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Single-donor spin qubits in silicon[1]

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The idea of using the spin of a single donor atom in silicon to encode quantum information goes back to the Kane proposal [1] in 1998. We have now resolved the technical challenges involved in the readout and control of the electron and nuclear spin of a single atom. The key breakthrough was the development of a device structure where the donor is tunnel-coupled to the island of an electrostatically-induced single-electron transistor [2]. This device allowed the single-shot readout of the electron spin with visibility $> 90\%$ and 3 μs readout time [3]. More recently we have integrated the single-shot readout device with a broadband microwave transmission line to coherently control the electron and nuclear spins. The resonance frequency of the electron is found by monitoring the excess spin-up counts while sweeping the microwave frequency. At any time, one of two possible frequencies is found to be in resonance with the electron spin, depending on the state of the nuclear spin. Alternately probing the two frequencies yields the (quantum nondemolition) single-shot readout of the nucleus, with fidelity $> 99.99\%$. Then we demonstrate the coherent control (Rabi oscillations) of both the electron and the nucleus, both detected in single-shot mode. The π-pulse fidelity is $\sim 70\%$ for the electron and $\sim 99\%$ for the nucleus. Hahn echo and multi-pulse dynamical decoupling sequences allow us to explore the true coherence of the qubits, yielding $T_{2e} \sim 200$ μs for the electron, and $T_{2n} \sim 60$ ms for the nucleus. These results are fully consistent with the bulk values for donors in a natural Si sample. Further improvements in qubit coherence can be expected by moving to isotopically pure ^{28}Si substrates.

[1] B. E. Kane, Nature **393**, 133 (1998).
[2] A. Morello *et al.*, Phys. Rev. B **80**, 081307(R) (2009).
[3] A. Morello *et al.*, Nature **467**, 687 (2010).

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