Theory of coherent spin transfer between two Silicon quantum dots

Jan Krzywda, Piotr Szańkowski, and Łukasz Cywiński

[1]*Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, Warsaw, Poland*

Recently silicon has established its position as one of the most promising materials for quantum computation. Gate-defined quantum dot based qubits in purified silicon heterostructures exhibit very long coherence times, due to very small number of environmental nuclear spins and spin-orbit interaction being much smaller than in GaAs quantum dots. Such features accounted for recently demonstrated high fidelity two-qubit gates [1] and single shot measurements [2].

Despite this progress, scalability of a system of many quantum dots is expected to be limited by system geometry, due to finite size of gates defining the dots and wiring connected to them [3]. Registers of a few qubits will have to be separated by distances large enough to make space for voltage contacts to the controlling gates, and operation of large-scale quantum computer will require transmission of quantum information over such distances.

It has been proposed to connect the registers simply by sending an electron spin qubit between them, exploiting in this way the naturally itinerant nature of electrons [4]. With properly designed gate pulses, the electron can be shuttled between neighboring dots within timescale orders of magnitude smaller then its coherence time. Transfer of electrons along a chain of 8 silicon quantum dots has been recently demonstrated experimentally [5], and coherent shuttling of electron spin through 4 GaAs quantum dots was shown before [6]. These breakthroughs motivate investigation of pssibility of long-distance coherent shuttling of electron spin in arrays of Silicon quantum dots.

We theoretically consider coherent transfer on an electron, with its spin initially in a superposition of energy eigenstates in finite magnetic field, between two quantum dots. Such a transfer is caused by an adiabatic change in energy detuning between the two dots. We focus on the case of unequal electron Zeeman splittings in the two dots, which causes the detuning at which the charge transfer occurs to be spin-dependent. This means that during the process of spin transfer, the spin and spatial degrees of freedom (electron being localized in one dot or the other) become entangled, and there is a finite time window in which the coherence of the electron state can be strongly perturbed by charge noise that is omnipresent in quantum dot qubit structues [7]. We analyze the decoherence during spin transfer caused by such a temporary conversion of spin qubit into a charge qubit, while paying special attention to features specific to Si quantum dots brought upon by existence of two low-energy valley states.

This research has been funded by the National Science Centre, Poland under QuantERA programme, Grant no. 2017/25/Z/ST3/03044.

[1] D. M. Zajac et al., *Science* **26**, 439-442 (2018)
[2] R. Zhao et al., arXiv:1812.08347 (2018)
[3] L. M. K. Vandersypen et al., *npj quantum Information* **3**, 34 (2017)
[4] https://www.quantera.eu/calls-for-proposals/funded-projects/58-si-qubus
[5] A. R. Millis et al., *Nature Communications* **10**, 1 (2018)
[6] T. Fujita et al., *npj Quantum Information* **3**, 22 (2017)
[7] J. Yoneda et al., *Nature Nanotechnology* **13**, 102-106 (2018)