QI 28: Spin Qubits

Time: Thursday 11:00–13:00 Location: F428

Invited Talk QI 28.1 Thu 11:00 F428

Conveyor-mode single-electron shuttling in Si/SiGe for a scalable quantum computing architecture — •Inga Seidler[1], Tom Struck[1], Ran Xue[1], Stefan Trellenkamp[2], Hendrik Bluhm[1], and Lars R. Schreiber[1] — [1]JARA-FIT Institute for Quantum Information, Forschungszentrum Jülich GmbH and RWTH Aachen University, Aachen, Germany — [2]Helmholtz Nano Facility (HNF), Forschungszentrum Jülich, Jülich, Germany

Small spin-qubit registers defined by single electrons confined in Si/SiGe quantum dots operate successfully and connecting these could permit scalable quantum computation. Shuttling the electron qubit between registers is a natural choice for high-fidelity coherent links. We demonstrate proof-of-principle of shuttling of a single electron by a gate induced propagating wave-potential in Si/SiGe. Independent from its length only four sinusoidal control signals and low tuning effort are required. We transfer a single electron over a distance of 420 nm and observe a high single-electron shuttling fidelity of 99.42+-0.02 % including a reversal of direction [1]. Theoretical considerations of dephasing mechanisms promise coherent transport over 10 um [2]. Measuring the sensor response while transferring the electron enables us to detect the electron motion. Our shuttle can be readily embedded in industrial fabrication of Si/SiGe qubit chips and paves the way to solving the signal-fanout problem for a fully scalable semiconductor quantum-computing architecture.

[1] I.Seidler et al., npj Quant. Inf. 8, 100 (2022). [2] V. Langrock et al., arXiv:2202.11793.

QI 28.2 Thu 11:30 F428

Driven non-local gates in double quantum dot spin qubits — •Stephen McMillan and Guido Burkard — Universität Konstanz, Konstanz, Deutschland

A critical element towards the realization of quantum networks is non-local coupling between nodes. Scaling connectivity beyond nearest-neighbor interactions requires the implementation of a mediating interaction often termed a "quantum bus". Cavity photons have long been used as a bus by the superconducting qubit community, but it has only recently been demonstrated that spin-based qubits in double quantum dot architectures can reach the strong coupling regime [1,2] and exhibit spin-spin interactions via real or virtual photons [3,4]. Two-qubit gate operations are predicted in the dispersive regime where cavity loss plays a less prominent role [5]. Here we explore the potential for driving entanglement, in the context of a CNOT operation, between two non-local single-spin qubits dispersively coupled to a common mode of a superconducting resonator. [1] X. Mi et al., Nature 555, 599 (2018) [2] N. Samkharadze et al., Science 359, 1123 (2018) [3] F. Borjans et al. Nature 577, 195 (2020) [4] P. Harvey-Collard et al. arXiv:2108.01206 (2021) [5] M. Benito et al. Phys. Rev. B 100, 081412(R) (2019)

QI 28.3 Thu 11:45 F428

Cavity QED with hybrid quantum-dot donor systems — •Jonas Mielke[1], Jason R. Petta[2], and Guido Burkard[1] — [1]University of Konstanz, Konstanz, Germany — [2]University of California, Los Angeles, USA

Nuclear spins show exceptionally long coherence times but the underlying good isolation from their environment is a challenge when it comes to controlling nuclear spin qubits.

A hybrid system in which an electron is shared between a quantum dot (QD) and ^{31}P donor atom implementing a e^{-}-spin-nuclear spin flip-flop qubit has been realized. Employing ac-magnetic fields, this system can be harnessed to couple the nuclear spin to microwave cavity photons [1,2]. A related system with an electron confined in a double QD and subject to a B-field gradient constitutes a flopping mode e^{-}-spin qubit that couples to cavity photons by electrical means [3,4].

We envision an architecture combining the key ideas of the two aforementioned systems and theoretically investigate the interaction between a nuclear spin with a microwave cavity by electrical means. We demonstrate nuclear spin readout [5] and a cavity mediated nuclear spin $\sqrt{i\mathrm{SWAP}}$-gate with a gate fidelity approaching 95% [6].

[1] Tosi et al., PRB 98, 075131 (2018)
[2] Tosi et al., Nat. Comm. 8, 450 (2017)
[3] Benito et al., PRB 96, 235434 (2017)
[4] Mi et al., Nature 555, 7698 (2018)
[5] Mielke et al., PRX Quantum 2, 020347 (2021)
[6] Mielke et al., arXiv:2209.10026 (2022)

QI 28.4 Thu 12:00 F428

Perspectives for a solid-state-based quantum register based on NV centers aligned along linear crystal defects in diamond — •Reyhaneh Ghassemizadeh, Wolfgang Körner, Daniel F. Urban, and Christian Elsässer — Fraunhofer Institute for Mechanics of Materials IWM, Wöhlerstr. 11, 79108 Freiburg, Germany

Due to its outstanding coherence properties, the negatively charged nitrogen-vacancy defect (NV center) in diamond has an excellent potential for implementing qubits in future solid-state-based quantum computing hardware. However, the structuring of point defects on the atomic scale remains an experimental challenge. We present a theoretical study using density functional theory (DFT) on the interaction between one dimensional crystal defects (dislocations) and NV centers [1]. We evaluate to which extent dislocation lines that are naturally present in diamond may be used for structuring NV centers. We model the most common types of dislocations in diamond and evaluate their influence on the defect formation energy, structural geometry, electronic defect levels and zero-field splitting (ZFS) parameters of NV centers in close proximity. Our simulations reveal that dislocations potentially trap NV defects with an energy release of up to 3 eV. In general, the properties of NV centers at dislocations show strong deviations with respect to their bulk values. However, the lowest energy configuration of a NV center at the core of a 30° partial glide dislocation shows very bulk-like properties. This opens the perspective to align multiple functional NV centers in a linear-chain arrangement.

[1] R. Ghassemizadeh, et al., Phys. Rev. B 106, 174111 (2022)

QI 28.5 Thu 12:15 F428

Controlling nuclear spin qubits in silicon carbide — •Pierre Kuna[1], Erik Hesselmeier[1], Di Liu[1], Vadim Vorobyov[1], Florian Kaiser[2], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart — [2]LIST, Luxembourg

The V2 color center in silicon carbide (SiC) emerged as promising CMOS compatible optically interfaced spin systems in solid state materials. V2 centers combine excellent spin and optical properties, i.e., ms spin coherence times and transform limited optical linewidth, even after nanophotonic integration[1]. Additionally, the di-atomic lattice of SiC provides an elegant pathway to further expand on existing quantum computing approaches demonstrated in the diamond counterpart.

Here, we present theoretical considerations and experimental results towards high-fidelity nuclear spin control in SiC. Using the V2 center as the control (electron) spin, and the surrounding nuclear spins as computational qubits, our first goal is to implement single shot readout (SSR). With this enabling technique, we plan to implement quantum computational algorithms on multiple nuclear spins.

We strive to demonstrate significantly increased fidelities and coherence times based the half-integer control spin, which results in a frozen core that prevents nuclear spin flip-flops. Additionally, the different gyromagnetic ratios of 29-silicon and 13-carbon nuclear spins should allow us to dynamically couple and decouple nuclear spins using an external magnetic field, which can increase the complexity of attainable quantum computing circuits.

[1] C. Babin et al., Nat. Mater. 21, 67 (2022)

QI 28.6 Thu 12:30 F428

Control and coherence of tin-vacancy qubits in diamonds — •C. Waas, H. Beukers, M. Pasini, N. Codreanu, J. Brevoord, L. De Santis, Z. Ademi, S. Niese, F. Gu, V. Dobrovitski, J. Borregaard, and R. Hanson — QuTech and Kavli Institute of Nanoscience, Delft University of Technology, 2628CJ Delft, The Netherlands

Color centers in diamonds are promising building blocks for realizing quantum network nodes, thanks to their good optical and spin properties as well as the naturally occurring ^{13}C-memory qubits in the diamond. Using NV centers, a multi-node network and teleportation of qubit states between non-neighboring nodes have been demonstrated (1). However, the optical properties of the NV currently hinder on-chip integration and scaling-up of quantum networks.

The tin-vacancy (SnV) center emerged as a resourceful alternative platform thanks to its improved optical properties, the second-long relaxation times expected around 1K, and compatibility with nanophotonic integrated devices, thanks to the first-order insensitivity to electric field fluctuations arising from its symmetry properties. Together with the recent developments in diamond nanofabrication techniques and hybrid integrated photonics, this makes the SnV interesting for realizing scalable platforms and on-chip devices. Here we report on the fabrication of single SnV centers in diamond and the investigation of their optical and spin coherence properties. Furthermore, we present our work towards spin-state control of the SnV qubit state at 1K.

(1) Hermans S. et al. Qubit teleportation between non-neighbouring nodes in a quantum network. Nature 605, 663-668 (2022).

QI 28.7 Thu 12:45 F428

Manipulating electron spin entanglement with a scanning tunnelling microscope — •Carsten Henkel[1] and Baruch Horovitz[2] — [1]Universität Potsdam, Institut für Physik und Astronomie — [2]Ben Gurion University of the Negev, Department of Physics, Beer Sheva, Israel

The tunnel current of a scanning microscope contains, in its fluctuations, information about localised spin sites in the contact region. In a magnetic field, this provides an alternative take on electron spin resonance spectroscopy. We showed previously that the features of the current spectrum can be explained by two localised spins that provide interfering tunnelling pathways [1]. The two spins experience effective exchange and Dzyaloshinskii-Moriya couplings and decay channels when the electronic contacts are integrated out [2]. Observed spin spectra can be fitted to the results of a master equation [3]. We report on voltage quenches and current measurements that manipulate the two-spin state and analyse its entanglement [2].

[1] B. Horovitz and A. Golub, Phys. Rev. B 99 (2019) 241407(R)
[2] B. Horovitz and C. Henkel, Phys. Rev. B (Lett.) 104 (2021) L081405
[3] Y. Manassen, M. Jbara, M. Averbukh, Z. Hazan, C. Henkel, and B. Horovitz, Phys. Rev. B 105 (2022) 235438