Two-qubit logic between distant spin qubits in silicon

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Coupling spin qubits to microwave photons provides an elegant approach for mediating long-range spin-spin interactions. The circuit quantum electrodynamics (QED) framework enables two-qubit gates which can be used for on-chip quantum links. In previous work, resonant spin-spin-resonator coupling in a silicon quantum device was demonstrated [1]. Most two-qubit gate schemes require a spin-spin coupling in the dispersive regime that is larger than the spin dephasing rates, as was recently observed in spectroscopic measurements [2]. In this work, we probe such a dispersive spin-spin interaction in the time-domain and demonstrate a two-qubit gate between spin qubits in silicon separated by 250 µm.

We form a double quantum dot (DQD) in a 28Si/SiGe heterostructure at each end of a 250 µm long high-impedance superconducting resonator (Figure 1) [3]. We trap a single spin in each DQD, and we enable tunable spin-charge hybridization with micromagnets. Due to mitigation of microwave losses [4], we can tune the spin-charge hybridization to reach the strong-coupling regime with spin-photon couplings up to around $g_s/2\pi$ = 40 MHz. The readout is implemented by direct dispersive spin sensing using the same resonator, with the signal-to-noise ratio largely improved by a Josephson traveling-wave parametric amplifier [5].

We first show universal single-qubit control over two flopping-mode qubits [6] and characterize their coherence times. Next, we bring the two spins into resonance with each other, but detuned from the resonator photons, and observe exchange (iSWAP) oscillations between the two remote spins up to 17 MHz. This frequency is consistent with the spectroscopic measurements [2]. Furthermore, we demonstrate that the coupling strength (2J) as well as the coherence times of the qubits can be tuned by two knobs: the inter-dot tunnel coupling and the spin-cavity detuning. In future work we intend to implement single-shot readout and improve the spin lifetimes while dispersively coupled to the resonator. These results pave the way for scalable networks of spin qubits on a chip.

References

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Figures

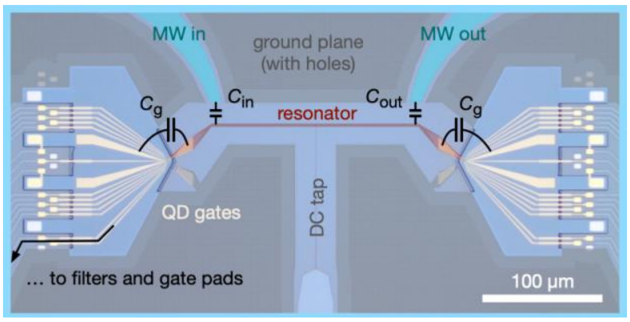

Figure 1: Spin-spin coupling device.