QI 11: Semiconductor Spin Qubits II: Si, Ge, and Color Centers

Time: Tuesday 11:00–12:45 Location: HS II

Invited Talk QI 11.1 Tue 11:00 HS II

Systematic High-Fidelity Operation and Transfer in Semiconductor Spin-Qubits — •Maximilian Rimbach-Russ — QuTech and Kavli Institute of Nanoscience, Delft University of Technology, Delft, The Netherlands

Spin-based semiconductor quantum dot qubits are a promising contender for realizing a fault-tolerant quantum processor. Their similarity to classical transistor allows for industrial fabrication techniques, relevant for scaling to fault-tolerant device sizes.

Recent developments have shown that high-fidelity shuttling, movement of the charge carrier while preserving spin-coherence, can be experimentally realized [1]. At the same time, novel control mechanisms that make full use of artificial or intrinsic spin-orbit interaction can be used to enable power efficient, fast, and high-fidelity quantum control [2,3,4]. Furthermore, optimized pulse control allows for an additional dynamic protection and speed to further increase the fidelity of qubit transfer and operations [5,6].

[1] M. De Smet et al., arXiv:2406.07267.

[2] C.-A. Wang et al., Science 385, 6707, 447 (2024)

[3] M. Rimbach-Russ et al., arXiv:2412.13658.

[4] V. John et al., arXiv:2412.16044.

[5] M. Rimbach-Russ, S.G.J. Philips, X. Xue, and L.M.K. Vandersypen, Quantum Sci. Technol. 8, 045025 (2023).

[6] C. V. Meinersen, S. Bosco, and M. Rimbach-Russ, arXiv:2409.03084.

QI 11.2 Tue 11:30 HS II

Singlet-triplet and exchange-only flopping-mode spin qubits — •Simon Stastny and Guido Burkard — University Konstanz, Konstanz, Germany

Electron or hole spins in quantum dots coupled to a microwave cavity are an established platform to realize qubits. In the first part of this work we combine the ST_0 qubit with the versatile flopping-mode method to achieve tunable cavity coupling. We therefore introduce a spin qubit consisting of two electrons in three quantum dots in a magnetic field gradient. Tunnel couplings between the dots allow for an orbital degree of freedom. The system operates in the ST_0 regime near the $|1,0,1\rangle \leftrightarrow |0,1,1\rangle$ charge transition. We calculate the effective transversal and longitudinal spin-photon couplings in this regime and investigate them by observing the cavity transmission near the dressed ST_0 resonance. In the second part of this work these calculations are extended to the exchange-only qubit, a setup which comprises four dots and three electrons is introduced. This system can be controlled only by the electrically tunable exchange parameters. In addition a analysis of the three charge states of this system and possible coupling protocols are discussed.

QI 11.3 Tue 11:45 HS II

Mitigating Crosstalk in Single Hole-Spin Qubits in Anisotropic Semiconductor Systems — •Yaser Hajati, Irina Heinz, and Guido Burkard — Physics department, Konstanz, University of Konstanz

Spin qubits based on valence band hole states in silicon (Si) and germanium (Ge) are highly promising candidates for quantum information processing, owing to their strong spin-orbit coupling and ultrafast operation speeds. As these systems scale up, achieving high-fidelity single-qubit operations becomes crucial. However, mitigating crosstalk between neighboring qubits in larger arrays, especially for anisotropic qubits with strong spin-orbit coupling such as hole spins in Ge, presents a significant challenge. In this study, we explore the impact of crosstalk on qubit fidelities during single-qubit operations and derive an analytical equation that provides a synchronization condition to eliminate crosstalk in anisotropic media. Our analysis suggests optimized driving field conditions that can robustly synchronize Rabi oscillations, minimizing crosstalk and showing a strong dependence on qubit anisotropy and the orientation of the external magnetic field. By incorporating experimental data, we identify a set of parameters that enable nearly crosstalk-free single-qubit gates, thereby advancing the development of scalable quantum computing architectures.

QI 11.4 Tue 12:00 HS II

Characterization of NV implanted diamond for NV dipolar coupled pairs — •Annarita Ricci and Rebekka Eberle — Fraunhofer Institute for Applied Solid State Physics, Tullastr. 72 , 79108, Freiburg im Breisgau

Recent advancement on the fabrication of diamond and the high precision control on single ion implantation techniques have opened new paths in the study of NV dipolar coupled pairs. Th magnetic interaction between the electron spins of two near-by NV centers is highly influenced by their relative spatial arrangement and orientation of the spins. Thus, in this research we focus on the characterization of different NV pairs systems in a sample variation. First, we show the magnetic resonance of NV-NV spin pairs and the quantification of the dipolar coupling strength. The coherence time is then measured by employing the Spin Echo protocol and Dynamical Decoupling techniques (DD). Furthermore, we analyze the coherent sources of errors, and an estimation of the best parameters to use is given, to optimize the control of the system. The finding contributes to a deeper understanding of NV centers pairs in diamond and their potential for advancing and scaling quantum technology.

QI 11.5 Tue 12:15 HS II

Coupling Silicon-Vacancy Color Center Spin Qubits with Acoustic Modes in Diamond HBARs — •Stefan Pfleging[1,2], Arianne Brooks[1,2], Chris Adambukulam[1,2], and Yiwen Chu[1,2] — [1]Department of Physics, ETH Zürich, Otto-Stern-Weg 1, CH-8093 Zurich, Switzerland — [2]Quantum Center, ETH Zürich, Otto-Stern-Weg 1, CH-8093 Zurich, Switzerland

The silicon-vacancy (SiV) color center's electronic spin is a promising platform for realizing a quantum memory in hybrid quantum system devices. It is highly strain susceptible and exhibits coherence times in the order of 10 ms at milli-Kelvin temperatures. Incorporating it into diamond high-overtone bulk acoustic wave resonators (HBARs) exhibiting high quality factors would allow for acoustic coupling to the defect. We first characterize the strain response of the SiV by applying an acoustic drive to it and sweeping the laser frequency across one of the optical transitions of the SiV. The intensity of the sidebands that the transition is expected to exhibit in its optical emission signal allows for quantifying the coupling of the acoustic mode to the color center. We then present an approach to manipulate the spin qubit with modes of the HBAR and show suitable conditions for efficient spin driving and optical readout. The sample architecture we use consists of a diamond, HBARs that contain SiVs, bonded to a chip with antennas used for piezoelectric driving of the HBAR modes. By measuring our device at milli-Kelvin temperatures, we aim to demonstrate coherent coupling between the HBAR modes and the SiV spin qubit.

QI 11.6 Tue 12:30 HS II

Entangling high nuclear spin memory qudits via electron spin communication qubits — •Wolf-Rüdiger Hannes and Guido Burkard — Department of Physics, University of Konstanz, 78457 Konstanz, Germany

Solid-state defects with optically addressable electron spin and long-lived nuclear spin hold promise for use as quantum network nodes. Of particular interest are nuclear isotopes with high spin quantum number I, which could be exploited in efficient error-correction [1] or high-dimensional one-way quantum processing [2]. Here we demonstrate a scheme to maximally entangle $d = 2I + 1$-dimensional memory qudits in separate nodes by repeated entanglement transfer from the electron spin qubits, each time prepared in two-qubit cluster states. The transfer uses a controlled-phase like gate mediated by the hyperfine coupling, and higher nuclear spins further require broad radio-frequency driving. Depending on I, this results in a nearly perfect scheme or it can be further improved by varying the coupling, e.g., through the use of alternating rotating frames or occupying different pairs of electron levels in the case of spin triplets.

[1] J. A. Gross, Phys. Rev. Lett. **127**, 10504 (2021).

[2] C. Reimer et al., Nature Physics **15**, 148 (2019).