Sub-nm-spaced frequency-addressed qubits

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Rare-earth-ions-doped inorganic crystals have properties which make them attractive for use as quantum computing hardware. The ions are naturally trapped, in a solid, with sub nm separations. The proximity between the ions results in large interactions and potentially allows fast gates, but they can still be separately addressed since different ions have different optical resonance frequency. The qubit state is stored in two of the hyperfine levels, which can have coherence times up to 33 s. The interaction that enables multi-qubit gates can be turned on at will and is based on that the permanent dipole moment changes as a control ion is transferred to the optically excited state which in turn Stark-shifts target qubit out of resonance. Initially the crystal has inhomogeneously broadened, GHz wide, absorption lines. Using optical pumping all ions within a frequency interval can be removed and then a peak of equivalent ions, each belonging to one instance of many parallel quantum computers can be positioned within the non-absorbing region. This qubit has then been efficiently transferred between different qubit states using robust complex hyperbolic secant pulses [1]. Pairs of qubits that interact strongly have also been distilled [1], see Fig 1.

In the ensemble approach all qubits have to be represented in all instances of quantum computers. This can scale unfavourably for large systems. One way of enhancing the scalability is to move towards using a single instance quantum computer. It has been shown that a single rare-earth-ion can be read out with fluorescence. One of the schemes investigated is based on using a specialized readout ion, of a species different from the qubit ions, which is doped in such a low concentration that there is only one such ion within the laser focal spot. When a qubit ion lying close to the readout ion is excited this will shift the readout ion out of resonance and the fluorescence will stop. With a searching strategy a set of interacting ions suitable as single instance qubits can be selected [2].

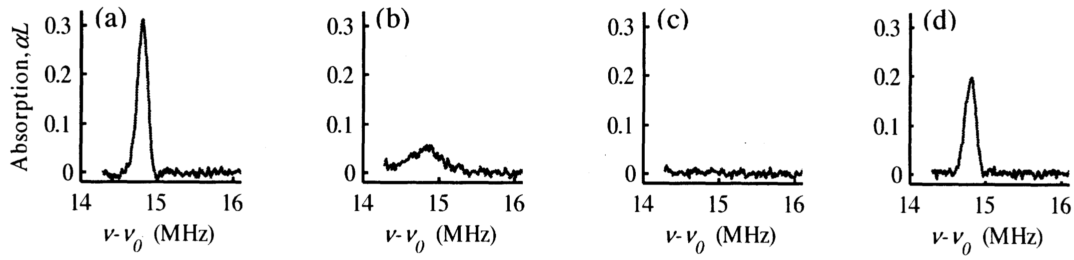

Figure 1. Distillation of ions that interact strongly with ions in a 20 MHz wide qubit control interval. The figure shows the absorption of the ions in the target qubit during different steps in the distillation process. (a) The original peak consists of both controllable and non controllable ions. (b) Exciting the control ions shifts the resonance frequencies of the strongly interacting ions. Only the non shifted ions of the target qubit absorption frequency remain. (c) The ions that do not shift have been removed. (d) After the control ions have relaxed back to the ground state, the ions that were shifted by the control ions in Figs 1b and 1c have now returned to their original resonance frequency. The resonance frequency of the ions in this peak was fully controlled by ions in the control interval.

References

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