Ge hole spin control using acoustic waves

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Hole spin qubits in germanium quantum wells have emerged as a leading platform for quantum information processing, offering fast all-electrical control and high-quality heterostructures [1,2]. The strong spin-orbit coupling in Ge not only facilitates electric dipole spin resonance but also opens unique pathways for acoustic spin control via strain-induced g-tensor modulation (g-TMR) [3]. In this work, we theoretically investigate the coherent control of a Ge hole spin qubit driven by surface acoustic waves (SAWs) [4]. By combining lattice elasticity theory with the Luttinger-Kohn and Bir-Pikus Hamiltonian, we model the spin dynamics in a realistic Ge/SiGe device architecture. Our numerical simulations demonstrate that the periodic strain from a Rayleigh wave modulates the g-tensor, enabling fast Rabi oscillations with frequencies exceeding 100 MHz at moderate acoustic powers. Crucially, we uncover a distinct angular dependence of the Rabi frequency when the in-plane magnetic field is rotated. This anisotropy arises from the intrinsic phase difference between the longitudinal and shear strain components of the SAW, which generates an elliptically polarized effective driving field. We show that the driving efficiency is determined by the relative chirality between this effective driving vector and the hole's Larmor precession. Furthermore, we analyze the impact of quantum dot geometry, revealing that confinement anisotropy can be engineered to enhance the spin-phonon coupling strength. Our results establish the theoretical foundation for SAW-driven control of Ge hole spins, offering a scalable route for spin-phonon hybrid architectures.

References

[1] G. Scappucci et al., Nat. Rev. Mater. 6, 926 (2021).
[2] H. Watzinger et al., Nat. Commun. 9, 3902 (2018)
[3] J. C. Abadillo-Uriel et al., Phys. Rev. Lett. 131, 097002 (2023).
[4] [4] C.-Y. Yuan and T.-K. Hsiao, arXiv:2512.23520 (2025)

Figures

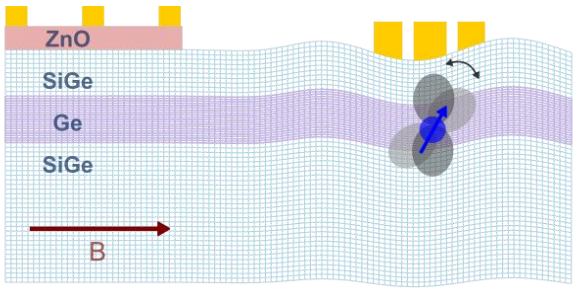

Figure 1: Schematic of the Ge hole spin qubit driven by a surface acoustic wave (SAW). The shaking peanut shape represents the oscillating g-tensor profile induced by the strain.

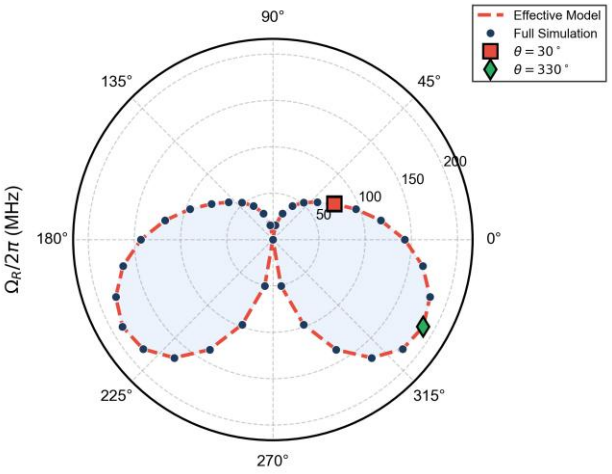

Figure 2: Calculated Rabi frequency anisotropy (dots) and g-TMR model (dashed line) as a function of the in-plane magnetic field angle. The driving efficiency is governed by the chirality matching between the elliptically polarized driving field and the spin precession.