A Silicon hole spin qubit coupled to nuclear spins

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What are the consequences of embedding a hole spin qubit in natural Silicon within a bath of thousands of nuclear spins? Can the hole act as a control ressource, or as probe of its environment? What limits do nuclear spins impose on the coherence of the qubit?

Hole Si spins, a promising platform for quantum computing, are expected to be both longitudinally and transversely coupled to nuclear spins owing to their anisotropic g-tensors. The transverse coupling leads to high-frequency noise on the qubit, but also enables to use the qubit as a local antenna to control nuclear spins. We directly measure this coupling by qubit noise spectroscopy [1], establishing our qubit as a mean of controlling its nuclear environment (Fig.1).

The longitudinal coupling leads to an Overhauser shift of the qubit frequency based on the surrounding nuclear spins polarization, thus to slow dephasing if the environment fluctuates. We use our control on nuclear spins to polarize them and measure the Overhauser shift. This establishes the qubit as a probe for its environment. We directly verify the role of nuclear spins in slow dephasing by using the qubit to correct their fluctuations, via an autonomous feedback scheme permitted by our control [2]. We observe a gain, placing an upper limit of 2.2µs on Ramsey-dephasing time due to hyperfine noise.

We then use our qubit as a tool to investigate nuclear spin relaxation time (Fig.2). We find that it can increase by two orders of magnitude, from 10s without the hole up to 15min in its presence, pointing towards freezing of the nuclear spin environment [3].

Our work establishes the first direct evidence of hyperfine noise on a Si hole spin qubit and paves the way towards control of the nuclear spin environment in Si.

References

[1] Hendrickx et al., Nat. Mater 23 (2024), 920-927
[2] Gangloff et al., Science, 364 (2019), 62-66
[3] Madzik et al., Sci. Adv., 6(2020)

Figures

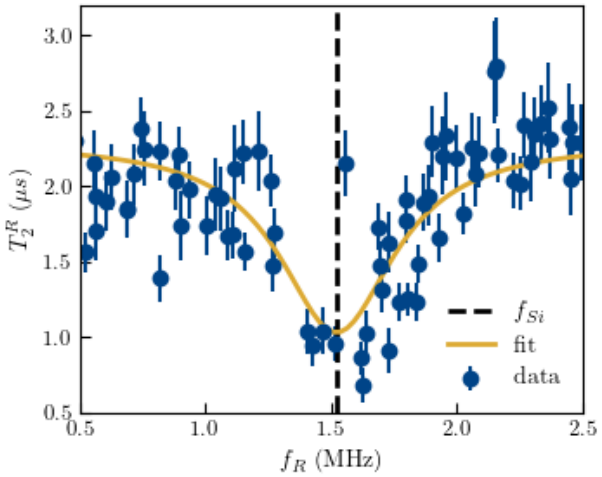

Figure 1: Rabi spectroscopy showing a dip, indicating sensitivity to a fast noise, at the frequency of nuclear spins.

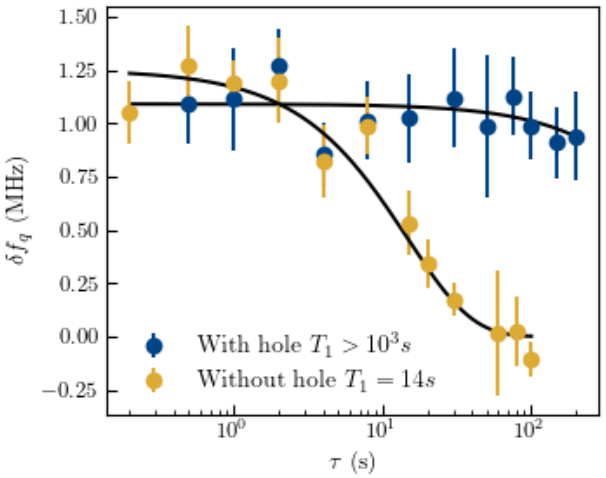

Figure 2: Relaxation of nuclear spin polarization based on the presence of the hole