Semiconductor spin qubits – vision, opportunities and challenges

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Quantum computation has captivated the minds of many for several decades. For much of that time, it was seen mostly as an extremely interesting scientific problem. In the last few years, we have entered a new phase as the belief has grown that a large-scale quantum computer can actually be built. Quantum bits encoded in the spin state of individual electrons in silicon quantum dot arrays, have emerged as a highly promising direction [1]. In this talk, I will present our vision of a large-scale spin-based quantum processor, and ongoing work to realize this vision.

First, we created local registers of spin qubits with sufficient control that we can program arbitrary sequences of operations, implement simple quantum algorithms, and achieve two-qubit gate fidelities of more than 99.5% [2]. We now achieve universal control of up to six qubits with respectable fidelities for initialization, readout, single- and two-qubit operations [3]. In unpublished work, we run an algorithm using all single- and two-qubit gates across the array. Furthermore, we tracked the stability of gate voltages and qubit frequencies over the course of 912 days.
Novel schemes relying on baseband instead of resonant single-spin control offer new opportunities for scaling [4]. We also use baseband pulse to achieve universal control of four singlet-triplet qubits in a 4x2 quantum dot array [5], entangling the first and last qubit in the array. The same device serves to explore exciton transport [6], magnon propagation and small-scale quantum phase transitions (both unpublished).

Second, we have explored coherent coupling of spin qubits at a distance via two routes. In the first approach, the electron spins remain in place and interact via virtual or real microwave photons in a superconducting on-chip resonator. We observe iSWAP oscillations between two spins separated by 250 micron [6] and transfer information from one spin to another via successive vacuum Rabi oscillations (unpublished). In the second approach, spins are shuttled across the wafer, preserving the spin state. We are now able to displace electron spins over an effective distance of 10 micron in less than 200 ns and with 99.5% fidelity [7]. Building on this, we realize a 99% fidelity two-qubit gate between mobile spins, and teleport a quantum state across the device (unpublished).
When combined, the progress along these various fronts can lead the way to scalable networks of high-fidelity spin qubit registers for computation and simulation [8].

References

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