Phonon effect on the singlet-triplet measurement of spins in quantum dots

Paweł Machnikowski, ukasz Marcinowski, Katarzyna Roszak

Institute of Physics, Wrocław University of Technology, 50-370 Wrocław, Poland

Qubit implementations involving spin states of carriers confined in quantum dots (QDs) are among the most promising proposals for solid-state quantum computing. To facilitate electrical control of electron-spin qubits, two-spin encoding has been proposed, which involves singlet and triplet configurations serving as the two qubit states. The measurement of spin states in QDs typically involves spin-to-charge conversion, followed by a charge measurement [1]. The former may rely on Pauli exclusion principle, which limits the charge dynamics depending on the spin configuration. The latter consists in measuring the current through a quantum point contact (QPC) adjacent to the QDs, which is affected (via Coulomb coupling) by the charge distribution in the QD system.

In one of the measurement schemes [2], the spin read-out is based on an analysis of the QPC current noise, in which the enhanced low-frequency fluctuations are present due to charge fluctuations in the spin-singlet configuration. Such a scheme is not only a feasible way of performing the measurement but also presents a considerable interest by itself. In fact, it is a weak measurement process, in which one can follow the joint dynamics of the system (QD) and measurement device (QPC) that, after a finite measurement time, leads to the full projective measurement with the final system state localized ("collapsed") to one of the classical alternatives that formed the initial quantum superposition.

In this presentation, I will first review the concept of spin measurement via spin-charge conversion and QPC-based current detection. Then, I will describe the idea of quantum stochastic dynamics that allows one to model the measurement on the single-run level as well as to compute the statistics of the QPC current traces that shows clear spin-dependent features [2]. Next, I will show how phonon-induced effects can be included in the model and I will describe an efficient stochastic simulation method for the system dynamics [3]. Finally, I will present the results of simulations of the weak measurement dynamics in the presence of carrier-phonon interaction, focusing on the three time scales that characterize the process: the singlet-triplet decoherence time, the localization time (the time it takes the system state to "collapse" to the basis state consistent with the measurement outcome), and the operational measurement time (the minimum period of data acquisition required to compute the spectral characteristics of the noise). As we have found [3], although including phonons as the additional source of noise increases the decoherence rates, it does not affect the other two time scales relevant to the measurement. Nonetheless, sufficiently fast (as compared to the QPC tunneling rates) phonon-induced relaxation at low temperatures critically affects the feasibility of the measurement scheme by suppressing the charge fluctuation, hence reducing the QPC current noise on which the measurement relies. On the contrary, at higher temperatures phonon-induced transitions contribute to charge fluctuations enhancing the spin-dependent features in the QPC noise, although still leaving the time scales unaffected [4].

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