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Embedding Silicon Spin Qubits in Superconducting Circuits

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Abstract: We demonstrate the strong coupling between a single electron spin in silicon and a single photon in a superconducting microwave cavity. Using the same cavity we perform rapid high-fidelity single-shot readout of two-electron spin states.

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Long coherence times of single spins in silicon quantum dots make these systems highly attractive for quantum computation. However, the realization of large networks of quantum dot-based spin qubits requires advancements in coherent long-range interconnects between the qubits, and more efficient use of the on-chip real estate [1]. A promising approach that addresses these challenges is to integrate spin qubits in a superconducting cavity.

While direct interactions between quantum dot-based spin qubits are limited to a submicron range, circuit quantum electrodynamics can be employed to extend this range to millimeter scale, by transferring quantum information via microwave photons. Here, we report the strong coupling between a single electron spin in a silicon double quantum dot and a microwave photon in an on-chip high-impedance superconducting cavity [2–5], a crucial requirement for the coherent cavity-mediated transfer of quantum information between distant spin qubits. The electric field component of the cavity couples directly to the dipole moment of the electron charge in the double quantum dot, and indirectly to the electron spin, through a local magnetic field gradient from a nearby micromagnet [6, 7]. A charge-photon coupling strength of 200 MHz and a spin-photon coupling strength as large as 15 MHz have been extracted, several times larger than the spin and cavity decay rates.

Another crucial requirement for operating spin-based quantum processors is the ability to read out spin qubits fast and in a single shot manner. So far, this has been achieved using nearby single-electron transistors (SETs) as charge detectors, in combination with a spin-to-charge conversion scheme [8]. However, these SET's come with additional resources (gate electrodes, electron reservoirs), which poses an additional hurdle for scaling up to dense spin qubit systems. An alternative approach is to connect a resonant circuit to gates that are already in place for confining electrons [9–11]. Here, we utilize the cavity to detect the charge susceptibility at a two-electron interdot transition. Using Pauli's exclusion principle to map charge to spin information, we demonstrate the gate-based readout of a two-electron spin state in a single shot with an average fidelity of >98% in 6 μs.

These results open the way to coherent long-range interactions between spin qubits and rapid high-fidelity readout using the same cavity, removing a major roadblock for the scalability of spin-based quantum processors.

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