HL 31: Quantum information systems (joint session HL/TT)

Time: Wednesday 15:00–17:30 Location: EW 203

HL 31.1 Wed 15:00 EW 203

Input-output theory for spin-photon coupling in Si double quantum dots — •Mónica Benito[1], Xiao Mi[2], Jacob M. Taylor[3], Jason R. Petta[2], and Guido Burkard[1] — [1]University of Konstanz — [2]Princeton University — [3]Joint Quantum Institute/NIST

The interaction of qubits via microwave frequency photons enables long-distance qubit-qubit coupling and facilitates the realization of a large-scale quantum processor. However, qubits based on electron spins in semiconductor quantum dots have proven challenging to couple to microwave photons. In this theoretical work [1] we show that a sizable coupling for a single electron spin is possible via spin-charge hybridization using a magnetic field gradient in a silicon double quantum dot. Based on parameters already shown in recent experiments, we predict optimal working points to achieve a coherent spin-photon coupling. Our predictions are in good agreement with recent measurements [2] which demonstrate strong coupling with spin-photon coupling rates of more than 10 MHz. These results open a direct path towards entangling single spins using microwave frequency photons. Furthermore, we employ input-output theory to identify observable signatures of spin-photon coupling in the cavity output field, which can provide guidance to the experimental search for strong coupling in such spin-photon systems and opens the way to cavity-based readout of the spin qubit.

[1] M. Benito, X. Mi, J. M. Taylor, J. R. Petta, and G. Burkard. arXiv:1710.02508.

[2] X. Mi, M. Benito, S. Putz, D. M. Zajac, J. M. Taylor, G. Burkard, and J. R. Petta. arXiv:1710.03265.

HL 31.2 Wed 15:15 EW 203

Synchronized high-fidelity quantum gates in Si/SiGe double quantum dots — •Maximilian Russ[1], D. M. Zajac[2], A. J. Sigillito[2], F. Borjans[2], J. M. Taylor[3], J. R. Petta[2], and Guido Burkard[1] — [1]Department of Physics, University of Konstanz, D-78457 Konstanz, Germany — [2]Department of Physics, Princeton University, Princeton, NJ 08544, USA — [3]JQI and QuICS, NIST and University of Maryland, College Park, MD 20742, USA

Motivated by recent experiments [1], we theoretically describe a high-fidelity controlled-NOT (CNOT) gate using the exchange interaction between the spins in neighboring quantum dots subject to a magnetic field gradient from a micromagnet. We use a combination of analytical calculations and numerical simulations to provide the optimal pulse sequences and parameter settings for the gate operation [2]. We present a synchronization method which avoids detrimental spin flips when the state of the control qubit is $|0\rangle$, and provide details about phase mismatches accumulated during the two-qubit gate. By synchronizing the resonant and off-resonant transitions and compensating these phase mismatches by phase control the overall gate fidelity can be increased significantly. Numerical simulations demonstrate a high tolerance towards charge noise coupled to the two spins due to a partial intrinsic refocussing mechanism.

[1] D. M. Zajac, A. J. Sigillito, M. Russ, F. Borjans, J. M. Taylor, G. Burkard, and J. R. Petta, arXiv:1708.03530 (2017)

[2] M. Russ, D. M. Zajac, A. J. Sigillito, F. Borjans, J. M. Taylor, J. R. Petta, and G. Burkard, arXiv:1711.00754 (2017)

HL 31.3 Wed 15:30 EW 203

Engineering of Coherent Defects in Silicon Carbide with Varying Irradiation Methods — •Christian Kasper[1], Victor Soltamov[1], Dmitrij Simin[1], Takeshi Ohshima[2], Vladimir Dyakonov[1,3], and Georgy Astakhov[1] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, 97074 Würzburg — [2]National Institutes for Quantum and Radiological Science and Technology, Takasaki, Japan — [3]Bavarian Center for Applied Energy Research (ZAE Bayern), 97074 Würzburg

Out of the many possible material systems, quantum centers in silicon carbide (SiC) have proven themselves to be promising candidates for qubits [1]. Whereas a wide availability and easy handling are crucial for a functioning device, long-preserving spin coherence is also essential for such systems [2]. By using the pulsed-ODMR technique we compare the coherence properties of silicon vacancies created with two common methods: Neutron and electron irradiation. Particularly, the spin-lattice relaxation time (T1) and spin coherence time (T2) are measured in a broad range of the silicon vacancy density for each of the two irradiation methods. Additionally, Ramsey-fringes were measured while selecting a coherent spin package by applying a second microwave frequency.

[1] D. Riedel et al., Phys. Rev. Lett. 109, 226402 (2012)

[2] Simin et al., Phys. Rev. B 95, 161201(R) (2017)

HL 31.4 Wed 15:45 EW 203

Simulating high-fidelity two-qubit gates with singlet-triplet qubits generated by capacitive coupling and interqubit exchange interaction — •Michael Wolfe[1], Pascal Cerfontaine[1], Fernando Calderon-Vargas[2], Jason Kestner[3], and Hendrik Bluhm[1] — [1]JARA-Institute for Quantum Information, RWTH Aachen University, D-52074 Aachen, Germany — [2]Department of Physics, Virginia Tech, Blacksburg, VA 24061, USA — [3]Department of Physics, University of Maryland Baltimore County, Baltimore, MD 21250, USA

Two-qubit gates in singlet-triplet qubits can be generated via capacitive coupling or interqubit exchange interaction. Both methods suffer considerably from charge noise and nearly all approaches to mitigate this effect rely on the fact that the noise is slow compared to the gate time. We show that in the strictly capacitive case where gate times are much slower, maximally entangling gates with fidelities above 99% are achievable by operating the qubit in a sweet spot regime that is predicted by a Hund-Mulliken model [1]. In addition, we find comparable fidelities when both interqubit exchange and capacitive interactions are simultaneously used to generate entanglement. We compare these theoretical results with gates that are found using an optimization technique that numerically searches for high-fidelity two-qubit gates using a full-noise and control error model [2]. [1] Wolfe et al., arXiv:1709.09165 (2017) [2] Cerfontaine et al., PRL 113, 150501 (2014)

HL 31.5 Wed 16:00 EW 203

Microwave saturation spectroscopy of silicon vacancies in SiC — •Victor Soltamov[1], Christian Kasper[1], Georgy V. Astakhov[1], Sergej A. Tarasenko[2], Alexander V. Poshakinskiy[2], Andrey N. Anisimov[2], Pavel G. Baranov[2], and Vladimir Dyakonov[1,3] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, 97074 Würzburg — [2]Ioffe Institute, 194021 St.Petersburg, Russia — [3]Bavarian Center for Applied Energy Research (ZAE Bayern), 97074 Würzburg

Negatively charged silicon vacancy (V_{Si}) center in Silicon Carbide (SiC) has been attracting growing attention due to their use in quantum sensing with optical pumping [1]. The core of the sensing methods is to precise measurement of the optically detected magnetic resonance (ODMR) signal frequency shift, induced by the external fields. A sensitivity of the measurement improves when the V_{Si} ground-state microwave transitions are narrow. That is why, understanding of the mechanisms responsible for inhomogeneous broadening of the ODMR line is of great importance. To establish the mechanisms we provided the study of the V_{Si} ODMR linewidth by means of microwave saturation spectroscopy. We revealed the presence of two types of broadening namely induced by randomly distributed strain fields and by randomly distributed local magnetic fields. The results allowed deeper understanding of the V_{Si} ground spin state properties and to propose new measurement protocols for quantum sensing with the V_{Si} centers.

[1] H. Kraus et al., Sci. Rep. 4, 5303 (2014).

15 min. break.

HL 31.6 Wed 16:30 EW 203

Fabrication and Characterization of a Quantum Bus Prototype in Si/SiGe — •Inga Seidler[1], Arne Hollmann[1], Veit Langrock[1], Stefan Trellenkamp[2], Christian Neumann[3], Dominique Bougeard[3], Hendrik Bluhm[1], and Lars R. Schreiber[1] — [1]JARA-FIT Institute for Quantum Information, RWTH Aachen University, Germany — [2]Helmholtz Nano Facility, Forschungszentrum Jülich GmbH, Germany — [3]Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Germany

Silicon based spin qubits in electrostatically defined quantum dots are well established and 1-qubit and 2-qubit gates are shown with high fidelities [1,2]. The missing link for building a large scale quantum computer is a long range coherent coupling mechanism. A candidate for a coupling mechanism is a 10 micron long quantum bus (QuBus), which transfers a single electron spin qubit along a 1D channel. We will present the concept of a QuBus that consists of a dense metal gate array required to appropriately shape the electrostatic potential within the channel. We optimized the fabrication yield of the three-layer metal gate pattern of the 320 nm long Si QuBus prototype. In addition, 10 mK transport measurements of a single electron transistor which operates as the charge sensor at the ends of a QuBus are shown.

[1] J. Yoneda ea., arXiv:1708.01454 [2] D. M. Zajac ea., arXiv:1708.03530

HL 31.7 Wed 16:45 EW 203

Towards atomic vapor based memories for quantum dot single photons - A variable EIT delay in Cesium — •Tim Kroh[1], Esteban Gomez Lopez[1], Janik Wolters[2], Alexander Thoma[3], Stephan Reitzenstein[3], Joahnnes S. Wildmann[4], Rinaldo Trotta[4], Eugenio Zallo[5], Armando Rastelli[4], Oliver G. Schmidt[6], and Oliver Benson[1] — [1]Humboldt-Universität zu Berlin — [2]Universität Basel — [3]Technische Universität Berlin — [4]Johannes Kepler Universität Linz — [5]Paul-Drude-Institut für Festkörperelektronik, Berlin — [6]IFW Dresden

Quantum memories will play a central part in synchronizing operational events in quantum networks, e.g. joint measurements between photons from different sources in order to implement entanglement swapping in quantum repeater protocols [1].

Here, we interface quantum light sources with an electromagnetically induced transparency (EIT) system, in principle suitable for quantum memory. First, we demonstrate precise strain-tuning of InGaAs quantum dot emission between the two 1.2 GHz hyperfine-split levels in the Cesium D1 transitions. Proceeding from this we explore the potential of EIT for variable delays for single photons [2]. In addition to application in synchronization of heralded single photon sources, these experiments lay the ground for atomic vapor-based quantum memories in hybrid quantum networks [3].

[1] Kimble, Nature 453, 1023 (2008)
[2] D. Höckel et al., Phys. Rev. Lett. 105, 153605 (2010)
[3] J. Wolters et al., Phys. Rev. Lett. 119, 060502 (2017)

HL 31.8 Wed 17:00 EW 203

Theory of long-range coherent electron shuttling devices in Silicon/Silicon-Germanium quantum wells — •Veit Langrock, Arne Hollmann, Inga Seidler, Lars R. Schreiber, and David P. DiVincenzo — JARA-FIT Institute for Quantum Information, RWTH Aachen University, Germany

Silicon quantum computing is at a stage where single qubits confined in electrostatically formed quantum dots with very long coherence times can be manufactured. To make the transition to large scale quantum computing, long range on chip coupling (over micrometer distances) is a building block that is currently still missing. A concept currently pursued experimentally is the coherent shuttling of electrons via moving electrostatic quantum dot configurations, with information encoded in the electron's spin state. In this talk, we present theoretical considerations and simulations regarding moving electrostatically formed quantum dots through a Silicon/Silicon-Germanium (Si/SiGe) quantum well. Emphasis will be put on the effects that interface disorder in the form of miscut steps along the Si/SiGe quantum well interfaces will have on the moving electron's spin environment, with the valley dependence in silicon playing a crucial role.

HL 31.9 Wed 17:15 EW 203

Spin-orbit interaction isotropy for holes in rectangular Si nanowires — •Marko J. Rancic, Christoph Kloeffel, and Daniel Loss — Department of physics, University of Basel

In this study we develop a model describing holes in rectangular nanowires in silicon (Si). In similarity with cylindrical nanowires, an electric field of intermediate strength can induce a sizable direct Rashba spin-orbit interaction (DRSOI). Our findings suggest that the magnitude of DRSOI is isotropic in case of germanium (Ge) due to the high degree of symmetry which Ge has. In contrast to that DRSOI is highly anisotropic in Si, dependant on the growth direction of the Si nanowire with respect to the main crystallographic axes. Still the DRSOI in si can be made significant ($\sim$ 0.5 meV) when the growth direction of the nanowire is chosen optimally, different to recent experimental studies.