TT 23: Quantum Information Systems (Joint session of HL, MA, O and TT organized by HL)

Time: Tuesday 9:30–12:30 Location: H15

TT 23.1 Tue 9:30 H15

Nuclear spins as quantum memories for quantum networks and repeaters — •Andreas Reiserer[1,2], Norbert Kalb[1,2], Machiel Blok[1,2], Koen van Bemmelen[1,2], Tim Taminiau[1,2], and Ronald Hanson[1,2] — [1]Kavli Institute of Nanoscience, TU Delft, The Netherlands — [2]QuTech, TU Delft, The Netherlands

A future quantum network will consist of quantum processors that are connected by quantum channels, just like conventional computers are wired up to form the Internet. To realize such network, we plan to use spin qubits in diamond, which combine access to few-qubit nuclear-spin registers with exceptional coherence properties. However, preserving the coherence of the register while generating entanglement between remote spins is an open challenge.

Here, we investigate the coherence of single ^{13}C spins that occur in an otherwise spin-free diamond sample of natural isotope abundance. Five individual nuclear spins are controlled via the weak hyperfine interaction with the electronic spin of a nitrogen vacancy (NV) center in a strong magnetic field. We encode quantum bits in the nuclear spins and investigate the loss of coherence caused by repeated electron spin initialization, which is required for any quantum protocol that is subject to errors. Encoding the qubits in a decoherence-protected subspace of two rather than one nuclear spin increases the robustness of the protocol and enables the investigation of a large parameter space with a single sample. Our results open perspectives for the realization of large scale quantum networks and quantum repeaters using NV centers with weakly coupled nuclear spins.

TT 23.2 Tue 9:45 H15

Long distance coupling of resonant exchange qubits — •Maximilian Russ and Guido Burkard — Department of Physics, University of Konstanz, D-78457 Konstanz, Germany

We investigate the effectiveness of a microwave cavity as a mediator of interactions between two resonant exchange (RX) qubits [1,2] in semiconductor quantum dots (QDs) over long distances [3], limited only by the extension of the cavity. Our interaction model includes the orthonormalized Wannier orbitals constructed from Fock-Darwin states under the assumption of a harmonic QD confinement potential. We calculate the qubit-cavity coupling strength g_r in a Jaynes Cummings Hamiltonian, and find that dipole transitions between two states with an asymmetric charge configuration constitute the relevant RX qubit-cavity coupling mechanism. The effective coupling between two RX qubits in a shared cavity yields a universal two-qubit iSWAP-gate with gate times on the order of nanoseconds over distances on the order of up to a millimeter.

[1] J. Medford et al., Phys. Rev. Lett. **111**, 050501 (2013).
[2] J. M. Taylor, V. Srinivasa, and J. Medford, Phys. Rev. Lett. **111**, 050502 (2013).
[3] M. Russ and G. Burkard, arXiv: 1508.07122 (2015)

TT 23.3 Tue 10:00 H15

Higher Order Spin Correlation in Semi-Conductor Quantum Dots — •Nina Fröhling, Jan Böker, and Frithjof Anders — Fakultät Physik, TU Dortmund, 44227 Dortmund, Deutschland

We study higher order auto-correlation functions of electron spin decay in an isolated semi-conductor quantum dot described by the central spin model. The electronic central spin is coupled to a bath of nuclear spins via hyperfine interaction, which dominates the short time regime. In a mean field approach the nuclear spin field is assumed to be frozen, since the precession frequency of the electron in the nuclear hyperfine field is much greater than the precession frequency of the nuclei in the hyperfine field of the electron. Since the higher order cumulants of this mean-field approximation vanish, these functions can serve as a tool to reveal the entanglement between the electron spin and the nuclear spin bath. We also evaluate analytically the symmetries exhibited by third order correlation functions in the high-temperature limit. It can be shown that the third order correlation function is constrained to a small subspace of all possible frequencies. Furthermore, we calculate the third order correlation function using the Lanczos-algorithm and statistic trace evaluation. The viability of this method is benchmarked by the analysis of the established spin noise spectrum given by the second order correlation function.

TT 23.4 Tue 10:15 H15

Spin Decoherence in a Pulsed Quantum Dot System — •Natalie Jäschke and Frithjof Anders — Fakultät Physik, TU Dortmund, 44227 Dortmund, Deutschland

In pump-probe experiments electron spin polarization in a semiconductor quantum dot is generated by periodic optical excitations. The decoherence of this polarization is dominated by the hyperfine interaction with a bath of nuclear spins in the short time regime. We aim for a theory that combines the effect of the periodic laser pulses and the nuclear spin bath on the electron spin polarization. Since the laser pulses occur on the shortest time scale of the system, and the electronic decay times are small compared to those of the nuclear spin bath, we treat the laser pumping quantum-mechanically using a Lindblad approach and keep the nuclear spins as frozen during that time. Then a classical simulation of the Overhauserfield bridges the time until the next laser pulse. We analyze the stability of different non-equilibrium nuclear spin bath distribution functions as well as the magnetic field dependent build up of a laser-induced nuclear spin polarization.

TT 23.5 Tue 10:30 H15

A model for slow decoherence in semiconductor quantum dots — •Wouter Beugeling, Frithjof B. Anders, and Götz S. Uhrig — Lehrstuhl für Theoretische Physik I/II, Technische Universität Dortmund, 44221 Dortmund, Germany

Quantum dots on semiconductor materials have been proposed as candidates for quantum computational applications. The information is carried by a single electron spin, which interacts with the substrate nuclei with a hyperfine coupling. The electron spin is manipulated with excitation by periodic laser pulses and by an external magnetic field. The nuclear spins can be polarized indirectly, due to the hyperfine coupling, an effect known as dynamical nuclear polarization.

The leading contribution in the dynamics is the Larmor precession, which dephases due to small frequency shifts from the hyperfine coupling. Typically, the dephasing causes almost complete decoherence at the time scale of the pulse interval. Thus, a different mechanism must be responsible for the finite coherence observed in experiments.

In this presentation, we propose a mechanism explaining the experimental findings. We study the dynamics using the Lindblad equation, which includes the non-unitarity from the decay of the excited state. We separate the time scales of the Larmor precession (fast) and the nuclear-spin dynamics (slow) by treating the hyperfine couplings in a perturbative fashion. We find low-frequency contributions that dephase at a much slower rate, providing a plausible explanation for the finite coherence at the pulse interval time. We support this claim with analytical derivations and numerical results.

30 min. Coffee Break

TT 23.6 Tue 11:15 H15

Force sensing via individual nitrogen-vacancy spins in diamond mechanical resonator — Phani Peddibhotla[1], Michael Barson[2], Kumar Ganesan[3], Preeti Ovartchaiyapong[5], Berndt Koslowski[4], Ania Jayich[5], Steven Prawer[3], Neil Manson[2], Marcus Doherty[2], and •Fedor Jelezko[1] — [1]Institute for Quantum Optics, University of Ulm, 89081 Ulm, Germany — [2]Laser Physics Centre, Australian National University, Canberra, Australia — [3]School of Physics, University of Melbourne, Victoria 3100, Australia — [4]Institute for Solid State Physics, University of Ulm, 89081 Ulm, Germany — [5]Department of Physics University of California, Santa Barbara

We propose to use the embedded nitrogen-vacancy (NV) defect states in single-crystal diamond cantilever for measuring external forces. In order to experimentally demonstrate the force sensing capabilities, we employed an atomic force microscope (AFM) tip to apply a force on the non-clamped end of the diamond cantilever, which in turn induces lattice strain to a NV center close to the clamping point of a cantilever. The strain-mediated coupling between NV spin and diamond mechanics is observable via clear signatures in the optically detected electron spin resonance (ESR) spectrum of the NV center [1, 2].

[1] J. Teissier et al., PRL 113, 020503 (2014). [2] P. Ovartchaiyapong,

et al., Nat. Commun. 5:4429 (2014).

TT 23.7 Tue 11:30 H15

Identification of the positively charge Nitrogen Vacancy center in diamond — Helmut Fedder[1], •Sina Burk[1], Mathias Pfender[1], Nabeel Aslam[1], Sebastian Zaiser[1], Philipp Neumann[1], Andrej Denisenko[1], Patrick Simon[2], José Garrido[2], Martin Stutzmann[2], Marcus Doherty[3], Neil Manson[3], Audrius Alkauskas[4], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Uni Stuttgart — [2]Walter Schottky Institut, TU München — [3]Australian National University, Canberra, Australia — [4]Center for Physical Sciences and Technology, Lithuania

Electron and nuclear spins associated with point defects in semiconductors are promising systems for solid state quantum technologies with applications in quantum information processing and quantum sensing. In a typical quantum register architecture, an electron spin is used as an ancilla for readout and control, whereas nuclear spins serve as register qubits [1-2]. Flip-flop processes of the electron spin limit the nuclear spin coherence time. This limitation can be overcome by controlling the defect's ionization state. Here we increase the coherence time of the ^{14}N nuclear spin associated with the Nitrogen-Vacancy center in diamond by controlling its charge state. We exploit planar double junction diodes fabricated by surface transfer doping with hydrogen [3] to rapidly switch the charge state from NV^- (S=1) to NV^+ (S=0). We verify the NV^+ state by nuclear magnetic resonance and demonstrate the enhancement of the ^{14}N coherence time. [1] Saeedi et al., Science 342, 830 (2013). [2] P.C. Maurer et al., Science 336, 1283 (2012). [3] M. Hauf et al., Nano Lett. 14, 2359 (2014)

TT 23.8 Tue 11:45 H15

Electrical Charge State Control of Single Defects in Silicon Carbide — •Matthias Widmann[1], Sang-Yun Lee[1], Matthias Niethammer[1], Ian Booker[2], Takeshi Ohshima[3], Nguyen Tien-Son[2], Adam Gali[4], Erik Janzén[2], and Jörg Wrachtrup[1] — [1]3.Phys. Institut, Stuttgart — [2]Dep. of Phys., Linköping — [3]Japan AEA, Takasaki — [4]Wigner Res.C f.Phys., Budapest

Atomic scale defects in solids attracted a lot of interest over the last decade, because their spins can be used to detect magnetic- and electric fields and temperature with high sensitivity. They are also promising candidates as qubits and used for quantum information processing. Mostly color centers in diamond, e.g. NV centers, and impurities in silicon are used in the past. A single NV spin can be read out optically at room temperature. Electrical readout is possible, but remains challenging. Spins in silicon can be driven and read out electrically very well, however require low temperatures. Spins in silicon carbide (SiC) can overcome these drawbacks. Their spins can be driven and detected both optically[1] and electrically at ambient conditions. SiC electrical properties are promising since integrated single spins in modern electronic devices will allow manipulation of spins in various manners. Here we extend our single defect studies[1] towards electrical manipulation of its charge state in order to get better insight about creation of isolated defects with desired spin quantum number. We will also present how the charge state control affects spin control, and discuss possible applications. 1. M. Widmann et al.,Nat. Mat. 14 (2015)

TT 23.9 Tue 12:00 H15

Spin Coherence Time of Si Vacancies in Silicon Carbide Exceeding One Millisecond — •D. Simin[1], H. Kraus[1,2], A. Sperlich[1], T. Ohshima[2], G. V. Astakhov[1], and V. Dyakonov[1,3] — [1]Experimental Physics VI, Julius Maximilian University of Wuerzburg, 97074 Wuerzburg — [2]Japan Atomic Energy Agency (JAEA), 370-1292 Takasaki, Japan — [3]ZAE Bayern, 97074 Wuerzburg

Quantum information processing has been the hot topic in the field of information theory for several decades. While great progress was achieved, both on the theoretical and experimental field, to recognize and to employ the most suitable material and information carrier from the vast amount of possibilities is still the main goal of ongoing research activities all over the world. Whereas a wide availability and easy handling are crucial for a functioning device, long-preserving spin coherence is also essential for such a system. Therefore, we investigate the coherence time properties of the Si-vacancies in a 4H-SiC wafer using the pulsed-ODMR technique. Implementing the common Rabi-, Ramsey-, Spin-Echo- and CPMG-sequences, we can precisely measure spin-lattice (T_1) and spin-spin (T_2) relaxation times. The measurements are not only conducted at ambient conditions, but also at different temperatures and in different magnetic fields. In particular, the coherent spin properties of the V_{Si} defect are investigated in the temperature range from 10K to 300K and at magnetic field strengths of up to 30mT. Using dynamic decoupling protocols we achieve spin coherence time exceeding 1ms, demonstrating the high potential of SiC for various quantum applications.

TT 23.10 Tue 12:15 H15

Controlled Implantation of Silicon Vacancy Layers for Quantum Applications in Bulk Silicon Carbide — •H. Kraus[1,2], C. Kasper[2], S.-I. Sato[1], M. Haruyama[1], S. Onoda[1], T. Makino[1], T. Ohshima[1], G. Astakhov[2], and V. Dyakonov[2,3] — [1]Japan Atomic Energy Agency, Takasaki, Gunma, Japan — [2]Exp. Physics VI, Julius Maximilian University of Würzburg — [3]ZAE Bayern, Würzburg

Quantum centers in silicon carbide (SiC) have already transcended their former reputation as mere performance-hampering defects. Their long spin lifetime, unique spin-preserving optical pumping mechanism[1], and the possibility of downscaling to single-photon source level[2,3] makes them viable candidates for a plethora of quantum applications in sensing, rf devices, and quantum computing.

One quantum center species, the silicon vacancy (V_{Si}), can be reliably and homogeneously produced in the bulk by electron or neutron[3] irradiation. In contrast, a method to implant defects at a specific depth would be very interesting, especially when aiming for spatially separated centers for single photon sources. We present a study on proton irradiation to create a layer of V_{Si} in an irradiation-energy-tunable depth in bulk SiC. We discuss the spectroscopic response of this layer, and compare the V_{Si} depth profile—measured by confocal microscopy—with the H^+ stopping power of silicon carbide. Finally, we extend this study on the effects of high energy heavy ion damage.

[1] H. Kraus et al., Nature Phys. **10**, 157 (2014)
[2] M. Widmann et al., Nature Mater. **14**, 164 (2015)
[3] F. Fuchs et al., Nature Commun. **6**, 7578 (2015)