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Realizing coherently convertible dual-type qubits with the same ion species

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Trapped ions constitute one of the most promising systems for implementing quantum computing and networking. For large-scale ion-trap-based quantum computers and networks, it is critical to have two types of qubit: one for computation and storage, and another for auxiliary operations such as qubit detection, sympathetic cooling and entanglement generation through photon links. Previously, it was assumed that such frequency-separated dual-type ion qubits have to be implemented in hybrid systems of two ion species. For hybrid systems, apart from the experimental complexity of trapping and cooling two ion species and the lower mixed-species gate fidelity than the same-species case, it is also challenging to control the fraction and the positioning of each qubit type in many-ion crystals. Moreover, the mass mismatch between the ion species makes it very difficult to realize sympathetic cooling and high-fidelity gates with the transverse phonon modes.
In this work we experimentally realize dual-type qubits that are coherently convertible to each other with the same species of 171Yb+ ions. We encode the qubits into two pairs of clock states of the 171Yb+ ions, and achieve microsecond-level conversion rates between the two types with one-way fidelities of 99.5% using bichromatic narrowband laser beams at wavelengths of 411 nm and 3,432 nm. We further demonstrate that operations on one qubit type, including sympathetic laser cooling, single-qubit gates and qubit detection, have crosstalk errors less than 0.06% on the other type, which is below the best-known error threshold of ˜1% for fault-tolerant quantum computing using the surface code.
Coherent conversion between different qubit types allows us to dynamically tune the fraction and positioning of each qubit type on demand in many-ion crystals during computation, which is highly desirable for efficient sympathetic cooling and quantum error correction in large-scale systems. In addition, the capability of fast and high-fidelity qubit type conversion indicates that entangling gates between different qubit types can be performed in exactly the same way as for gates with the same qubit types, hence eliminating the challenging requirement for mixed-species high-fidelity gates. The demonstrated below-threshold crosstalk errors between the dual types of qubits, together with their fast high-fidelity coherent conversion, opens up prospects of wide applications in large-scale quantum computing and quantum networking.

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