Spin-based quantum computing in semiconductor quantum dots

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Quantum dots (QDs) are semiconductor nanostructures where a few electrons or holes (missing valence band electrons) can be electrostatically trapped in discrete states. The latest experimental progress in fabrication of one- and two-dimensional sizable arrays of QDs suggest that quantum information science applications are feasible in these devices, as originally envisioned by Loss and DiVincenzo [1]. Spin qubits in Si and Ge are considered strong candidates for realizing a large-scale quantum processor due to the small qubit dimensions, compatibility with CMOS technology, long coherence times and possibility to operate beyond 1 Kelvin. Recent experiments have demonstrated single-qubit gate fidelities above 99.9% [2] and two-qubit gate fidelities up to 98% [3]. Important challenges concerning scalability of spin qubits defined on QDs can be overcome by turning the qubits electrically controllable. In the case of electrons one can take advantage of the intrinsic spin-orbit coupling or gradients of magnetic field (for example created by external micromagnets). The physics of holes, dictated by the Luttinger-Kohn Hamiltonian, has attracted much attention lately because it naturally brings the electrical handle thanks to a strong spin-orbit coupling without analogous in electron systems.

I will summarize recent progress towards a scalable quantum computing architecture with Si QDs embedded in a micromagnet stray field. This includes low-power high-fidelity electric-dipole spin resonance [4], protection of the spin qubit from charge detuning fluctuations [5], two-qubit gates within a quantum node via capacitive coupling [6], and a circuit quantum electrodynamics device in which an electron spin is strongly coupled to a microwave superconducting resonator photon [7–9]. Then I will present our latest results on hole spin qubits in Ge. By modeling planar QD hole spin qubits we showed that, contrary to common belief, they can present strong and tunable spin-orbit interaction if the confinement potentially is properly squeezed [10].

Although these devices are a promising platform for a future fault tolerant quantum computer, the promptest application is analog quantum simulation. I will then discuss the role of QD devices on efficient simulations of the Fermi-Hubbard model and exotic spin models.

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