Phonon-induced decay of the electron spin in quantum dots

Vitaly N. Golovach, Alexander Khaetskii, and Daniel Loss

Department of Physics and Astronomy, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland

Phase coherence of spin in quantum dots is of central importance for spin-based quantum computation in the solid state [1,2]. Sufficiently long coherence times are needed for implementing quantum algorithms and error correction schemes. If the qubit is operated as a classical bit, its decay time is given by the spin relaxation time T_1, which is the time of a spin-flip process. For quantum computation, however, the spin decoherence time T_2 — the lifetime of a coherent superposition of spin up and spin down states — must be sufficiently long. In semiconductor quantum dots, the spin coherence is limited by the dot *intrinsic* degrees of freedom, such as phonons, spins of nuclei, excitations on the Fermi surface (*e.g.* in metallic gates), fluctuating impurity states nearby the dot, electromagnetic fields, etc. It is well known (and experimentally verified) that the T_1 time of spin in quantum dots is extremely long, extending up to 100 μs. The decoherence time T_2, in its turn, is limited by both spin-flip and dephasing processes, and can be much smaller than T_1, although its upper bound is $T_2 \leq 2T_1$. Knowledge of the mechanisms of spin relaxation and decoherence in quantum dots can allow one to find regimes with the least spin decay.

In our work [3], we study spin relaxation and decoherence in a GaAs quantum dot due to spin-orbit interaction. We derive an effective Hamiltonian which couples the electron spin to phonons or any other fluctuation of the dot potential. We show that the spin decoherence time T_2 is as large as the spin relaxation time T_1, under realistic conditions. For the Dresselhaus and Rashba spin-orbit couplings, we find that, in leading order, the effective magnetic field can have only fluctuations transverse to the applied magnetic field. As a result, $T_2=2T_1$ for arbitrarily large Zeeman splittings, in contrast to the naively expected case $T_2 \ll T_1$. We show that the spin decay is drastically suppressed for certain magnetic field directions and values of the Rashba coupling constant. Finally, for the spin coupling to acoustic phonons, we show that $T_2=2T_1$ for all spin-orbit mechanisms in leading order in the electron-phonon interaction.

[1] D. Loss and D.P. DiVincenzo, Phys. Rev. A **57**, 120 (1998); cond-mat/9701055.

[2] D.D. Awschalom, D. Loss, and N. Samarth, eds., *Semiconductor Spintronics and Quantum Computing* (Springer, New York, 2002).

[3] V.N. Golovach, A. Khaetskii, and D. Loss, cond-mat/0310655.