2-Qubit Gates in a Scalable Architecture

We have demonstrated a 2-qubit gate [1] using single electron spins in isotopically enriched Si-28 by performing 1- and 2-qubit operations in a quantum dot system using the exchange interaction, as envisaged in the original Loss-D Vincienco proposal. We realize CNOT gates via controlled phase (CZ) operations [23] combined with single-qubit operations. Direct gate-voltage control provides single-qubit addressability, together with a switchable exchange interaction. The device layout is easily extendable to larger numbers of qubits.

1-Qubit Gates with High Fidelities & Ultra-long Coherence Times

In isotopically-enriched Si-28 both quantum dot and single atom qubits show 1-qubit gate control fidelities $F_\alpha > 99\%$ [1-3] and the $^{31}P$ nuclear spin qubit has $F_\alpha > 99.9\%$ [2-3]. Using dynamical decoupling the coherence times can reach $T_\text{coh}^{\text{spin}} = 0.5\ s$ for the electron and $T_\text{coh}^{\text{spin}} = 30\ s$ for the nuclear spin [2].

High-fidelity Qubit Readout & Long Spin Lifetimes

Electron spin readout in both quantum dots and single atom qubits employs spin-dependent tunneling and either SET [5] or QPC [6] charge sensing. We have measured electron spin readout fidelities $F_\text{SR} > 99\%$ [3] and electron qubit lifetimes of $T_\text{1e} > 99.9\%$ [3,8], due to their very long lifetimes $T_\text{1e} \approx 30\ s$ [3].

High-speed Logic Gates

High-speed, high-fidelity qubits can be operated in Si quantum dots using either dc gate voltage pulses [9] or resonant ac gate voltage pulses [10]. Recently, we have demonstrated coupling between four quantum dots [11], and shown how tuning the internal degrees of freedom in double dot qubits can increase significantly the measured coherence time [12].

Donor Qubits in a Scalable Architecture

Atomic precision engineering of donor qubits with electron spin $F_\alpha = 99.6\%$, $T_\text{1e} = 30\ s$ and error rates $\lesssim 10^{-1}\%$. Precision donor positioning [13-14] allows understanding the exact environment [15] of many qubit systems [16] and a route to scale to a surface code architecture [23].

Quantum Error Correction Theory

The theory teams at Melbourne and Maryland are leaders in the areas of solid-state theory and device modelling, spin-qubit architectures [18], robust qubit control [19-20], and QEC for spin qubits, having played a key role in the development of surface code QEC [21-22]. Most recently we have developed a detailed architecture for single atom qubits [23] that is capable implementing surface code QEC.