Hyperfine interaction induced dephasing of coupled spin qubits in semiconductor double quantum dots

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We investigate theoretically the hyperfine (hf) induced dephasing of two-electron-spin states in a double quantum dot (DQD) with a finite singlet-triplet splitting J. In particular, we derive an effective pure dephasing Hamiltonian, which is valid when the hf-induced mixing is suppressed due to the relatively large J and the external magnetic field. Using both a quantum theory based on resummation of ring diagrams [1] and semiclassical methods, we identify the dominant dephasing processes in regimes defined by values of the external magnetic field, singlet-triplet splitting J, and inhomogeneity in the total effective magnetic field. We address both free induction and Hahn echo decay of superposition of singlet and unpolarized triplet states (both cases are relevant for S-T_0 qubits realized in DQDs), and we also study hf-induced exchange gate errors for two single-spin qubits. Theoretical results relevant for recent experiments in GaAs [3] and InGaAs [4], as well as predictions for silicon-based quantum dots are presented [2].

For the S-T_0 qubit we find that in the absence of a magnetic field gradient across the DQD, inhomogeneous broadening for an S-T_0 qubit is significantly suppressed relative to a single spin qubit, with the most significant source of inhomogeneous broadening being the term proportional to the square of the fluctuations of the longitudinal Overhauser field difference between the dots. Another important decoherence channel is due to the dressing of the singlet state by the polarized triplets due to transverse Overhauser fields. Throughout a wide range of parameters, these two terms compete for the role of the dominant source of decoherence, leading to a non-monotonic dependence of the T_2 dephasing time on J. On the other hand, in the presence of the field gradient the two-spin eigenstates are now superpositions of the S and T_0 states, and there is a finite electron spin polarization in each of the two quantum dots. Random longitudinal Overhauser field difference can now cause dephasing between the two-spin eigenstates, in analogy to inhomogeneous broadening in a single spin qubit - the S-T_0 encoding acquires more of a single-spin-qubit decoherence characteristics as the singlet-triplet mixing increases. This increased hf-induced dephasing is the price that one has to pay for having two-axis control (with the x axis rotations provided by the field gradient) over the S-T_0 qubit.

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