Dynamics of entanglement of two electron spins interacting with nuclear spin baths

Igor Bragar and Łukasz Cywiński

Laboratory for Cryogenic and Spintronic Research, Insitute of Physics, Polish Academy of Sciences, Warszawa, Poland

In semiconductors quantum dot spin qubits the interaction with the nuclear bath is the main source of decoherence [1]. Creation of entangled states of two spins is now experimentally possible [2], and the hyperfine interaction with the nuclei is expected to be the main mechanism leading to disentanglement. We present a comprehensive theoretical overview of hyperfine-induced entanglement dynamics in double quantum dots. We consider various realistic states of the nuclear reservoir: a thermal equilibrium state [3], a narrowed state (with well-defined longitudinal component of the Overhauser field) in each dot, and a correlated state in which the interdot difference of the longitudinal Overhauser field is fixed. Furthermore, apart from the case of free evolution of the state of two electron spins, we consider a spin echo sequence with the π pulses applied simultaneously to the two electron spin qubits. The narrowing of the nuclear state leads to a magnetic-field dependent characteristic time of disentanglement, while the echo signal shows very little magnetic field dependence for fields much larger than the characteristic magnitude of the Overhauser fields. We present exact calculations performed using the uniform hf coupling model (a “box wavefunction” approximation), and exact calculations with two nuclear species is used to establish the timescale on which the uniform coupling approach is applicable. The echo signal at high fields is also calculated using the Ring Diagram Theory [4] used previously in the case of single-spin echo.

This research is supported by funds of Polish National Science Center (NCN), grant no. DEC-2012/07/B/ST3/03616.

[1] Ł. Cywiński, *Acta. Phys. Pol. A* **119**, 576 (2011).

[2] R. Brunner, Y.-S. Shin, T. Obata, M. Pioro-Ladriere, T. Kubo, K. Yoshida, T. Taniyama, Y. Tokura, and S. Tarucha *Phys. Rev. Lett.* **107**, 146801 (2011); K.C. Nowack, M. Shafiei, M. Laforest, G.E.D.K. Prawiroatmodjo, L.R. Schreiber, C. Reichl, W. Wegscheider, and L.M.K. Vandersypen, *Science* **333**, 1269 (2011).

[3] P. Mazurek, K. Roszak, R. W. Chhajlany, and P. Horodecki, arXiv:1304.1749 (2013).

[4] Ł. Cywiński, W.M. Witzel, and S. Das Sarma, *Phys. Rev. B* **79**, 245319 (2009).