Materials Science and Technology Division

“Singlet-triplet qubits in silicon quantum dots”

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Abstract:

Quantum dot (QD) spins are promising candidates for scalable quantum computation (QC). Electrical readout and control of single spins in QDs have proven challenging, yet GaAs double QDs, where spin blockade and charge sensors enable observation of single/two-spin dynamics, have seen impressive experimental progress. Recent experiments [1] have demonstrated quantum coherence and the distinct possibility of using the two-electron singlet and unpolarized triplet as the two states of a logical qubit, with reliable initialization, single-qubit rotation, and measurement. Yet the hyperfine interaction with the nuclei provides a fundamental limit to spin lifetimes in GaAs, a fact which has spurred intense research into Si QDs. Silicon is often regarded as the best semiconducting host material for spin qubits because of its excellent spin coherence properties: spin-orbit coupling is very small while the hyperfine interaction can be reduced by isotopic enrichment. The biggest obstacle to spin QC in Si is the valley degree of freedom, which I will discuss at length. At the Si/SiO_2 interface two valleys are relevant to the ground orbital state, which introduces fundamental complications in distinguishing spin and orbital degrees of freedom. Scattering at the interface lifts the valley degeneracy by producing a valley-orbit coupling Δ, yet the exact form and magnitude of Δ is generally not known a priori and is sample-dependent. With this in mind we have established the precise criteria for realizing spin qubits in Si QDs [2]. I will show that, for small Δ, a singlet-triplet qubit cannot be constructed since a number of different states may be initialized, leading to different experimental outcomes. For large valley splitting ($\Delta >> kT$) the experiment is analogous to GaAs. A Zeeman field can be used to distinguish between different initialized states for any valley splitting, and sweeping a uniform magnetic field provides a useful method for estimating Δ. An important consequence of our work is the proposed new experimental method for estimating the valley splitting Δ in Si QDs, particularly when $\Delta < kT$. This work is supported by LPS-NSA.

[1] J. R. Petta, A. C. Johnson, J. M. Taylor, E. A. Laird, A. Yacoby, M. D. Lukin, C. M. Marcus, M. P. Hanson, and A. C. Gossard, Science **309**, 2180 (2005).

[2] Dimitrie Culcer, Lukasz Cywinski, Qiuzi Li, Xuedong Hu, and S. Das Sarma, arXiv:0903.0863, submitted to Phys. Rev. Lett.

Host: Zhenyu Zhang