NANO COLLOQUIA 2025 - S3 SEMINAR

Quantum-information processing with hole-spin qubits in silicon

Thursday January 16, 2025 – 14:30

ON-SITE - S3 Seminar Room, Third Floor, Physics Building
ONLINE - https://tinyurl.com/NanoColloquia

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Abstract

Semiconductor nanotechnology shows promising perspectives in quantum-information processing, thanks to its compatibility with classical circuitry and with the advanced manufacturing techniques of modern devices. In this context, hole-spin qubits in Si-based devices offer advantages in terms of scalability and control on qubit integration and manipulation, even at temperatures as high as 4 K [1]. Here, decoherence caused by the hyperfine interaction is suppressed thanks to the natural abundance of spinless isotopes, and additionally through isotopic purification. Furthermore, the large and natural spin-orbit coupling of holes makes the qubit amenable to all-electrical manipulation, without the need to introduce magnetic-field gradients [2].

In this seminar, we address the possible application of hole-spin qubits as quantum sensors of their electrostatic environment. Indeed, the multiband character of hole states makes the qubit properties highly dependent on the presence and distance of a remote charge from the qubit, and makes it possible to exploit such properties for state discrimination and parameter estimation [3]. We account for the interplay between device geometry, spin-orbit coupling, and interband mixing, with the aim of identifying the optimal geometry and approach to quantum sensing. Our results can be readily generalized through a comparison with a two-site Hubbard model, and through the derivation of the Fisher information for a Rabi and Ramsey measurement, which is independent of the qubit implementation. In the final part of this seminar, we analyze the possibility of involving excited states in the manipulation of the qubit [4]. Indeed, transitions involving states beyond the qubit subspace allow for alternative, and usually faster manipulation schemes, and, in addition, contribute significantly in few-particle interacting configurations. Specifically, these transitions show manipulation frequencies that exceed those of the qubit by several orders of magnitude. Additionally, they show a high degree of tunability on the eigenstate composition, thus further underlying the importance of the multiband character of the hole.

[1] L. C. Camenzind, S. Geyer, A. Fuhrer, et al., Nature Electronics 5, 178 (2022)
[2] S. D. Liles, F. Martins, D. S. Miserev, et al., Phys. Rev. B 104, 235303 (2021)
[3] G. Forghieri, A. Secchi, A. Bertoni, et al., Phys. Rev. Res. 5, 043159 (2023)
[4] E. Fanucchi, G. Forghieri, A. Secchi, et al., arXiv.2411.05526 (2024)

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