

Hole spin cQED – a bright future

Simon Zihlmann

L. Noirot, S. Granel, K. Leuckefeld, J. Dutems, M. Nurizzo, R. Maurand,
Univ. Grenoble Alpes, CEA, Grenoble INP, IRIG Phelias, Grenoble, France

H. Niebojewski, B. Bertrand
Univ. Grenoble Alpes, CEA, LETI, Minatec Campus, Grenoble, France

J.-C. Abadillo-Uriel
Instituto de Ciencia de Materiales de Madrid, Consejo Superior de Investigaciones Cientificas, Madrid 28049, Spain.

Simon.zihlmann@cea.fr

Coherent spin-photon interfaces between microwave photons and spins in silicon quantum dots are now routinely achieved [1-3]. 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 flopping mode spin qubits reported to date remain limited, hindering their use in practical applications. Here, we report on a hole spin delocalized in a double quantum dot formed in a silicon nanowire MOS device coupled to a high impedance superconducting microwave resonator [3]. With Rabi frequencies exceeding 100 MHz and coherence times in the microsecond range, we show that delocalized spins can achieve high qubit quality factors, enabling high-fidelity gate operations.

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. Our first approach in creating high-quality spin-cQED environments using semi-industrial flip-chip technology for 3D integration will be discussed.

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

- [1] Samkharadze et al. *Science*, 359 (2018)
- [2] Mi et al. *Nature*, 555 (2018)
- [3] Yu et al. *Nat. Nanotechnol.* 18 (2023)
- [4] Dijkema et al. *Nat. Phys.* 21 (2025)

Figures

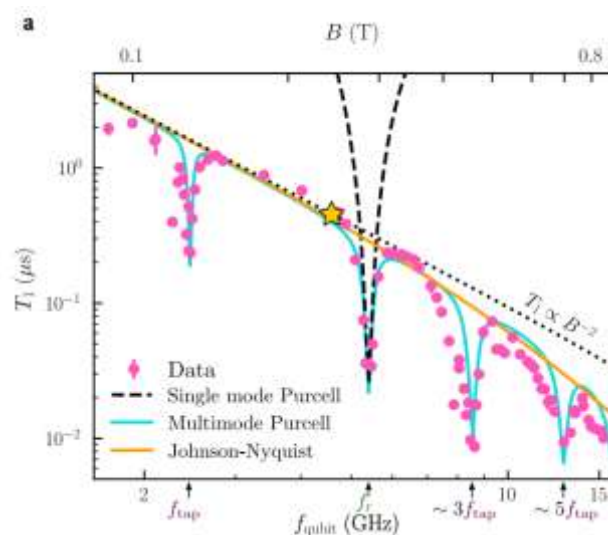


Figure 1: Energy relaxation time of a hole spin flopping-mode qubit as a function of energy.
