Spin-Dependent Scattering off Neutral Donors in Silicon Field-Effect Transistors

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Silicon based quantum computation has attracted much interest since its original proposal by Kane [1], where the spins of ordered arrays of donor atoms (e.g. phosphorus or antimony, with ~10 nm spacing) embedded in a silicon substrate are the basis for quantum information storage and manipulation. An integral part of any quantum computation architecture is a high-fidelity qubit readout. For donor qubits in silicon, this requires novel nanoelectronic devices for sensing the spin polarization of individual donors. One promising route for realizing such a spin readout device for donor qubits in silicon is by exploiting spin-dependent scattering of conduction electrons by the neutral donors. Neutral impurity scattering is spin-dependent because different spin configurations of the conduction and donor electrons (singlet or triplet) imply a different spatial distribution of the two-electron wavefunction, which translates into a difference in scattering cross-sections. We use accumulation-mode field-effect transistors (aFET) formed in isotopically enriched silicon to study this effect for small ensembles of donors[2], with the FET channel implanted with a small ensemble of ^{121}Sb donors (Fig. 1). Spin-dependent scattering is detected using electrically detected magnetic resonance with a modified X-band ESR spectrometer (Bruker Elexsys 580) where spectra show resonant changes in the source-drain voltage for conduction electrons and electrons bound to donors (Fig. 2). Typical spectra show a strong central peak from the conduction electrons (g_{ce}= 1.9998) and six weaker peaks from ^{121}Sb donor electrons and correspond to the six nuclear spin projections (g_{de}= 1.9985 and hyperfine coupling constant A = 6.62 mT), in good agreement with published ESR data for silicon. The high sensitivity of EDMR promises to allow scaling to the few and single-donor regime with optimized nano-scale devices for readout of single nuclear spin states in qubit donors. The utilization of spin-dependent scattering for the readout of donor spin-states in silicon based quantum computers will be discussed.

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[1] B. E. Kane, Nature 393, 133-137 (1998)

[2] C. C. Lo, J. Bokor, T. Schenkel, J. He, A. M. Tyryshkin, S. A. Lyon, Appl. Phys. Lett. 91, 242106 (2007)

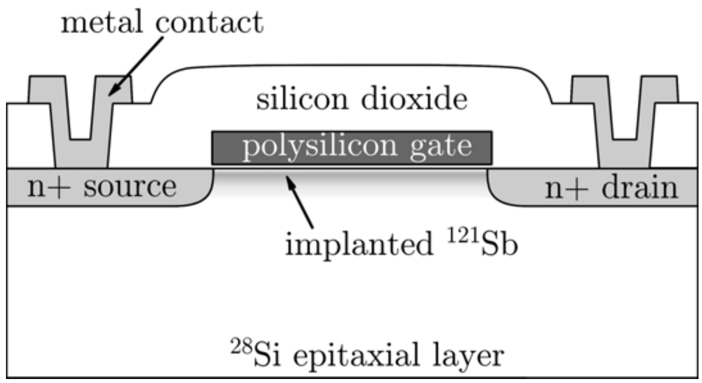

Fig 1: Schematic cross-section of an aFET. Devices are fabricated on isotopically enriched ^{28}Si epitaxial layers. The channel region is implanted with ^{121}Sb donors, and the n+ source/drain regions are implanted with As.

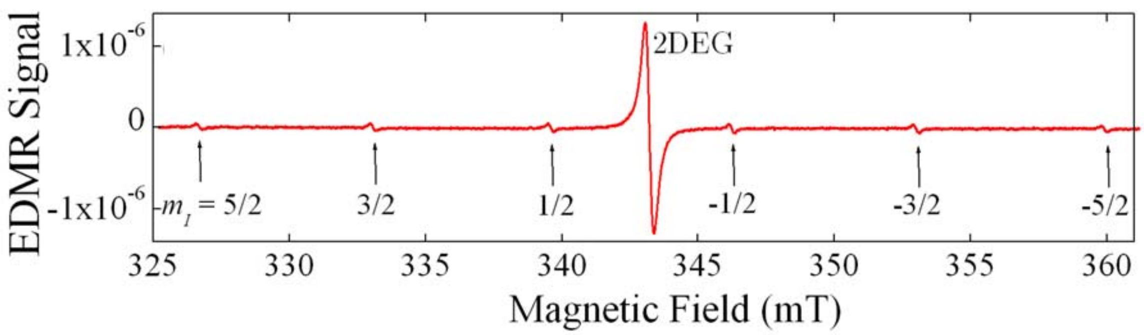

Fig 2: EDMR spectrum from an ^{121}Sb-doped aFET at 5K (I_{ds} = 1.58 μA, V_g = 0.45V). The large central feature corresponds to the resonance of the conduction electrons (or 2 dimensional electron gas, 2DEG), and the six smaller peaks corresponds to the resonance of donor electrons for different donor nuclear spin projections as labeled.