Geometric phases in semiconductor spin qubits : Manipulations and decoherence

Gergely Zarand,[1,2] Pablo San-Jose,[2] Burkhard Scharfenberger,[2] Alexander Shnirman,[3] Gerd Schon[2]

[1] Institute of Physics, Technical University Budapest, Budapest, H-1521, Hungary,
[2] Institut fur Theoretische Festkoorperphysik and DFG-Center for Functional Nanostructures (CFN), Universitat Karlsruhe, D-76128 Karlsruhe, Germany,
[3] Institut fur Theoretische Physik, Universitat Innsbruck, A-6020 Innsbruck, Austria

We describe the effect of geometric phases induced by either classically or quantummechanically treated electric fields acting on single electron spins in quantum dots in the presence of spin-orbit coupling.

We show that fluctuating electric fields induce random non-Abelien geometric phases that lead to spin relaxation and dephasing due to spin-orbit coupling, even in the absence of an external magnetic field. We develop first a semiclassical formalism and then a full quantum treatment of the electromagnetic field and estimate the decay rates due to piezoelectric phonons and conduction electrons in the circuit, both representing dominant electric noise sources and thus limiting the use of such spins as qubits. We also find that in small external magnetic fields Ohmic fluctuations are responsible for the dominant spin relaxation.

We also discuss how this geometric effect could be used to control the geometric phases and perform quantum coherent spin manipulations in multi-dot systems without using high-frequency magnetic fields.

[1] P. San-Jose, G. Zarand, A. Shnirman, and G. Schön, Phys. Rev. Lett. 98, 160405 (2007).
[2] P. San-Jose, G. Schön, A. Shnirman, and G. Zarand, Physica E 40, 76 (2007).
[3] P. San-Jose, B. Scharfenberger, G. Schön, A. Shnirman, and G. Zarand, [arXiv :0710.3931, accepted for Phys. Rev. B].