the first motional sidebands transitions. We observe that a position that maximizes the carrier coupling suppresses the sideband, and vice versa [4], although the maximum carrier coupling is located at an intensity node, antinode, or in between, depending on the choice of carrier transition.

The study of the interaction of such a light field with single ions is relevant in the context of achieving faster and lower error Mølmer-Sørensen entangling gates with suppressed off-resonant carrier coupling [5], and for exploring laser cooling in unusual regimes.

[1] K. K. Mehta et al. "Integrated optical addressing of an ion qubit", Nature Nanotechnology 11.12 (2016).

[2] K. K. Mehta et al. "Integrated optical multi-ion quantum logic", Nature 586.7830 (2020).

[3] R. J. Niffenegger et al. "Integrated multi-wavelength control of an ion qubit", Nature 586.7830 (2020).

[4] A. B. Mundt et al. "Coupling a Single Atomic Quantum Bit to a High Finesse Optical Cavity", Phys. Rev. Lett.89 (2002).

[5] K. K. Mehta et al. "Towards fast and scalable trapped-ion quantum logic with integrated photonics", Advances in Photonics of Quantum Computing, Memory, and Communication, XII 10933 (2019).

Primary authors: MORDINI, Carmelo (ETH Zurich); RICCI VASQUEZ, Alfredo (ETH Zurich); ZHANG, Chi (ETH Zurich); MALINOWSKI, Maciej (ETH Zurich); KIENZLER, Daniel (ETH Zurich); MEHTA, Karan (ETH Zurich); HOME, Jonathan (ETH Zurich)

Presenter: MORDINI, Carmelo (ETH Zurich)

Session Classification: Quantum Information & Computing