A hole spin flopping mode qubit: fast and coherent

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Coherent spin-photon interfaces between microwave photons and spins in silicon quantum dots are now routinely achieved [1-4]. The key ingredient in resolving this outstanding challenge was the engineering of a large electric-dipole moment linked to the spin, achieved by delocalizing a spin within a double-quantum dot under the influence of spin-orbit interaction. These spin qubits, also known as flopping-mode spin qubits, have enabled the first SWAP operations between spin qubits separated by over 250 micrometers [4], paving the way to address the wiring challenges in dense spin qubit processors.

However, the coherence properties of such qubits reported to date remain limited, hindering their use in practical applications. Here, we report on a flopping mode qubit based on a hole spin delocalized in a double quantum dot formed in a silicon nanowire MOS device coupled to a superconducting microwave resonator [3]. We show that delocalized spins can achieve gate quality factors of 380, 20 times higher than previous reports [4] and close to state of the art spin qubits [5], enabling high-fidelity gate operations while coupled to a photonic resonator.

Furthermore, we present a comprehensive analysis of the mechanisms limiting spin relaxation and dephasing in a hybrid spin cQED architecture. Our findings reveal that spin relaxation is dominated by radiative decay due to a structured electromagnetic environment (Purcell effect); while dephasing is limited by photon shot noise at operational points where the spin is first-order insensitive to charge noise. This suggests that with an optimized cQED architecture, considerably longer coherence times can still be achieved potentially revealing intrinsic limitations to spin coherence such as phonon driven spin relaxation or hyperfine interactions.

With strong spin-photon coupling and promising single-qubit properties demonstrated here, hole spin flopping-mode qubits emerge as a promising platform for scalable quantum architectures.

References

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[3] Yu et al. Nature Nanotechnol. 18 (2023)
[4] Dijkema et al. Nature Physics (2024)
[5] Stano et al. (arXiv 2021)

Figures

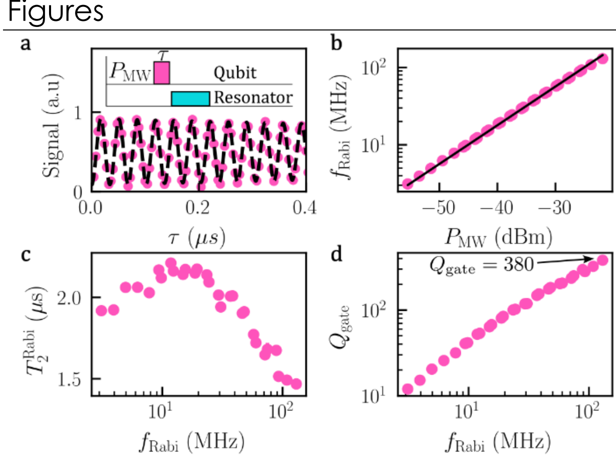

Figure 1: a) Rabi oscillation from which are extracted both Rabi frequency f_{Rabi} (b) and coherence time T_2^{Rabi} (c) for different drive power P_{MW}, from which is computed the gate quality factor $Q_{\mathrm{gate}} = 2 f_{\mathrm{Rabi}} T_2^{\mathrm{Rabi}}$ (d).