Dephasing Dynamics of Optically Active Electron and Hole Spin Qubits in Self-Assembled Quantum Dots

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Using solid-state spin qubits for quantum information processing requires a detailed understanding of the decoherence mechanisms. For electron spins in quantum dots (QDs), considerable progress has been achieved in strong external magnetic fields; however, decoherence at very low magnetic fields remains puzzling when the magnitude of the Zeeman energy becomes comparable with intrinsic couplings. Phenomenological models of decoherence currently recognize two types of spin relaxation; fast ensemble dephasing due to the coherent precession of spin qubits around nearly static but randomly distributed hyperfine fields (~2ns) and a much slower process (>1μs) of irreversible relaxation of the spin polarization due to nuclear spin co-flips with the central spin. Here, we demonstrate that not only two but three distinct stages of decoherence can be identified in the relaxation. Measurements and simulations of the spin projection without an external field clearly reveal an additional decoherence stage at intermediate timescales (~750ns) [1]. The additional stage corresponds to the effect of coherent dephasing processes that occur in the nuclear spin bath itself induced by quadrupolar coupling of nuclear spins to strain driven electric field gradients, leading to a relatively fast but incomplete non-monotonic relaxation of the central spin. For hole spins we observe a one to two orders of magnitude slower dephasing due to the reduced hyperfine interaction of the p-like Bloch wave function. In addition, time domain measurements of T2* show faster dephasing rates with increasing external magnetic field. We attribute this to electronic noise, which broadens the distribution of Zeeman frequencies via the linear coupling of the hole g-tensor to the local electric field. Strategies to counteract this noise source as well as measurements of T2 (via spin-echo) are discussed [2]. To overcome these limitations, logical spin qubits as formed from the singlet and triplet states of two electrons or holes in a pair of coupled quantum dots could potentially be a more powerful alternative than using single spins. This is due to singlet-triplet energy splitting which is in first order independent of electric field noise.

[1] A. Bechtold et al., Nature Physics 11, 1005–1008 (2015)
[2] T. Simmet et al., in preparation