# HL 82: Quantum Information Systems

Time: Friday 9:30–11:15 Location: POT 81

HL 82.1 Fri 9:30 POT 81

**Resonant driving of silicon vacancies in 4H-SiC** — •Matthias Widmann[1], Roland Nagy[1], Matthias Niethammer[1], Ilja Gerhardt[1,2], Ivan G. Ivanov[3], Sophia Economou[4], Takeshi Oshima[5], Nguyen Tien-Son[3], Cristian Bonato[6], Sang-Yun Lee[7], Erik Janzén[3], and Jörg Wrachtrup[1,2] — [1]3rd Institute of Physics, IQST and Research Center SCOPE, Stuttgart — [2]Max-Planck Institute, Stuttgart — [3]Department of Physics, Chemistry and Biology, Linkoeping University — [4]Department of Physics, Virginia Tech, Blacksburg — [5]National Institutes for Quantum and Radiological Science and Technology (QST), Takasaki — [6]Institute of Photonics and Quantum Science, Heriot-Watt University — [7]Center for Quantum Information, Korea Institute of Science and Technology (KIST), Seoul

Spins associated to atomic scale defects in solids are attractive as sensitive probes and are promising candidates for quantum information processing (QIP) [1]. Our research is based on spin defects in silicon carbide (SiC), a technologically-relevant wide-bandgap semiconductor which offers spin-active defects with long coherence times at room temperature [2]. In this work, we extend our previous single spin study [2] by investigating optical and spin properties of the silicon vacancy in 4H-SiC via resonant optical and spin driving and discuss their potential use for quantum computing and quantum communication [3].
[1] F. Jelezko et al, PRL 100, (2012).
[2] M. Widmann et al, Nat. Mater 14 (2015).
[3] Ö. Soykal et al, PRB 93 (2016).

HL 82.2 Fri 9:45 POT 81

**Cavity mediated entanglement generation between the electron spins of two NV$^-$ centers** — •Vladislav Shkolnikov[1], Guido Burkard[1], and David Awschalom[2] — [1]Department of Physics, University of Konstanz, D-78457 Konstanz, Germany — [2]Institute for Molecular Engineering, University of Chicago, Chicago, IL 60637, USA

While long spin coherence times and efficient single-qubit quantum control have been implemented successfully in negatively charged nitrogen-vacancy (NV) centers in diamond, the controlled coupling of remote NV spin qubits remains challenging. Here, we propose and analyze a controlled-phase (CPHASE) gate for the spins of two NV-centers embedded in a common optical cavity and driven by two off-resonant lasers. The excitation of the first NV, generated by the laser, can later be emited into the cavity and then reabsorbed by the second NV. The excited states in this process are only virtually occupied and it allows to generate entangling gate between the NV-centers, that is not limited by the excited state lifetime. We derive an analytical model for the case when spin-spin interaction in the excited state can be neglected and perform a numerical simulation taking it into account. We predict entangling gates with the operation time 500 ns, which is much smaller than spin coherence time in the NVs. In combination with previously demonstrated single-qubit gates, CPHASE allows for arbitrary quantum computations.

HL 82.3 Fri 10:00 POT 81

**High-resolution NMR spectroscopy on small spin ensembles using a hybrid spin sensor** — •Matthias Pfender[1], Nabeel Aslam[1], Philipp Neumann[1], Hitoshi Sumiya[4], Shinobu Onoda[5], Carlos A. Meriles[3], Junichi Isoya[2], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart — [2]Research Center for Knowledge Communities, University of Tsukuba — [3]Department of Physics, CUNYCity College of New York — [4]Sumitomo Electric Industries Ltd., Itami, Japan — [5]Takasaki Advanced Radiation Research Institute, Takasaki, Japan

In the last few years, the nitrogen-vacancy defect in diamond has emerged as an exceptional quantum sensor for magnetic and electric fields, capable of detecting proton spins outside the diamond. However, the performance of the NV electron spin alone limits the achievable resolution of an NV NMR spectroscopy experiment to about 200 Hz [2,3]. By using the NV's inherent nitrogen nuclear spin we form a robust hybrid quantum sensor, capable of performing NMR spectroscopy on nanometer sized samples. The hereby obtained spectra are not limited by the electron spin lifetimes, but rather by the sample spins. We perform NMR spectroscopy on spins inside and outside the diamond, reaching a frequency resolution of 10 Hz and 100 Hz, respectively, enough to extract structural information of the molecule.

[1] Staudacher, T. et al. Science 339, 561-563 (2013).

[2] Kong, X., Stark, A., Du, J., McGuinness, L. P. & Jelezko, F. Phys. Rev. Applied 4, 24004 (2015).

[3] Zaiser, S. et al. Nat Commun 7, 12279 (2016).

### Coffee Break

HL 82.4 Fri 10:30 POT 81

**Defect Engineering in Silicon Carbide** — •Christian Kasper[1], Hannes Kraus[1,2], Dimitrij Simin[1], Yoshinori Suda[3], Takeshi Ohshima[2], Wataru Kada[3], Shunsuke Kawabata[3], Tomoya Honda[2,4], Yasuto Hijikata[4], Georgy Astakhov[1], and Vladimir Dyakonov[1,5] — [1]Exp. Physics VI, Julius Maximilian University of Würzburg — [2]National Institutes for Radiological Science and Technology(QST, formerly Japan Atomic Energy Agency), Takasaki, Japan — [3]Gunma University, Kiryu, Japan — [4]Saitama University, Saitama, Japan — [5]ZAE Bayern, Würzburg

Because of their long spin lifetime[1] and their unique spin-preserving optical pumping mechanism[2], quantum centers in silicon carbide (SiC) are promising candidates for spin based quantum information processing. Well known methods to produce one of these quantum center species, the silicon vacancy, homogeneously in the bulk are electron or neutron[3] irradiation. In contrast, a method to implant silicon vacancies at a specific position would be a huge improvement in terms of defect engineering.

In this study, the generation of silicon vacancies in bulk SiC as a result of proton irradiation can be verified. By the use of confocal microscopy, we show that the implantation depth is tunable by varying the irradiation energy. Further, we verify that by proton beam writing silicon vacancies can be implanted at a specific position in a SiC crystal.

[1] Simin et al., arXiv:1602.05775v2 (2016)

[2] H. Kraus et al., Nature Phys. **10**, 157 (2014)

[3] F. Fuchs et al., Nature Commun. **6**, 7578 (2015)

HL 82.5 Fri 10:45 POT 81

**Three-spin qubits under the influence of tunneling noise** — •Maximilian Russ and Guido Burkard — Department of Physics, University of Konstanz, D-78457 Konstanz, Germany

We investigate the behavior of qubits consisting of three electron spins in double and triple quantum dots subject to external electric fields[1]. Our model includes two independent bias parameters, $\varepsilon$ and $\varepsilon_M$, and two independent tunnel couplings, $t_l$ and $t_r$, which all couple to external electromagnetic fields and can be controlled in experiments by gate voltages applied to the quantum dot structures. By varying the detuning parameters one can switch the qubit type by shifting the energies in the single quantum dots thus changing the electron occupancy in each dot resulting in different qubit encodings. We focus on random electromagnetic field fluctuations, i.e., "charge noise", at each gate resulting in dephasing of the qubit. We pay special attention to charge noise with respect to the tunnel couplings due to recent interest in symmetric gate operations where the tunnel barrier is controlled. We search for sweet spots and double sweet spots, working points which are least susceptible to noise and compare the results to detuning noise. As a result, we show the absence of non-trivial double sweet spots in the case for tunneling noise.
[1] M. Russ, F. Ginzel, and G. Burkard, Phys. Rev. B 94, 165411 (2016)

HL 82.6 Fri 11:00 POT 81

**3-axis magnetometer utilizing silicon vacancy defect spins in 4H silicon carbide** — •Matthias Niethammer[1], Matthias Widmann[1], Sang-Yun Lee[1,4], Pontus Stenberg[2], Olof Kordina[2], Takeshi Ohshima[3], Nguyen Tien-Son[2], Erik Janzén[2], and Jöerg Wrachtrup[1] — [1]3rd Institute of Physics, University of Stuttgart, IQST and Research Center SCoPE — [2]Department of Physics, Chemistry and Biology, Linköping University — [3]National Institutes for Quantum and Radiological Science and Technology, Takasaki — [4]Korea Institute of Science and Technology, Seoul

Due to their inherent nature spins are very sensitive to magnetic fields.

The Zeeman effect can thus be used to sense magnetic fields. Solid state systems as silicon carbide (SiC) can host defects with high spin states, which can be optically detected such as the silicon vacancy ($V_{Si}$) in 4H-SiC down to the single level at room temperature [1]. In our previous work we showed that the $C_{3V}$ symmetry of this system together with the spin state of $S=\frac{3}{2}$ allows extraction of the magnetic field strength and polar angle [2,3]. Here we demonstrate that an analytical solution in combination with pulsed spin manipulation techniques can be used to measure the complete magnetic field vector even in a large dynamic range [4]. Combined with electrical readout such approaches can lead to highly sensitive and integrated quantum vector magnetometers [5].

1. Widmann et al, Nat. Mater 14(2), 164-168 (2014) 2. Simin et al, Phys Rev Appl 4(1), 014009 (2015) 3. Lee et al, Phys Rev B 92(11), 115201 (2015) 4. Niethammer et al, Phys Rev Appl 6(3), 034001 (2016) 5. Cochrane et al, Sci. Rep. 6, 37077 (2016)