Long-Range Coupling of Spins with Microwave-Frequency Photons

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Electron spins are excellent candidates for solid state quantum computing due to their exceptionally long quantum coherence times, which is a result of weak coupling to environmental degrees of freedom. However, this isolation comes with a cost, as it is difficult to coherently couple two spins in the solid state, especially when they are separated by a large distance. Here we combine a large electric-dipole interaction with spin-orbit coupling to achieve spin-photon coupling. Vacuum Rabi splitting is observed in the cavity transmission as the Zeeman splitting of a single spin is tuned into resonance with the cavity photon. We achieve a spin-photon coupling rate as large as $g_s/2\pi$ = 10 MHz, which exceeds both the cavity decay rate $\kappa/2\pi$ = 1.8 MHz and spin dephasing rate $\gamma_s/2\pi$= 2.4 MHz, firmly anchoring our system in the strong-coupling regime [1]. We next utilize spin-photon coupling to achieve a resonant spin-spin interaction between two spins that are separated by more than 4 mm [2]. An enhanced vacuum Rabi splitting is observed when both spins are tuned into resonance with the cavity, indicative of a coherent spin-spin interaction. Our results demonstrate that microwave-frequency photons can be used as a resource to generate long-range two-qubit gates between spatially separated spins.

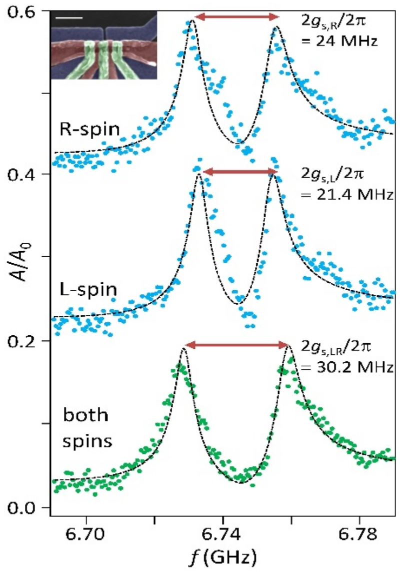

Figure: Cavity-mediated spin-spin coupling. The cavity transmission amplitude A/A_0 is plotted as a function of frequency f. Vacuum Rabi splitting is observed when each spin is brought into resonance with the cavity mode. The vacuum Rabi splitting is enhanced by a factor of $\sqrt{2}$ when both spins are simultaneously brought into resonance with the cavity mode, indicating a coherent spin-spin coupling over a distance exceeding 4 mm.

References

[1] X. Mi, M. Benito, S. Putz, D. M. Zajac, J. M. Taylor, G. Burkard, and J. R. Petta, *A coherent spin–photon interface in silicon*, Nature **555**, 599 (2018).
[2] F. Borjans, X. G. Croot, X. Mi, M. J. Gullans, and J. R. Petta, *Resonant microwave-mediated interactions between distant electron spins*, Nature **577**, 195 (2020).

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