The manifold of spin-orbit interactions in hole spin qubits

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Hole spin qubits in semiconductor quantum dots show versatile interactions with electric fields thanks to the spin-orbit interactions (SOI) in the valence bands. This allows for fast electrical manipulation and strong spin-photon interactions suitable for long-range entanglement. In this talk, we review the latest developments in the understanding of SOI in hole spin qubits, with a particular focus on planar Ge/GeSi heterostructures. We show that the coupling between the in-plane and out-of-plane motions in these heterostructures results in small rotations of the principal axes of the g-tensor [1]. This gives rise to a specific g-tensor modulation resonance (g-TMR) mechanism, which is strongly enhanced when the magnetic field lies in-plane by the g-factor anisotropy $g_\perp >> g_{||}$. More importantly, inhomogeneous shear strains induced by the differential thermal contraction of the materials also give rise to such rotations and may eventually rule the physics of the qubits [2]. We also discuss the Rashba- and Dresselhaus-like interactions arising from such inhomogeneous strains and from symmetry breaking at the Ge/GeSi interfaces [3]. We draw the implications for one- and two-qubit gates and for spin lifetimes. We show, in particular, that the sweet spots of a given fluctuator are actually sweet lines on the unit sphere describing magnetic field orientation, whose analysis provides many insights about SOI and can help optimize the devices [4]. Finally, we discuss the prospects for strain engineering in hole spin qubits.

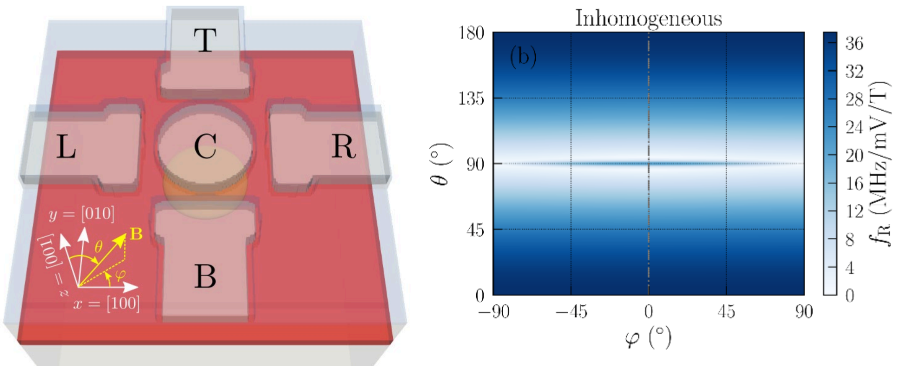

Figure 1: Sketch of a Ge/GeSi heterostructure device and map of the Rabi frequency as a function of the orientation of the magnetic field in inhomogeneous cool-down strains [2].

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[2] J.-C. Abadillo-Uriel *et al.*, Physical Review Letters **131**, 097002 (2023).
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[4] L. Mauro *et al.*, Physical Review B **109**, 155406 (2024).