Hole spin qubits in Si MOS structures

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Semiconductor spin qubits have the potential to leverage existing industrial transistor technology for large-scale quantum circuits. Central to today's semiconductor industry are metal-oxide-semiconductor (MOS) structures. Advanced manufacturing techniques now enable the integration of billions of transistors onto a single chip. Achieving scalability in quantum systems will depend on harnessing the sophisticated nanofabrication capabilities of the CMOS industry.

Holes in quasi-one-dimensional (1D) nanostructures are particularly promising for implementing fast and coherent qubits. The mixing of heavy- and light-hole states due to the 1D-confinement results in an unusually strong and electrically tunable direct Rashba spin-orbit interaction (SOI) [1], with sweet spots for charge and hyperfine noise [2], enabling ultra-fast hole spin qubits with reduced sensitivity to noise [3]. Conveniently, such a 1D-system can be realized using today's industry-standard transistor design, known as the fin field-effect transistor (FinFET). Adapting FinFETs for quantum dot integration [4] could significantly accelerate the scale-up of quantum computers by building on decades of semiconductor industry advancements.

In this talk, I will present our work on hole spin qubits in silicon FinFETs, focusing on the spin-orbit physics. The strong SOI not only enables fast, all-electrical spin control - even at temperatures well above 1 Kelvin [5] - but also leads to a remarkably anisotropic exchange interaction [6]. Consequently, the exchange Hamiltonian no longer has the Heisenberg form and can be engineered such that it enables two-qubit controlled rotation gates without compromising speed or fidelity. The SOI also facilitates phase-driving of hole spin qubits at frequencies orders of magnitude lower than the qubit frequency [7].

Moving towards a scalable spin qubit architecture, I will discuss how capacitive crosstalk complicates gate-based dispersive sensing of spin qubits [8] and how this challenge can be overcome [9]. Furthermore, I will share our strategy for achieving greater uniformity and reproducibility in device fabrication, as well as how we have accelerated the device design-fabrication-measurement cycle using our in-house built cryogenic probe station [10].

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