High Fidelity Microwave Gates with Ca43

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We present progress towards improved microwave driven quantum logic gate speeds and fidelities in a next-generation surface-electrode ion-trap.

Trapped ions are a leading candidate for building a general-purpose quantum computer [1]. As spontaneous emission is an incoherent process, good candidate qubits for such a device are separated by a dipole forbidden transition. Common choices are optical frequency electric-quadrupole transitions [2] and ground-state, hyperfine magnetic-dipole transitions in the microwave regime [3]. For both qubit choices, quantum logic operations are usually driven by lasers, achieving two-qubit entangling gate operation timescales of microseconds and fidelities exceeding 99.9%. However, laser driven quantum logic gates can only offer a limited fidelity due to photon scattering processes. As ion-trap quantum processors increase in size, coherent, individual addressing of qubits also becomes more challenging. Microwave driven logic gates between hyperfine qubits don’t suffer from this fidelity limitation. In addition, microwaves can be easily integrated into microfabricated surface-traps which may simplify scalability requirements. Analogously to laser driven gates, microwave driven two-qubit logic gates rely on coupling the ion state to the ion-crystal motion. This can be achieved using far-field microwaves in combination with a strong static magnetic field gradient [4]. An alternative approach is to exploit near-field microwave interference to generate large amplitude gradients, which are determined by the electrode geometries [5, 6]. Operating in this near-field regime, we have previously realised two-qubit gates with 99.7(1)% fidelity, approaching the state-of-the-art laser driven gate fidelities [7].

We present progress towards improving the state-of-the-art microwave driven two-qubit gate speed and fidelity. This is enabled through a novel qubit choice and an improved trap design. Operating at the 288 G hyperfine clock $\pi$-transition of $^{43}$Ca reduces spectator transition effects due to increased transition splittings. The trap is designed to produce a large magnetic field gradient whilst passively nulling the microwave field at the ions position. This design offers reduced off resonant excitation for a given two-qubit gate speed. Larger gradients are also facilitated by reducing the ion-electrode separation to 40 microns, half of our previous separation [7]. The reduced ion-electrode separation comes at the cost of increased electric field noise, which couples to the ions motion and hence is detrimental to gate fidelities. The trap is designed to suppress the motional heating rate by operating cryogenically at ~20 K [8].


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