HL 10: Quantum information systems

Time: Monday 15:00–17:15 Location: H36

HL 10.1 Mon 15:00 H36

Stimulated Microwave Emission from Opticaly Pumped Vacancy Defects in 4H Silicon Carbide for Maser Applications — •Andreas Gottscholl[1], Andreas Sperlich[1], Georgy V. Astakhov[2], Moritz Fischer[1], and Vladimir Dyakonov[1] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, 97074 Würzburg — [2]Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden

Masers are already well known for decades, nevertheless their application as telecomunications amplifier is highly limited due to their operating conditions requiring vacuum techniques and cryogenic temperatures. Just recently a new generation of room-temperature masers was invented based on spin-properties of pentacene and diamond, respectively. In this study, we pave the way for a silicon carbide based maser to overcome the maser-threshold and which may potentially offer some advantages over the other approaches. In order to get a population inversion, we use opticaly pumped silicon vacancies and by applying an external magnetic field we tune the microwave transition into the range of 10 GHz [1]. Using magnetic resonance techniques, we characterize the system including population inversion, pumping efficiency and ultimately stimulated microwave emission [2]. In combination with a high-Q resonator ($Q_L \approx 50000$) our material is well on its way to become a suitable maser system with a wide-ranging applicability.

[1] Kraus et al., Nat. Phys. **10**, 152 (2014)
[2] Fischer et al., Phys. Rev. Applied. **9**, 054006 (2018)

HL 10.2 Mon 15:15 H36

Optimization of the Dispersive Readout of a Spin Qubit — •Benjamin D'Anjou and Guido Burkard — Universitätstr. 10, D-78464 Konstanz, Deutschland

Recently, strong coherent coupling of semiconductor spin qubits with a superconducting microwave resonator was demonstrated in several settings [1-3]. These breakthroughs pave the way for quantum information processing platforms that combine the long coherence times characteristic of solid-state spin qubits with the long-distance connectivity, fast control, and fast high-fidelity non-demolition readout that have so far been the hallmark of superconducting qubit implementations. Here, we analyze the dispersive readout of a single spin in a double quantum dot coupled to a microwave cavity via its dipole moment. The strong spin-photon coupling arises from the admixture of electronic charge and spin induced by a strong local magnetic field gradient. We estimate the expected signal-to-noise ratio of the readout accounting for both Purcell spin relaxation and spin relaxation arising from sources of electric noise. In particular, we analyze the tradeoff between maximizing the spin-photon coupling strength and minimizing spin relaxation. We give expressions for the values of the experimentally tunable parameters that maximize the signal-to-noise ratio.

[1] Mi et al., Nature 555, p. 599 (2018)
[2] Landig et al., Nature 560, p. 179 (2018)
[3] Samkharadze et al., Science 359, p. 1123 (2018)

HL 10.3 Mon 15:30 H36

Entangling distant single electron spin qubits via circuit quantum electrodynamics — •Mónica Benito and Guido Burkard — Department of Physics, University of Konstanz, Konstanz, Germany

The recent realization of a coherent interface between electron spin qubits fabricated in quantum dots and superconducting transmission line resonators [1,2,3] opens the way for implementing resonator-mediated two-qubit entangling gates. In order to couple a spin to the resonator electric field, some type of spin-charge hybridization is needed, which deteriorates the coherence properties of the spin qubit. In this work we focus on single electron spin qubits placed in double quantum dots and hybridized to the charge degree of freedom via an externally applied magnetic field gradient [4]. We calculate entangling gate fidelities both in the dispersive and resonant regime accounting for errors due to the spin-charge hybridization.

[1] X. Mi et al., Nature 555, 599 (2018).
[2] N. Samkharadze et al., Science 359, 1123 (2018).
[3] A. J. Landig et al., Nature 560, 179 (2018).
[4] M. Benito et al., Phys. Rev. B 96, 235434 (2017).

HL 10.4 Mon 15:45 H36

Polytypism induced sign reversal in zero-field splitting of silicon vacancies in 6H-SiC — •Victor Soltamov[1], Vladimir Dyakonov[1], Timur Biktagirov[2], Wolf Gero Schmidt[2], Uwe Gerstmann[2], Boris Yavkin[3], Sergei Orlinskii[4], and Pavel Baranov[5] — [1]Experimental Physics VI, Julius-Maximilian University of Würzburg, 97074 Würzburg, Germany — [2]Lehrstuhl für Theoretische Materialphysik, Universität Paderborn, 33098 Paderborn, Germany — [3]3rd Institute of Physics, University of Stuttgart, 70569 Stuttgart, Germany — [4]Kazan Federal University, 420008 Kazan, Russia — [5]Ioffe Institute, 194021 St. Petersburg, Russia

Negatively charged S = 3/2 silicon vacancy centers in Silicon Carbide (SiC) are one of the candidates featuring unique functionality for quantum sensing [1, 2], as well as for quantum communication [3]. The polytypism of SiC, i.e., the ability to form many different crystal structures, appears as an additional lever to reach the ideal combination of magnetic and optical characteristics. Here the properties of the zero-field splitting (ZFS) of these centers in 6H-SiC are uncovered by means of EPR and ENDOR techniques, combined with first-principles calculation. We show that the centers possess not only significantly different absolute values of ZFS, but also differ in their sign. This diversity is rationalized by a flattened/elongated character of their spin density distribution.

[1] D. Simin et al., Phys. Rev. B 95, 161201(R) (2017).
[2] S.-Y. Lee et al., Phys. Rev. B 92, 115201 (2015).
[3] S. E. Economou and P. Dev, Nanotechnology 27, 504001 (2016).

15 min. break

HL 10.5 Mon 16:15 H36

Cavity quantum electrodynamics with spin and valley — •Christoph Adelsberger, Monica Benito, and Guido Burkard — Department of Physics, University of Konstanz, D-78464 Konstanz, Germany

The energy level structure of a double quantum dot fabricated in Si/SiGe combines orbital, spin and valley degrees of freedom [1]. Although it has been demonstrated that in some cases the orbital and spin degrees of freedom can be isolated from the valley in order to engineer a strong interaction between the electronic spin and a photon in a coupled superconducting microwave resonator [2,3,4], it is desirable to understand the general role of the valley in this kind of cavity quantum electrodynamics setup. First, we analyze the possibility for a strong interaction between the valley degree of freedom and a microwave photon, which could benefit from protection against charge noise [5]. Then we incorporate the spin degree of freedom and investigate the possible hybrid qubits that provide a useful relation between coupling strength to the photons in the resonator and decoherence due to typical noise sources. We expect that these results contribute to the future performance of long-distance coupling between qubits in this potentially scalable semiconductor quantum dot systems.

[1] G. Burkard and J. R. Petta, PRB **94**, 195305 (2016).
[2] X. Mi et al., Nature **555**, 599 (2018).
[3] N. Samkharadze et al., Science **359**, 1123 (2018).
[4] M. Benito et al., PRB **96**, 235434 (2017).
[5] X. Mi, S. Kohler, and J. R. Petta, PRB **98**, 161404(R) (2018).

HL 10.6 Mon 16:30 H36

Ultrafast electric phase control of a quantum dot exciton — •Alex Widhalm[1], Amlan Mukherjee[1,2], Sebastian Krehs[1], Björn Jonas[1], Nandlal Sharma[1], Peter Kölling[1,2], Andreas Thiede[2], Jens Förstner[1,2], Dirk Reuter[1], and Artur Zrenner[1] — [1]Physics Department, University of Paderborn — [2]Department of Electrical Engineering, University of Paderborn, Paderborn 33098, Germany

In our experiment we created a superposition state of a quantum dot exciton, whose quantum phase is subsequently manipulated by ultrafast Stark tuning. The resulting phase shift is measured by Ramsey interference. Previously we have already shown, that the coherent phase of a QD exciton can be manipulated electrically by phase-locked RF signals [1]. Here we have designed ultrafast BiCMOS chips for the generation of electric pulses (rise times <20 ps @ cryogenic operationality) and RF-photodiodes with embedded high quality InGaAs QDs. Electric connections have been established by short distance wire bonding. This hybrid approach enables us to perform electric phase control synchroneous to double pulse ps laser excitation. We are able to demonstrate electrically controlled phase manipulations with magnitudes up to 3π and the electric control of the QD occupancy on time scales below the dephasing time of QD exciton [2].

Ref: [1] S. de Vasconcellos et al., Nature Photonics 4, 545 (2010).
Ref: [2] A. Widhalm et al., Applied Physics Letters 112(11):111105 (2018).

HL 10.7 Mon 16:45 H36

Optimal choice of state tomography quorum formed by projection operators — VIOLETA N. IVANOVA-ROHLING[1] and •NIKLAS ROHLING[2] — [1]Department of Mathematical Foundations of Computer Science, Institute of Mathematics and Informatics, Bulgarian Academy of Sciences, Akad.G.Bonchev, block 8, 1113 Sofia, Bulgaria — [2]Center for Quantum Spintronics, Department of Physics, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway

The density matrix of a n-dimensional quantum system, can be estimated by repeatedly performing projections on $n+1$ measurement operators. Ideally, the eigenbases of these operators form a set of mutually unbiased bases [1]. However, the situation is different if, due to restrictions in the experimental setup, only certain measurments are available. One example for this is the restriction to single-shot spin-to-charge conversion measurements for two spin qubits ($n = 4$) in a double quantum dot where measuring the charge state is equivalent to projections on individual quantum states. In order to perform state tomography under this restriction for n dimensions, $n^2 - 1$ different quantum states need to be selected. While it is possible to use states from a set of mutually unbiased bases [2], we present here numerically optimized sets of quantum states which perform significantly better regarding the expected precision of the tomography scheme [3].

[1] W. K. Wootters and B. D. Fields, Ann. Phys. **191**, 363 (1989)
[2] N. Rohling and G. Burkard, Phys. Rev. B **88**, 085402 (2013)
[3] V. N. Ivanova-Rohling and N. Rohling, arXiv:1810.09484

HL 10.8 Mon 17:00 H36

Spin exchange in quantum dot arrays — •FERDINAND KUEMMETH — Niels Bohr Institute, University of Copenhagen

Using an array of quantum dots in a GaAs heterostructure, defined and controlled by top gates, we explore the properties of a multielectron dot for inducing coherent spin exchange processes between neighboring and non-nearest-neighbor one-electron dots.

Our measurements indicate that a multielectron quantum dot with 50-100 electrons serves as an excellent mediator, preserving speed and coherence of the resulting spin-spin coupling while providing functionalities that may be of practical importance. These include speed (mediated two-qubit rates up to several gigahertz), distance (of order of a micrometer), voltage control, possibility of sweet spot operation (reducing susceptibility to charge noise), and reversal of the interaction sign [1] (useful for dynamical decoupling from noise). By detuning two one-electron dots with respect to the multielectron dot, we map out different configurations useful for long-distance spin exchange, including indirect, direct, and on-site exchange mediated by the multielectron dot [2].

Our results show a pathway to implementing fast, non-nearest neighbor two-qubit gates in semiconducting spin qubits. I will show our recent efforts into extending the mediated spin coupling into two dimensions.

[1] F. K. Malinowski, F. Martins, et al, Phys. Rev. X 8, 011045 (2018) [2] F. K. Malinowski, F. Martins, et al, arXiv:1808.09736