FM 14: Quantum Computation: Hardware Platforms I

Time: Monday 14:00–16:00 Location: 3044

Invited Talk FM 14.1 Mon 14:00 3044

Quantum simulation and computation with spins in quantum dots — •Uditendu Mukhopadhyay[1], Juan P Dehollain[1], Vincent P. Michal[1], Yao Wang[2], Bernhard Wunsch[2], Christian Reichl[3], Werner Wegscheider[3], Mark S. Rudner[4], Eugene Demler[2], and Lieven M. K. Vandersypen[1] — [1]TU Delft — [2]Harvard University — [3]ETH Zürich — [4]University of Copenhagen

Electrostatically defined quantum dots in semiconductors are one of the leading platforms for the development of quantum technologies, owing to their fast and efficient control and measurement, as well as their compatibility with industrial semiconductor fabrication. At the Vandersypen lab, we use the electrons confined in quantum dots to perform quantum simulation and computation.

In this talk, I will delve into some of our latest experiments. I will begin with a description of the types of quantum dot arrays that we operate, highlighting the techniques that we have developed recently to overcome the problem of disorder and efficient control, which is crucial to the operation and scale-up of these systems as quantum simulators and processors. I will then describe our latest quantum simulator device-a 2x2 plaquette of quantum dots in a GaAs heterostructure-which we use to demonstrate Nagaoka ferromagnetism, one of the well-known theories of ferromagnetism based on the Hubbard model, which had yet to be demonstrated experimentally. Finally, I will present the capabilities of our silicon-based 2-qubit quantum information processor, with an outlook on how this technology can be further developed towards a large-scale universal quantum computer.

FM 14.2 Mon 14:30 3044

Engineering Si-based quantum devices viable as hardware back-end in a full-stack quantum computer prototype — •Thorsten Last, Nodar Samkharadze, Amir Sammak, Delphine Brousse, Pieter Eendebak, Richard Versluis, Menno Veldhorst, Lieven Vandersypen, and Jeremy Veltin — QuTech - TU Delft/TNO, Lorentzweg 1, 2628 CJ Delft, NL

We will present a technology development framework in which Si spin qubit based quantum devices can become a viable option as hardware back-end in prototype quantum computers (QC). A chip which is considered to be a component of such an architecture asks for more stringent specs in stability than required for proof of principle experiments. Taking this requirement into account we developed a manufacturing feedback loop including materials, fabrication and electrical screening. However, implementing these device manufacturing needs in shared R&D facilities is found to be a challenging task. Still, parts of the feedback loop have been applied to manufacture Si-based devices made to host two spin qubits. Our devices consist of gate-defined double quantum dots formed in an undoped Si-28 quantum well embedded in a SiGe heterostructure. Fast readout of the quantum dot states is performed with a nearby single electron transistor. The devices consistently reach the few-electron regime. Spin lifetimes of around 30 ms are in line with previous results on Si. The device tune up to qubit-level is ongoing. If completed these devices will be utilized as processing units in our QC prototype platform (www.quantum-inspire.com).

FM 14.3 Mon 14:45 3044

Spin relaxation induced by valley-orbit coupling in a single Si quantum dot — •Amin Hosseinkhani and Guido Burkard — Department of Physics, University of Konstanz, Germany

The spin of isolated electrons in Silicon quantum dot heterostructures is a promising candidate for quantum information processing. While silicon offers weak spin-orbit coupling and nuclear-spin free isotopes, the valley degree of freedom in silicon couples to spin and can degrade the qubit performance by opening a relaxation channel. We build on effective mass theory to obtain the valley phase and splitting for a single quantum dot spin qubit as a function of the applied magnetic and electric field. These enable us to develop the theory of spin-relaxation induced by valley-orbit coupling. We show that it is important to consider all four physical spin-valley states into the qubit logical states in order to describe the qubit relaxation.

FM 14.4 Mon 15:00 3044

Low-temperature ohmic contacts to n-ZnSe for all-electrical quantum devices — •Felix Hartz[1], Johanna Janssen[2], Till Huckemann[1], Malte Neul[1], Lars R. Schreiber[1], and Alexander Pawlis[2] — [1]JARA - Institute for Quantum Information, RWTH Aachen University, Germany — [2]Peter Grünberg Institute 9 and JARA - FIT, Forschungszentrum Jülich GmbH, Germany

The most advanced semiconductor spin qubits are realized in gate defined quantum dots in ^{28}Si. Qubit performance has been improved by isotopical purification and qubit integration in Si/SiGe heterostructures finally limited by spin valley splitting. ZnSe is an ideal host material for gate defined quantum dots as it has no valleys, provides a photonic link [1] and is potentially nuclear spin free after isotopical purification [2]. Prerequisite to all-electrical qubits are ohmic contacts to ZnSe operating at cryogenic temperatures that have not been realized so far. Here we present a complete analysis on ohmic contacts to n-type ZnSe. By $in-situ$ Al metallisation of the ohmic contact without breaking ultra-high vacuum conditions, we avoid the natural ZnSe oxide and therefore achieve a record contact resistivity of $(2.3\pm0.8)\cdot10^{-5}\,\Omega\mathrm{cm}^2$ at room temperature and $(4\pm2)\cdot10^{-5}\,\Omega\mathrm{cm}^2$ at 4 K. We demonstrate local ohmic contacts combining the $in-situ$ technique with selective regrowth yielding low resistivity contacts with $(1.7\pm0.2)\cdot10^{-4}\,\Omega\mathrm{cm}^2$ also operating at 4 K ($(1.4\pm0.4)\cdot10^{-3}\,\Omega\mathrm{cm}^2$). This allows for a new type of quantum devices such as gate defined quantum dots in ZnSe. [1] K. Sanaka ea., Nano Lett. (2012) [2] A. Pawlis ea., Appl. Electron. Mater. (2019)

FM 14.5 Mon 15:15 3044

Long-Distance Charge Transport in (Al,Ga)As — •Matthias Künne[1], Stefan Trellenkamp[2], Julian Ritzmann[3], Arne Ludwig[3], Andreas D. Wieck[3], and Hendrik Bluhm[1] — [1]JARA-FIT Institute for Quantum Information, Forschungszentrum Jülich GmbH and RWTH Aachen University, D-52074 Aachen, Germany — [2]Helmholtz Nano Facility, Forschungszentrum Jülich GmbH, D-52425 Jülich, Germany — [3]Lehrstuhl für angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44801 Bochum, Germany

For scalable quantum computing architectures, a transfer of the qubit information over distances of at least a few microns is advantageous, e.g. for making space for signal vias [1]. For electron spin qubits, one possibility is to move the electrons themselves.

In my talk, I will present a device designed to allow the shuttling of electrons over 7 microns. We employed high-yield, multi-layer electron beam lithography to fabricate the required metallic gates. I will show initial results on the characterization of the device.

[1] L. M. K. Vandersypen et al., npj Quantum Inf. 3, 34 (2017)

FM 14.6 Mon 15:30 3044

Fast universal holonomic manipulation of a two-qubit register — •Vlad Shkolnikov and Guido Burkard — Department of Physics, University of Konstanz, D-78457 Konstanz, Germany

Geometric phases arising from cyclic evolution of quantum systems open new strategies for quantum technologies. Here we consider theoretically the perspective to use these phases to achieve universal control over the defect registers in diamond. In particular we focus on the electron spin of a nitrogen-vacancy center coupled to the nuclear spin of a neighbouring carbon-13 atom. By tuning the system first to the ground state level anticrossing and then mixing the electronic $m_s=0$ and $m_s=-1$ levels, we achieve that the nuclear spin quantization axis becomes dependent on the state of the electron spin. This allows one to perform hyperfine assisted universal set of holonomic gates on this two qubit register using microwave tones only. This has a clear advantage over the conventional methods that use radio frequency pulses to couple to the nuclear spin due to its low gyromagnetic ratio. We will discuss the pulse protocols to realize the set of gates necessary for universal computation and show how one can initialize and read out the system in our scheme.

FM 14.7 Mon 15:45 3044

Scalable Rare Earth Ion Quantum Computing Nodes (SQUARE) — •David Hunger — Karlsruhe Institute of Technology, Karlsruhe, Germany

Quantum technologies rely on materials that offer the central resource of quantum coherence, that allow one to control this resource and to harness interactions to create entanglement. Rare earth ions (REI) doped into solids have an outstanding potential in this context and could serve as a scalable, multi-functional quantum material. REI provide a unique physical system enabling a quantum register with a large number of qubits, strong dipolar interactions between the qubits allowing fast quantum gates, and coupling to optical photons - including telecom wavelengths - opening the door to connect quantum processors in a quantum network. The flagship project SQUARE aims at establishing individually addressable rare earth ions as a fundamental building block of a quantum computer, and to overcome the main roadblocks on the way towards scalable quantum hardware. The goal is to realize the basic elements of a multifunctional quantum processor node, where multiple qubits can be used for quantum storage, quantum gates, and for coherent spin-photon quantum state mapping.