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Developing a multi-qubit gate zone for use in a large scale ion shuttling architecture

The field of quantum computing with trapped ions has seen many milestone achievements, the challenge for the future lies in scaling ion processors to qubit numbers capable of tackling interesting problems –without forgoing the high fidelities seen in smaller prototypes. One class of large-scale ion trapping architecture comprises dedicated regions for trapping, measurement, storage and interaction between the qubits, combined with the ability to shuttle ions between regions.

We encode qubits in the hyperfine ground state manifold of trapped Yb+171 ions. Quantum control utilises global microwave fields provided via in-vacuum antennae and a static magnetic field gradient [1]. Ions are off resonant with the global fields until shuttled to interaction zones at designated positions in the gradient, altering their Zeeman splitting accordingly. In addition to providing individual qubit addressability, the magnetic field gradient couples the spin and motional degrees of freedom of the ions, allowing use of the motional state as a quantum bus. The strength of the gradient dictates the strength of the spin-motion coupling, which further determines the speed and fidelity of quantum gates. The microwave scheme seeks to address some of the challenges associated with scaling up laser-based schemes, only a fixed number of global fields are required independent of system size in contrast to a number of lasers that scales with the qubit number. In addition the scheme benefits from the relative maturity of commercially available microwave technology.

Previous work has relied on permanent precisely aligned magnets to produce the required magnetic field gradient for the microwave gate scheme. We seek to create a strong on-chip gradient utilising wires beneath the chip surface, which would allow the gradient to be switched on and off, not possible with permanent magnets. Without switching of the gradient idle ions must be shuttled through regions of large magnetic field, rendering them susceptible to dephasing –problematic for realizing quantum algorithms. Furthermore, the buried wire layer can be incorporated as a step in chip production using standard micro-fabrication processes, suitable for use in large-scale ion trap arrays.
We present work towards realising a multi-qubit 'interaction'region, designed to be easily integrated as a repeating unit in micro-fabricated ion trapping chips, in line with the road map to a large-scale quantum computer as outlined in [2].

[1] S.Weidt et al. Phys. Rev. Lett. 117, 220501 (2016)
[2] Bjoern Lekitsch et al. Science Advances 3.2 (2017)

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