How inhomogeneities enhance the manipulability of Ge spin qubits

José Carlos Abadillo-Uriel
Esteban Rodríguez-Mena
Biel Martínez
Yann-Michel Niquet

Univ. Grenoble Alpes, CEA, IRIG-MEM, Grenoble, France

jcgau64@gmail.com

In recent years, there has been a growing interest in utilizing hole spins in silicon and germanium for quantum information processing. One reason for this is the strong spin-orbit interaction present in the valence band of these materials, which allows for versatile interactions with electric fields. As a result, there have been demonstrations of fast electrical manipulation of hole spin qubits [1] and strong spin-photon interactions [2], which are useful for generating long-range entanglement. While these experimental advances are well-established, there is still much to learn on the theoretical side. For example, Ge hole qubits can be operated with in-plane magnetic fields [3], which cannot be easily explained by the expected spin-orbit mechanisms like cubic Rashba or g-tensor modulation resonance.

In this work, we go beyond the usual models for electrical spin manipulation in semiconductor quantum dots. We perform simulations of realistic Ge devices and find that both the electrostatics [4] and the strain [5] display inhomogeneities that heavily affect the performance of hole spin qubits. In particular, we identify overlooked spin-orbit mechanisms that enable manipulation under in-plane magnetic fields and enhance the expected Rabi frequencies. Our simulations show that these mechanisms are dominating the physics of isotropic hole spin qubits.

References

[1] G. Scappucci et al., Nat. Rev. Mater **6**, 926-943 (2021)
[2] C. Yu et al., arXiv:2206.14082 (2022)
[3] N. Hendrickx et al., Nature **591**, 580–585 (2021)
[4] B. Martínez et al., Phys. Rev. B **106**, 235426 (2022)
[5] J. C. Abadillo-Uriel et al., arXiv:2212.03691 (2022).

Figures

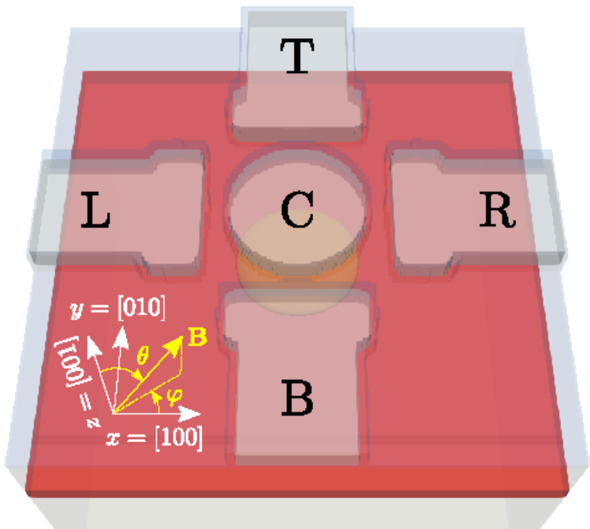

Figure 1: Simulated isotropic Ge quantum dot device.

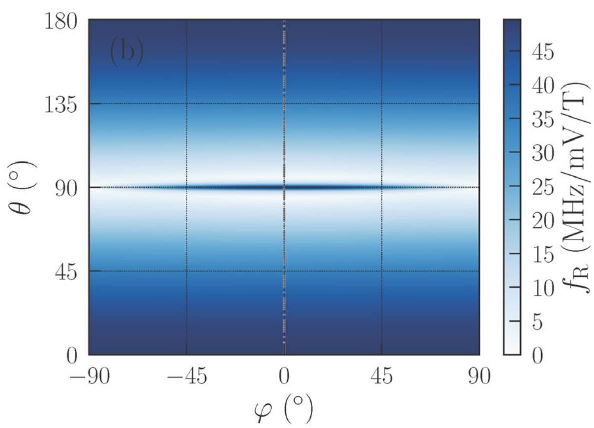

Figure 2: Pattern of Rabi frequencies as a function of magnetic field orientation.