Pure Dephasing of the Spin of the Electron Confined in a Quantum Dot: the Role of the Hyperfine-Mediated Interactions

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We have investigated decoherence due to pure dephasing of a localized spin qubit interacting with a nuclear spin bath. Although in the limit of a very large magnetic field the only decoherence mechanism is spectral diffusion due to dipolar flip-flops of nuclear spins, with decreasing field the hyperfine-mediated interactions between the nuclear spins become important. Taking advantage of their long-range nature, we have resummed the leading terms in an 1/N expansion of the decoherence time-evolution function (N being the large number of nuclear spins interacting appreciably with the electron spin).

For the case of the thermal uncorrelated bath we believe that our theory is applicable down to low magnetic fields (~10 mT in large GaAs dots) allowing for comparison with recent experiments on spin echo in GaAs quantum dot spin qubits [Koppens et al., *PRL* **100**, 246802 (2008)]. Within this approach we have calculated the free evolution and spin echo decoherence as a function of the number of the nuclei in the bath (i.e.~the quantum dot size) and the magnetic field. For the spin echo evolution we show that the dominant decoherence process at low fields is due to interactions between nuclei having significantly different Zeeman energies (i.e. ~nuclei of As and two isotopes of Ga in GaAs), and we find qualitative agreement with experiments performed at low B fields. Our theory for free induction decay in a narrowed nuclear bath is shown to agree with an exact solution for decoherence due to hyperfine-mediated interaction which can be obtained when all the nuclei-electron coupling constants are identical, and it is also in qualitative agreement with measurements in InGaAs quantum dots [Greilich et al., *Science* **313**, 341 (2006)]. We also find an agreement with an exact numerical simulation of spin echo in a system with N = 20 nuclear spins.

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