QI 3: Semiconductor Spin Qubits I: Silicon

Time: Monday 11:00–12:30 Location: HS II

Invited Talk QI 3.1 Mon 11:00 HS II

Conveyor-mode shuttling of electron spin qubits in Si/SiGe for scalable architectures — Tom Struck[1], Mats Volmer[1], Max Beer[1], Ran Xue[1], Alex Willmes[1], Max Oberländer[1], Till Huckemann[1], Arnau Sala[1], Łukasz Cywiński[2], Hendrik Bluhm[1,3], and •Lars R. Schreiber[1,3] — [1]JARA-FIT Institute for Quantum Information, Forschungszentrum Jülich GmbH and RWTH Aachen University, Germany — [2]Institute of Physics, Polish Academy of Sciences, Warsaw, Poland — [3]ARQUE Systems GmbH, Germany

Long-range coherent qubit coupling is a missing functional block for a scalable architecture of a spin-qubit based quantum computer. In a conveyor-mode shuttle, the spin-qubit is adiabatically transported while confined to a propagating sinusoidal potential in a gate-defined quantum channel [1]. Its key feature is the all-electrical operation by only few easily tunable input terminals. I present progress on conveyor-mode single electron shuttling in Si/SiGe. In a 10 micron long shuttle device, we experimentally demonstrate a shuttle fidelity of 99.7 % across the full device and back and a shuttle-based charge initialization of 34 quantum dots [2]. We observe spin coherent shuttling by separation and rejoining of a spin EPR pair [3] and map electrostatic disorder and the valley splitting [4]. Recent progress on silicon foundry fabrication and in shuttling through T-junctions could enable two-dimensional sparse qubit-architecture hosting millions of spin-qubits.

[1] Langrock ea. PRX Quantum 4, 020305 (2023). [2] Xue ea. Nat. Commun. 15, 2296 (2024). [3] Struck ea. Nat. Commun. 15, 1325 (2024). [4] Volmer ea. npj Quantum Inf. 10, 61 (2024).

QI 3.2 Mon 11:30 HS II

Long distance spin shuttling enabled by few-parameter velocity optimization — •Alessandro David[1], Akshay Menon Pazhedath[1,2], Lars R. Schreiber[3,4], Tommaso Calarco[1,2,5], Hendrik Bluhm[3,4], and Felix Motzoi[1,2] — [1]PGI-8, Forschungszentrum Jülich, Germany — [2]Theoretical Physics, University of Cologne, Germany — [3]JARA-FIT Forschungszentrum Jülich and RWTH Aachen, Germany — [4]ARQUE Systems GmbH, Germany — [5]Università di Bologna, Italy

Spin qubit shuttling via moving conveyor-mode quantum dots in Si/SiGe offers a promising route to scalable miniaturized quantum computing. Recent modeling of dephasing via valley degree of freedom and well disorder dictate a slow shutting speed which seems to limit errors to above correction thresholds if not mitigated. We increase the precision of this prediction, showing that typical errors for 10 μm shuttling at constant speed results in O(1) error, using fast, automatically differentiable numerics and including improved disorder modeling and potential noise ranges. However, remarkably, we show that these errors can be brought to well below fault-tolerant thresholds using trajectory shaping with very simple parametrization with as few as 4 Fourier components, well within the means for experimental in-situ realization, and without the need for targetting or knowing the location of valley near degeneracies.

QI 3.3 Mon 11:45 HS II

Single-qubit gates with enhanced and intrinsic spin-orbit interaction via electron shuttling — •Akshay Menon Pazhedath[1,2], Alessandro David[1], Tommaso Calarco[1,2,3], and Felix Motzoi[1,2] — [1]Peter Grünberg Institute-Quantum Control (PGI-8), Forschungszentrum Jülich GmbH, D-52425 Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, Zülpicher Straße 77, 50937 Cologne, Germany — [3]Dipartimento di Fisica e Astronomia, Università di Bologna, 40127 Bologna, Italy

Electric Dipole Spin Resonance (EDSR) is a technique mediated by the spin-orbit interaction to obtain high-fidelity single-qubit gates with semiconductor spins. To overcome the weak intrinsic spin-orbit coupling of silicon-based devices, a synthetic spin-orbit field is usually introduced by a carefully designed micro-magnet. However, micromagnets also increase the coupling of the spin with voltage noise and their placement is challenging for industrial fabrication processes. In this work we look at the larger spatial mobility of the recently emerging spin-shuttling architectures as an opportunity to perform EDSR without the help of a micro-magnet. We simulate the use of large amplitude oscillations to increase the resonance strength for various spin-orbit settings of the silicon heterostructure. We also explore the effect that the valley degree of freedom has on gate times and fidelities. Furthermore, we investigate the feasibility of performing fast high-fidelity single-qubit gates by employing simple optimal control techniques.

QI 3.4 Mon 12:00 HS II

Landau Zener Stückelberg Majorana Interferometry for valley states in conveyor-mode spin-shuttler — •Priyanka Yashwantrao[1,2], Alessandro David[1], Tommaso Calarco[1,3,4], and Felix Motzoi[1,3] — [1]PGI-8, FZJ, Jülich, Germany — [2]Universität Bonn, Bonn, Germany — [3]THP, Universität Köln, Köln, Germany — [4]University of Bologna, Bologna, Italy

Spin-shuttling devices coherently transport the spin state of a solid-state charge carrier for tens of micrometers, enabling the scalability of semiconductor quantum processors as in the proposed SpinBus architecture [1]. In Si/SiGe heterostructure the transport fidelity is deteriorated by the presence of valley [2] which depends on the atomic arrangement. The information about spacial distribution of valley splitting and eigenstate orientation would help to perform better transport experiments. Although it is currently possible to measure the valley splitting [3], this information is not complete as valley models [4] predict the orientation of the eigenstates to be a sequence of non-linear avoided crossings. In this work, we simulate numerically the technique of 'LZSM Interferometry' [5] to predict the valley behavior along a spin-shuttler. The excited valley population is studied as a function of position, amplitude and frequency. We elaborate on techniques to characterize and extract information about the valley Hamiltonian.

[1] Künne et al., Nat Commun 15, 4977 (2024) [2] Zwanenburg et al., Rev. Mod. Phys. 85, 961 (2013) [3] Volmer et al., npj Quantum Inf 10, 61 (2024) [4] Wuetz et al., Nat Commun 13, 7730 (2022) [5] Shevchenko, et al., Phys. Rept. 492, 1 (2010)

QI 3.5 Mon 12:15 HS II

Superadiabatic Landau-Zener model and the valley transitions during electron shuttling in Si — •Jonas de Lima and Guido Burkard — Department of Physics, University of Konstanz, D-78457 Konstanz, Germany

The transition dynamics of two-state systems with time-dependent energy levels is one of the basic models in quantum physics and has been used to describe various physical systems. We propose here a generalization of the Landau-Zener (LZ) problem characterized by distinct paths of the instantaneous eigenstates as the system evolves in time, while keeping the instantaneous eigenenergies exactly as in the standard LZ model [1]. We show that these paths play an essential role in the transition probability P between the two states, and can lead to a substantial reduction of P. We find that it is even possible to achieve P=0 in an instructive extreme case, as well as large P even in the absence of any anticrossing point. The superadiabatic LZ model can describe valley transition dynamics during charge and spin shuttling in semiconductor quantum dots and leads to strategies to enhance the valley shuttling fidelity that constitute a drastic improvement compared with previous strategies.

[1] J. R. F. Lima and G. Burkard, arXiv:2408.03173