A heat-resilient hole spin qubit in silicon

Victor Champain
G. Boschetto, H. Niebojewski, B. Bertrand, L. Mauro, M. Bassi, V. Schmitt, X. Jehl, S. Zihlmann, R. Maurand, Y.-M. Niquet, C. B. Winkelmann, S. De Franceschi, B. Martinez, B. Brun

Univ. Grenoble Alpes, CEA, Grenoble INP, IRIG-Pheliqs, Grenoble, France.

Victor.champain@icfo.eu

Electrically controlled spin qubits are rapidly progressing toward scalability, with multiqubit processors demonstrated in Group IV semiconductors, up to six qubits in silicon [1] and ten in germanium [2]. However, the simultaneous operation of several qubits has been shown to degrade their individual performance [3], likely due to local heating from control pulses and the thermal susceptibility of spin qubits, i.e., the temperature dependence of their Larmor frequencies. This temperature dependence has been systematically studied for 6 electron spin qubits in silicon, and a puzzling non-linear thermal susceptibility has been reported [4].

In this work [5], we study the thermal susceptibility of a hole spin qubit in silicon. Owing to spin-orbit coupling, hole spins exhibit a strong anisotropic response to magnetic fields. In particular, their longitudinal spin-electric susceptibility (LSES), the sensitivity of the Larmor frequency to gate voltage, varies with magnetic field orientation and can vanish at specific "sweet spots" [6].

By measuring how the Larmor frequency evolves with temperature, we demonstrate that hole spins also exhibit thermal susceptibility, reaching values up to 10MHz/K, similar to electron spins in silicon (Fig. 1). Rotating the magnetic field reveals a strong correlation between electrical and thermal susceptibilities, pointing to a shared origin rooted in spin-orbit interaction. We propose a microscopic model involving a bath of electric dipoles that thermally activate and alter the local electric field experienced by the qubit. Numerical simulations with randomly distributed dipoles reproduce experimental observations and suggest a surprisingly small dipole moment of 1e·pm. Crucially, we identify magnetic field orientations for which the Larmor frequency becomes temperature-independent. This work provides both a physical understanding of spin thermal susceptibility and practical strategies to suppress it, offering a route to protect hole spin qubits against heating effects, even at millikelvin temperatures.

References

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[4] Undseth et al., Phys. Rev. X 13, 041015 (2023)
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Figures

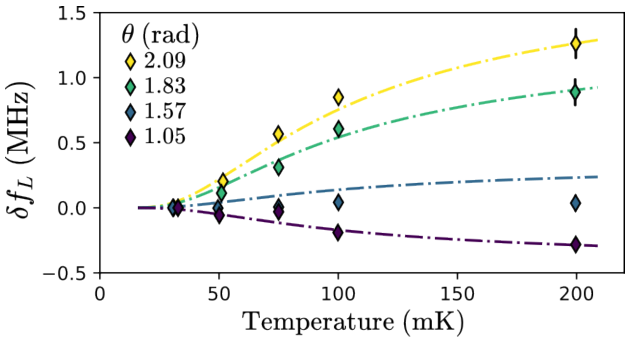

Figure 1: Larmor frequency shift measured as a function of temperature.