Fast, High-Fidelity Entanglement in Multi-Ion Chains

E. R. B. Hirsch,[1,*] I. R. Øvergaard,[1] D. J. Webb,[1] G. Canalella,[1] K. Shinbrough,[1] O. Băzăvan,[1] S. Saner,[1] R. Srinivas,[1] and C. J. Ballance[1]

[1] *Clarendon Laboratory, Department of Physics, University of Oxford, Parks Road, Oxford OX1 3PU, United Kingdom*

The trapped ion platform has demonstrated among the highest reported two-qubit gate fidelities and coherence times, and constitutes a promising platform for quantum computing. A longstanding limitation of the trapped-ion platform, however, is the duration of two-qubit gates. Previous work has demonstrated two-qubit gate durations below the motional period ($\lesssim 1\ \mu s$) for Raman-mediated gates [1]. Mølmer-Sørensen gates mediated instead by motional sidebands of an infrared quadrupole carrier transition are limited by off-resonant carrier coupling, which we have mitigated geometrically via structured light addressing in previous work [2].

Here, we present a new apparatus with custom crossed acousto-optical deflectors for individual addressing of $^{40}Ca^+$ ions in chains of 5-10 along the 729 nm quadrupole transition. With dual high-numerical aperture objectives, we prepare individually addressed beams with 1.50(1) um waist radius and crosstalk error of $4.16(2) \times 10^{-4}$. We present work toward an array of individually addressed standing waves for fast, reconfigurable, carrier-free two-qubit gates, for which we have designed a robust interferometric stabilization scheme for optical phase control near the ion position.

Increasing ion number leads necessarily to an increase in the number of nearby motional modes, which are often excited as we drive faster two-qubit gates. We plan to mitigate residual spin-motion entanglement from these spectator modes via amplitude pulse shaping [1]. With these tools, we aim to demonstrate two-qubit Mølmer-Sørensen gates that are non-adiabatic with respect to the motional mode frequency, for application in high-speed, high-fidelity, intermediate-scale quantum computing.

[1] V. M. Schäfer, et. al, Nature (London) 555, 75 (2018).
[2] S. Saner, O. Băzăvan, et. al, Phys. Rev. Lett. 131, 220601 (2023).

* emily.hirsch@physics.ox.ac.uk