QI 6: Implementations II

Time: Tuesday 9:30–12:45 Location: BEY/0245

Invited Talk QI 6.1 Tue 9:30 BEY/0245

Erbium dopants for quantum networks — •Andreas Reiserer — Technical University of Munich, TUM Center for Quantum Engineering (ZQE), Am Coulombwall 3A, 85748 Garching, Germany

Despite decade-long research into different physical systems, demonstrating a scalable platform for quantum networks and distributed quantum information processing remains an outstanding challenge. In this context, our group investigates the use of erbium dopants in silicon and silicate crystals. This platform offers unique potential for up-scaling: First, erbium dopants can exhibit second-long coherence in a temperature range accessible with 4He cryocoolers. Second, the optical transition of erbium is among the narrowest spectral features ever measured in a solid. Thus, frequency-multiplexed addressing of individual dopants gives access to an unprecedented qubit density. Finally, by embedding the dopants into slow-light waveguides or optical resonators with a high quality factor, the optical lifetime can be reduced via the Purcell effect. This has enabled lifetime-limited photon emission in the telecommunications C-band, where optical fiber losses are minimal. Furthermore, it has paved the way for the optical spin readout of erbium dopants and for spectroscopy of their surrounding nuclei. Taken together, our results thus establish erbium dopants as a promising new hardware platform that may facilitate the implementation of scalable quantum networks and repeaters based on single emitters at telecommunications wavelengths.

QI 6.2 Tue 10:00 BEY/0245

Shadow Wall Epitaxy: All-in-situ fabrication of ZnSe-based Quantum Devices — •Christine Falter[1,2], Yurii Kutovyi[1,2], Nils von den Driesch[1,2], Denny Dütz[2,3], Lars R. Schreiber[2,3], and Alexander Pawlis[1,2] — [1]Peter Grünberg Institute, Forschungszentrum Jülich GmbH, 52428 Jülich, Germany — [2]JARA-FIT, Jülich Aachen Research Alliance, Forschungszentrum Jülich and RWTH Aachen University, Germany — [3]JARA-Institute for Quantum Information, RWTH Aachen University, 52074 Aachen, Germany

The wide band-gap semiconductor ZnSe offers a wide range of unique optical and electrical properties, which make it a promising candidate for a variety of quantum devices. In standard fabrication schemes, device performance is often limited by surface states and defects introduced during ex-situ applied processing steps. With this in mind, we have developed a Shadow Wall technique for molecular beam epitaxy (MBE), which allows for all-in-situ device fabrication making all post processing steps obsolete. The technique relies on the pre-patterning of vertical walls on the substrate and the precise alignment of material fluxes during deposition. Using our technique we have realized an all-in-situ ZnSe-based field effect transistor (FET). In our contribution, we demonstrate the MBE growth of high quality ZnSe layers on pre-patterned substrates, the optimization of the electronic band-structure and the electrical characterization of the final device. The optimization of the ZnSe FET platform is a first step towards the realization of qubits based on gate defined quantum dots in ZnSe.

QI 6.3 Tue 10:15 BEY/0245

Harnessing the non-Abelian Berry phase for universal control of zero-field spin qubits — •Baksa Kolok[1,2], Csongor Hunyady[1], and András Pályi[1,2] — [1]Department of Theoretical Physics, Institute of Physics, Budapest University of Technology and Economics — [2]HUN-REN-BME-BCE Quantum Technology Research Group, Budapest University of Technology and Economics

Spin qubits in semiconductor quantum dots achieve their longest coherence times at zero magnetic field when nuclear spins are suppressed, making zero-field operation attractive. It also promises reduced control complexity by removing the need for magnets and enabling electrical, baseband manipulation. In this talk, I present a control framework that realizes universal quantum computation in sparse quantum-dot arrays operating entirely at zero magnetic field. Initialization and readout rely on singlet-triplet energy separation and Pauli spin blockade. Single-qubit gates emerge geometrically: when a qubit is shuttled around closed loops in the array, it accumulates a non-Abelian Berry phase that implements a deterministic SU(2) rotation. Although the number of accessible loops, and thus the native gate set, is discrete, we show that in generic devices two loops already provide full single-qubit controllability. Moreover, the same pair of loops suffices for complete quantum process tomography, enabling characterization of decoherence in zero-field architectures. Combined with exchange-based entangling gates, these results position sparse quantum-dot arrays as a promising platform for high-coherence, all-electric quantum computation without magnetic fields or microwave pulses.

QI 6.4 Tue 10:30 BEY/0245

Modelling readout of spin qubits using a single electron transistor — •Domonkos Svastits[1,2], Sudipto Das[1], Aritra Sen[1], and András Pályi[1,3] — [1]Budapest University of Technology and Economics, Budapest, Hungary — [2]Qutility @ Faulhornlabs, Budapest, Hungary — [3]HUN-REN-BME-BCE Quantum Technology Research Group, Budapest, Hungary

Spin qubits in semiconductor quantum dots are a promising platform for scalable quantum computing. However, current qubit operations remain too noisy for practical applications, with qubit readout often being the noisiest operation. Readout typically uses Pauli blockade spin-to-charge conversion combined with charge sensing. In this work, we present a microscopic model of charge sensing implemented by a single-electron transistor (SET), intended to guide improvements in spin-qubit readout, focusing on an n-type Silicon double quantum dot equipped with a micromagnet. Our model provides a microscopic, dynamical description of the measurement process. We show the measurement induces unwanted back-action in the form of incoherent transitions between qubit energy eigenstates, similar to predictions for a QPC (D. Svastits et al., arXiv:2505.15878 [quant-ph]). We also calculate how the measurement rate, i.e. the speed of the measurement, depends on the qubit Hamiltonian. We find that the parameter dependence of readout infidelity, post-measurement state mixedness and leakage are well explained by the transition rates and the measurement rate. Finally, we propose experimentally practical strategies to increase the measurement rate while suppressing the transition rates.

QI 6.5 Tue 10:45 BEY/0245

Ge-based qubit heterostructure: A 3-in-1 photoelectron spectroscopy study — •Andreas Fuhrberg[1], Maximilian Oezkent[2], Kevin-P. Gradwohl[2], Sergii Chernov[4], Volkmar Koller[4], Christoph Schlueter[4], Hans-Joachim Elmers[3], and Martina Müller[1] — [1]Universität Konstanz — [2]IKZ, Berlin — [3]Universität Mainz — [4]DESY, Hamburg

Semiconductor spin qubits are a key component in quantum information processing. Ge-based hole spin qubits have also proven to be a suitable system for realizing spin qubits. Strain-induced $Ge_{0.8}Si_{0.2}/Ge/Ge_{0.8}Si_{0.2}$ heterostructures are a common way to build such components. At both interfaces, holes are confined by a strain-induced valence band offset (VBO) - an essential device parameter.
A set of three synchrotron-based photoemission experiments are performed to investigate the interfaces of Ge-based qubit heterostructures by varying the thickness of (i) the central Ge-layer and (ii) $Ge_{0.8}Si_{0.2}$ overlayer. Using hard X-ray momentum microscopy (MM), the valence band along the symmetry points Γ, X and L is characterized, and the VBO near both interfaces is quantized. MM reveals an increased energy shift of ≈ 50 meV between the heavy/light hole band and the spin-orbit band for (i) Ge and (ii) $Ge_{0.8}Si_{0.2}$ bands near the respective interface. An MM-based diffraction experiments and hard X-ray photoelectron spectroscopy further analyse the interface structure and chemistry. Together, this three-in-one photoelectron spectroscopy technique provides a nearly full characterization of the Ge-hole spin qubits main structure and supports the qubit optimization process.

30min. break

QI 6.6 Tue 11:30 BEY/0245

The flopping-mode exchange-only spin qubit — •Simon Stastny[1] and Guido Burkard[2] — [1]Universität Konstanz, Konstanz, Germany — [2]Universität Konstanz, Konstanz, Germany

Electron or hole spin qubits in quantum dots coupled to a microwave cavity are an established platform to realize spin qubits. One promising qubit is the exchange-only spin qubit, that allows for full baseband control, without magnetic fields. In this work we propose a spin qubit, that couples exchange-only qubit states to a cavity by adding a charge degree of freedom to the established three dot exchange-only qubit. The proposed qubit is a generalized flopping mode qubit: It comprises four quantum dots with three electrons, operating near the $(0,1,1,1) \leftrightarrow (1,0,1,1) \leftrightarrow (1,1,0,1)$ charge transition. The qubit as well as its resulting transversal and longitudinal spin photon couplings allow for full baseband control. the couplings and quasi static noise of the qubit are analyzed. We find dephasing times exceeding the estimated gates times, thus the proposed qubit is a promising system to realize baseband-controlled resonator-mediated (longitudinal) two qubit gates.

QI 6.7 Tue 11:45 BEY/0245

Reinforcement learning entangling operations on spin qubits — •Mohammad Abedi[1,2] and Markus Schmitt[1,3] — [1]PGI-8 (Quantum Control), Forschungszentrum Jülich, Wilhelm-Johnen-Straße, 52428, Jülich — [2]Fakultät für Physik, Universität Regensburg, Universitätsstraße 31, D-93051, Regensburg — [3]Fakultät für Informatik und Data Science, Universität Regensburg, Universitätsstraße 31, D-93040, Regensburg

High-fidelity control of one- and two-qubit gates past the error correction threshold is an essential ingredient for scalable quantum computing. We present a reinforcement learning (RL) approach to find entangling protocols for semiconductor-based singlet-triplet qubits in a double quantum dot. Despite the presence of realistically modelled experimental constraints, such as various noise contributions and finite rise-time effects, we demonstrate that an RL agent can yield performative protocols, while avoiding the model-biases of traditional gradient-based methods. We optimise our RL approach for different regimes and tasks, including training from simulated process tomography reconstruction of unitary gates, and investigate the nuances of RL agent design.

QI 6.8 Tue 12:00 BEY/0245

Spin Qubit Leapfrogging: Dynamics of shuttling electrons on top of another — •Nicklas Meineke and Guido Burkard — Faculty of Physics, University of Konstanz, 78464 Konstanz, Germany

In recent years spin shuttling has distinguished itself as a promising candidate for achieving high fidelity medium range interactions between spin qubits and presents a powerful tool for enabling scalable semiconductor spin quantum computing architectures in the future.

Modelling the process of a shuttled spin qubit encountering a stationary quantum dot, we investigate the dynamics of the (1,1)-(0,2) charge transition in a silicon double quantum dot with non-vanishing inter-valley coupling. This enables us to describe the process of the mobile electron leapfrogging over the stationary one i.e. transitioning from a (1,1,0)- to a (0,1,1)-charge state, occupying a (0,2,0) state inbetween. Here the triplets will occupy a valley excited state to circumvent Pauli-Spin-Blockade leading to a S*T0 splitting approximately equal to the valley splitting in the stationary dot. Consequently this protocol will implement an entangling gate, which can be tuned by waiting in this configuration. For the gate to be noise-resistant and controllable the valley splitting at the location of the middle dot needs to be very low. Therefore this opens up the possibility to make practical use and isolate low-valley splitting hotspots on a wafer, which would otherwise act as error sources.

QI 6.9 Tue 12:15 BEY/0245

Highly crystalline superconducting resonators grown on reconstructed sapphire via Thermal Laser Epitaxy and Molecular Beam Epitaxy — •Thomas J. Smart[1], Marc Neis[2], Roudy Hanna[1,2], Marcello Gaurdascione[2], Michael Schleenvoigt[1], Joscha Domnick[1], Benjamin Bennemann[1], Janine Lorenz[3], Jin Hee Bae[1], Abdur R. Jalil[1], Pavel A. Bushev[2], Felix Lüpke[3], Peter Schüffelgen[1], Detlev Grützmacher[1], and Rami Barends[2] — [1]Peter Grünberg Institute of Semiconductor Nanoelectronics (PGI-9), Forschungszentrum Jülich & Jülich Aachen Research Alliance; 52425, Jülich, Germany — [2]Peter Grünberg Institute of Functional Quantum Systems (PGI-13), Forschungszentrum Jülich, Campus-Boulevard 79, 52074, Aachen, Germany — [3]Peter Grünberg Institute of Quantum Nanoscience (PGI-3), Forschungszentrum Jülich, 52425, Jülich, Germany

In the ongoing search for optimizing quantum computing hardware, many alternative superconducting materials are being investigated, including nitrogen-based compounds with large superconducting band gaps, high Tc values, and resistance to oxidation. Concurrently, thermal reconstruction of substrates via Thermal Laser Epitaxy enables enhanced epitaxial growth and pristine interface quality. We demonstrate the growth of highly crystalline TiN on reconstructed sapphire via Molecular Beam Epitaxy, subsequently fabricated into superconducting resonators. These resonators produce internal quality factors greater than 2e6 at single-photon values, among the highest recorded for crystalline TiN on sapphire.

QI 6.10 Tue 12:30 BEY/0245

Characterization of driven unwanted state transitions in superconducting circuits — •Sumeru Hazra, Wei Dai, Daniel. K. Weiss, Pavel D. Kurilovich, Thomas Connolly, Harsh K. Babla, Shraddha Singh, Vidul R. Joshi, Andy Z. Ding, Pranav D. Parakh, Jaya Venkatraman, Xu Xiao, Luigi Frunzio, and Michel H. Devoret — Department of Applied Physics, Yale University, New Haven, CT, USA

Microwave drives are essential for the control and readout of superconducting quantum circuits. Ideally, strong drive increases the speed and fidelity of such operations, however, in practice, strong drives also induce unwanted state transitions that corrupt these operations. In this talk, I will present a comprehensive investigation of drive-induced transitions in a fixed-frequency qubit subjected to microwave tones over a broad 9 GHz range. By combining a pump-probe spectroscopy with driven Hamiltonian simulations, we identify the physical origins of these transitions and group them into three mechanisms: (i) Resonant interactions with parasitic two-level systems activated by drive-induced ac-Stark shifts, (ii) Intrinsic multi-photon transitions out of the computational subspace, and (iii) Inelastic scattering processes where the qubit exchanges energy with spurious electromagnetic modes or TLS defects. I will show that Floquet steady-state simulations, supplemented with finite-element electromagnetic modeling, accurately predict all transitions that do not involve TLSs. These results establish a unified framework for predicting and eliminating drive-induced unwanted transitions.