Spin-based Quantum Information Processing in Silicon

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Electron spin qubits in silicon are excellent candidates for scalable quantum information processing (QIP) due to the very long spin lifetimes (T_1) and coherence times (T_2) that are accessible in silicon [1] and because of the enormous investment to date in silicon MOS technology. Electron spin qubits in silicon can be localized using either dopant atoms (eg. phosphorus) [2,3] or in electrostatically gated quantum dots [4]. This talk will review the current status of research in both of these qubit systems.

Projective readout of the qubit is an essential criterion for any QIP system. Due to the challenges of controlling and manipulating single spins in silicon, it is only very recently that single-shot readout of an electron spin has been demonstrated. This experiment [5] used a device consisting of implanted phosphorus donors, tunnel-coupled to a silicon Single Electron Transistor (Si-SET), where the SET island was used as a reservoir for spin-to-charge conversion [6] – see Figures 1 and 2. The readout fidelity obtained was better than 90% and the spin lifetime T_1 was up to 6 s.

Electron spin lifetimes approaching 100 ms have also been measured recently in electrostatically-defined Si MOS quantum dots [7]. Disorder at the Si/SiO_2 interface has made it challenging to form dots with a controllable number N of electrons, down to $N = 1$, as required for an electron spin qubit. However recent developments in multi-gate technology have enabled the formation of Si-MOS dots with high tunability of N [8], together with detailed examinations of spin-filling and valley splitting [9].

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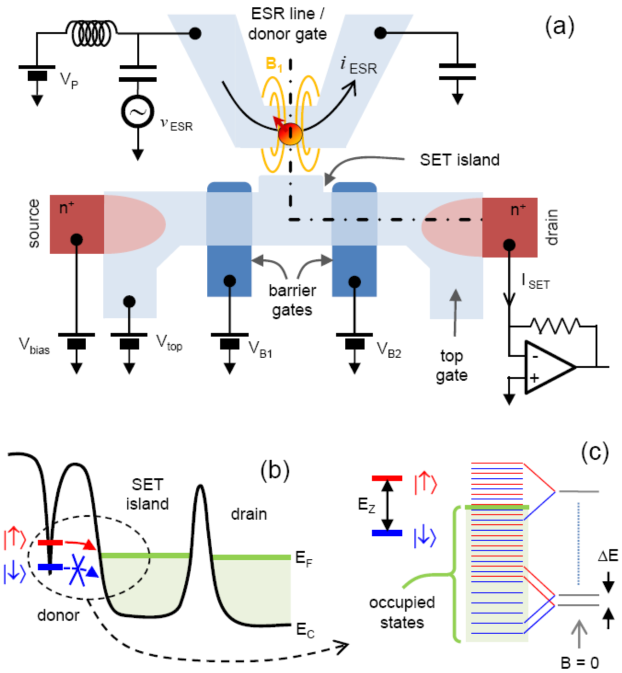

Figure 1 – P-donor Electron Spin Qubit: (a) Schematic top view of a Si:P spin qubit device. The donor-SET island distance is ~ 50 nm. (b) Energy profile along the dash-dotted line in (a). The density of electron states in the SET island is approximated as a quasi-continuum. (c) In reality, the SET has a finite number of electrons, as shown. [Taken from Ref. 6]

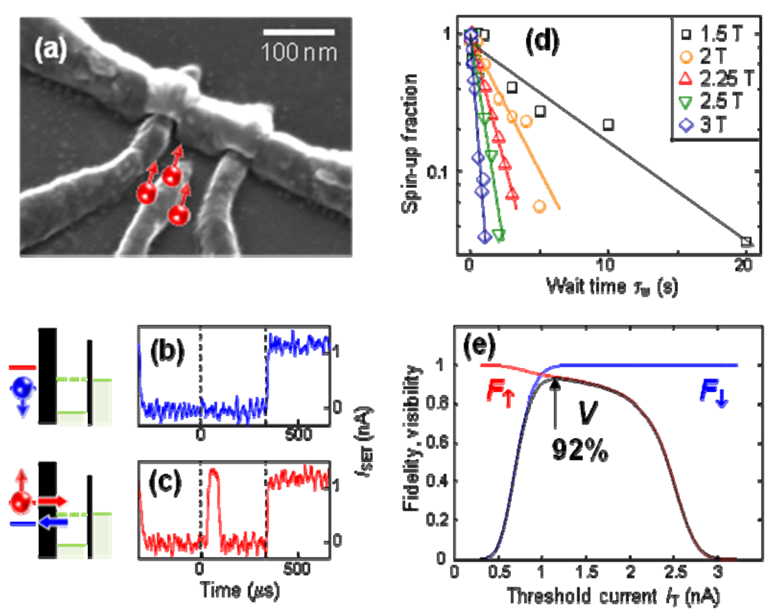

Figure 2 – Single-shot electron spin readout and lifetime in Si: (a) Scanning electron micrograph of the device. (b,c) Real-time SET current traces characteristic of a spin-down (b) and spin-up (c) electron. (d) Decay of spin-up fraction as a function of wait time, at different magnetic fields. The solid lines are exponential fits to extract T_1. (e) Readout fidelities and visibility. [Taken from Ref. 5]