Long-lived states in Si-based quantum computing nano-architectures: decoherence and relaxation for spin and valley states

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The pursuit of spin and quantum entanglement-based devices in solid state systems has become a global endeavor. Semiconductor architectures hold promise for quantum information processing (QIP) applications due to their large industrial base and perceived scalability potential. Electron spins in silicon in particular may be an excellent architecture for QIP, and also for spin electronics (spintronics) applications. While the charge of an electron is easily manipulated by charged gates, the spin degree of freedom is well isolated from charge fluctuations. This leads to very good spin quantum bit (qubit) stability or quantum coherence properties, based in a material with a mature existing technology. Inherently small spin-orbit coupling and the existence of a spin-zero Si isotope also facilitate long single spin coherence times. The many-valley nature of silicon is in principle a drawback for QIP, however, in the presence of bi-axially strain only the two lowest valleys are present, which further split in the presence of confinement.

Here we present a theoretical study of the relaxation processes in Si quantum dot based architectures. We find T_1, the spin-flip time, to be extremely large, dominated hyperfine coupling with ^{29}Si at B=0. The same processes determine singlet-triplet relaxation times T_{ST}, which occurs mainly due to higher energy virtual states with subsequent phonon emission. We find the spin-orbit coupling effects to be negligible, appearing as a higher order correction. Our calculations show that relaxation processes are at least three orders of magnitude larger than for similar GaAs proposed architectures, presenting important practical milestones on the way to design and construct a silicon-based quantum computer.