Stage de recherche M2

Modeling two-qubit gates in Germanium spin qubits

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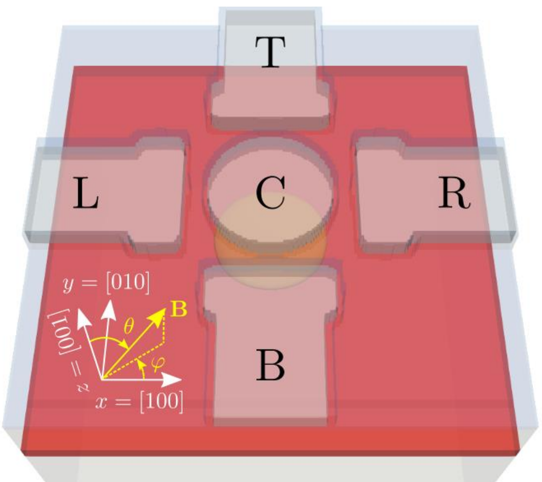
Project description:

Germanium spin qubits have made outstanding progress in the past few years [1, 2]. In these devices, the information is encoded as a coherent superposition of the spin states of a hole confined in a quantum dot. The spins can be manipulated electrically owing to spin-orbit coupling, and can be entangled through exchange interactions, enabling a variety of one- and two-qubit gates required for quantum computing and simulation.

At IRIG/MEM, we support the progress of these emerging quantum technologies with state-of-the-art modelling [2, 3, 4]. In particular, we are developing the TB_Sim code, able to simulate very realistic qubit devices down to the atomic scale.

Achieving high-fidelity two-qubit gates is one of the key challenges toward scalable quantum processors. **The goal of this master project is thus to model a "controlled-Z" (CZ) two-qubit gate in a realistic device geometry**. In such a CZ gate, the spin of one qubit makes a rotation around the z axis that depends on the state of an other qubit. The exchange interaction responsible for this dependence arises from a subtle interplay between inter-dot tunneling and Coulomb repulsion. The student will thus solve the time-dependent Schrödinger equation for the dynamics of the two qubits in the presence of Coulomb interactions, using a newly developed time-dependent configuration-interaction solver [5]. The impact of noise and disorder (due, e.g., to charges moving around in the materials) on the fidelity of the CZ operation will be investigated.

This Master thesis may be followed by a PhD project on spin manipulation and entanglement in arrays of spin qubits. The Master/PhD candidate will have the opportunity to interact with a lively community of experimentalists working on spin qubits at CEA and CNRS.



Model for a Germanium spin qubit: A quantum dot is shaped in a Germanium quantum well (red) by the potentials applied to the C/L/R/T/B gates. The up and down spin states of the hole trapped in this quantum dot are split by the magnetic field **B** *and used as a basis for coherent superpositions. The yellow shape is the isodensity surface that encloses 90% of the charge of the hole.*

Master student profile and qualifications:
The candidate must have a master in quantum or condensed matter physics/engineering, and a taste for numerical modeling. Excellent communication skills in English and the ability to work in a research team are required.

How to Apply:
Candidates should send a short motivation letter, a CV and transcripts of grades (License, M1) to Yann-Michel Niquet (yniquet@cea.fr).

Scientific environment and workplace:
The successful candidate will join the “Laboratory of Atomistic Simulation (L_Sim)” of the “Modeling and Exploration of Materials (MEM)” service of the Interdisciplinary Research Institute of Grenoble (IRIG). The group modeling spin qubits comprises two permanent researchers, two PhD students and two postdocs. They work in very close collaboration with the members of the PHELIQS/LATEQS lab who measure spin qubits.

More information about MEM here.
More information about the IRIG institute here.

MODÉLISATION,
EXPLORATION DES MATÉRIAUX

References related to the topic:

[1] *A four-qubit germanium quantum processor*,
N. W. Hendrickx *et al.*, Nature **591**, 580 (2021) [arXiv:2009.04268].

[2] *Robust and localised control of a 10-spin qubit array in germanium*,
V. John *et al.*, Nature Communications **16**, 10560 (2025) [arXiv:2412.16044].

[3] *Hole-spin driving by strain-induced spin-orbit interactions*,
J.-C. Abadillo-Uriel *et al.*, Physical Review Letters **131**, 097002 (2023) [arXiv:2212.03691].

[4] *Variability of hole-spin qubits in planar germanium*,
B. Martinez, Y.-M. Niquet, Physical Review Applied **25**, 014018 (2026) [arXiv: 2507.04953].

[5] *Dressed basis sets for the modeling of exchange interactions in double quantum dots*,
M.-J. Rodriguez *et al.*, Physical Review B **112**, 115428 (2025) [arXiv:2504.18281].