HL 95: Spintronics/Quantum information: Vacancies in diamond and SiC (HL, jointly with TT)

Time: Friday 9:30–12:45 Location: H14

HL 95.1 Fri 9:30 H14

Optical detection of coherent electron spin states of vacancy defects in silicon carbide — •Sang-Yun Lee[1], Helmut Fedder[1], Torsten Rendler[1], Matthias Widmann[1], Nguyen Tien Son[2], Erik Janzén[2], and Jörg Wrachtrup[1] — [1]University of Stuttgart, Stuttgart, Germany — [2]Department of Physic, Chemistry and Biology, Linköping University, Linköping, Sweden

The diamond has been known as a hosting material in which an existing single spin system can be addressed optically at room temperature. A recent study has revealed that the individually detectible spin state can also exist in silicon carbide (SiC) [1]. However, the recent experimental finding has been done only on a newly found unknown defect in SiC. Among the other well known defects in SiC, the silicon vacancy (V_{Si}) can be another candidate because its coherent spin state has been successfully observed at room temperature with long life time by electron spin resonance [2], though the single spin detection is yet in question. While the conventional spin resonance method is suffered by the limited sensitivity, the optically detected magnetic resonance has been successfully used for the single spin detection. Thus the first step to elucidate whether this defect can be used as a room temperature solid state spin qubit, is to test the optical detection of its spin state at room temperature. We hereby report the optically detected spin coherence of the V_{Si} spin ensemble at room temperature. Our efforts on single spin detection will be presented too.

[1] W. F. Koehl, *et al.*, Nature 479, 84 (2011)
[2] V. A. Soltamov, *et al.*, Physical Review Letters 108, 226402 (2012)

HL 95.2 Fri 9:45 H14

Resonant addressing and manipulation of silicon vacancy spin qubits in silicon carbide — •Daniel Riedel[1], Franziska Fuchs[1], Hannes Kraus[1], Andreas Sperlich[1], Vladimir Dyakonov[1,2], Alexandra Soltamova[3], Vladimir Ilyin[4], Pavel Baranov[3], and Georgy Astakhov[1] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, D-97074 Würzburg — [2]ZAE Bayern, D-97074 Würzburg — [3]Ioffe Physical-Technical Institute, St. Petersburg, RU-194021 Russia — [4]Saint Petersburg Electrotechnical University, St. Petersburg, RU-194021 Russia

Although several candidates have yielded feasible features for solid-state quantum information processing, there is a search for new systems with even higher potential [1].

We report that silicon vacancy (V_{Si}) defects in silicon carbide comprise the technological advantages of semiconductor quantum dots and the unique spin properties of nitrogen-vacancy defects in diamond.

Similar to atoms, the V_{Si} qubits can be controlled under the double radio-optical resonance conditions, allowing for selective addressing and manipulation [2]. Magnetic resonance techniques are used to clarify the V_{Si} spin multiplicity and reveal a long spin memory.

Our results pave the way for potential applications of the V_{Si} defect in quantum information processing and spintronics.

References:
[1] D. DiVincenzo, Nature Materials 9, 468 (2010).
[2] D. Riedel et al., Physical Review Letters 109, 226402 (2012).

HL 95.3 Fri 10:00 H14

Intrinsic defects in silicon carbide LEDs as a perspective single photon source — •Franziska Fuchs[1], Victor Soltamov[2], Stefan Väth[1], Pavel Baranov[2], Eugeny Mokhov[2], Georgy Astakhov[1], and Vladimir Dyakonov[1,3] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, 97074 Würzburg — [2]Ioffe Physical-Technical Institute, St. Petersburg, 194021 Russia — [3]ZAE Bayern, 97074 Würzburg

Single photon sources, reliably emitting on demand, are necessary for optical quantum computer architectures. Several systems seem suitable for this purpose, including atoms, molecules, quantum dots and colour centres in diamond. All these systems are difficult to implement, since they either only work at low temperatures, or do not emit at typical wavelengths used in existing telecommunication infrastructure. We suggest another system - silicon vacancy defects in silicon carbide, emitting photons in the near infrared [1]. We fabricated light emitting diodes based on intrinsic defects in silicon carbide. The room temperature electroluminescence reveals two strong emission bands in visible and NIR, the latter assigned to silicon vacancy defects. Our approach can be used to realize an electrically driven single photon source for quantum telecommunication.

[1]Riedel et al.: Resonant Addressing and Manipulation of Silicon Vacancy Qubits in Silicon Carbide, Phys. Rev. Lett.109,226402(2012)

HL 95.4 Fri 10:15 H14

A novel metastable spin triplet in diamond — •Matthias Widmann[1], Sang-Yun Lee[1], Helmut Fedder[1], Torsten Rendler[1], Moritz Eyer[1], Sen Yang[1], Petr Siyushev[1], Marcus Doherty[2], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, University Stuttgart, Germany — [2]Laser Physics Center, National University, Canberra, Australia

In this talk a newly found, photo stable single spin center in a HTHP diamond nano-pillar, will be introduced. This new defect poses many properties, similar to those of the well-known NV-center in diamond. However, optically detected magnetic resonance showed positive contrast at room temperature in contrast to NV-centers. The photo physics and spin physics of this new defect have been studied to understand the enhancement of photon emission (contrast up to 45 %) at three different electron spin resonance frequencies. It will be shown that the defect contains a singlet ground-, and excited state, and a metastable spin 1 triplet state which act as a shelving state. The strong enhancement of photon emission by ESR can be attributed to the huge difference in the deshelving rates of each triplet states. It will be also shown that the coherent spin manipulation of the metastable triplet state is possible at room temperature. Even though the electron spin coherence time is limited by the life time of the triplet state (up to 2.5 μs), these findings suggest that the electron spin in this spin system can be used to read-out the coupled nuclear spin state because the nuclear spin can be protected during the initialization and storage processes thanks to the spin-less electron ground state.

HL 95.5 Fri 10:30 H14

Nuclear spin control with a transient electron spin ancilla — •Helmut Fedder[1], Sang-Yun Lee[1], Matthias Widman[1], Torsten Rendler[1], Moritz Eyer[1], Sen Yang[1], Petr Siyushev[1], Marcus Doherty[2], Neil Manson[2], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut and Research Center SCoPE, University Stuttgart, Germany — [2]Laser Physics Center, Research School of Physics and Engineering, Australian National University, Canberra, Australia

Electron spins associated with point defects in crystals are promising systems for solid state quantum technology [1-3]. In particular, defects with a spin-less ground state and an excited triplet state have been proposed as universal ancillae for addressing nuclear spins [2]. In here we demonstrate the control of an individual ^{13}C lattice nuclear spin in diamond by exploiting a hitherto unknown electron spin defect that features an excited triplet state. Using optical and microwave control, we demonstrate coherent manipulation of the triplet electron spin and characterize its photo-physics. We then show coherent manipulation of the nuclear spin in the spin-less electronic ground state.

[1] J.J.L. Morton et al. Solid-state quantum memory using the 31P nuclear spin. Nature 455, 1085 (2008).
[2] V. Filidou et al. Ultrafast entangling gates between nuclear spins using photoexcited triplet states. Nature Phys. 8, 596 (2012).
[3] P.C. Maurer et al. Room-Temperature Quantum Bit Memory Exceeding One Second. Science 336, 1283 (2012).

HL 95.6 Fri 10:45 H14

Entanglement by measurement and Bell inequality violation with spins in diamond — •Wolfgang Pfaff[1], Tim H. Taminiau[1], Lucio Robledo[1], Hannes Bernien[1], Matthew Markham[2], Daniel J. Twitchen[2], and Ronald Hanson[1] — [1]Kavli Institute of Nanoscience Delft, Delft University of Technology, Netherlands — [2]Element Six, Ltd., Ascot, UK

Single spins in diamond have emerged as a promising platform for quantum information processing in the solid state. In particular, individual nuclear spins coupled to nitrogen-vacancy (NV) centers have been recognized as excellent candidates for solid state qubits, because they combine outstanding stability, excellent control by spin resonance techniques, and high-fidelity optical initialization and readout provided by the NV center.

Here we report the achievement of a milestone towards quantum computation with spins: The creation of high quality quantum entanglement between two nuclear spins in diamond. Entanglement is an important resource for quantum computation and lies at the heart of many key quantum protocols, such as teleportation and error correction. We show that we can produce entangled states of high fidelity using a projective quantum measurement. Our technique is nondestructive, and thus leaves the quantum information that is required for further computation unharmed. This enables us to demonstrate a violation of Bell's inequality for the first time with spins in the solid state.

Ref: Pfaff et al., Nature Phys., doi:10.1038/nphys2444 (2012).

Coffee break

HL 95.7 Fri 11:15 H14

Spin polarisation mechanism in nitrogen-vacancy and related colour centres of diamond — Lachlan Rogers[1], Neil Manson[2], and •Fedor Jelezko[1] — [1]Institut für Quantenoptik, Universität Ulm, Ulm, Deutschland — [2]Laser Physics Centre, Australian National University, Canberra, Australia

Optically induced spon polarisation of the negatively charged nitrogen vacancy centre in diamond (NV^-) has been known for a considerable time but there has not been a satisfactory account of how it arises. This lack of explanation is of concern because spin polarisation is the key unique property that allows the centre to function as a room temperature qubit. An optical emission band with ZPL at 1042 nm is understood to arise from a transition between spin-singlet levels which lie between the triplet ground and excited states. We report properties of the singlet levels obtained using spectroscopic techniques on the 1042 nm band. Importantly, we resolve the long-standing uncertainty over the order of these singlets. This improved understanding of the singlet system leads to a tentative description of the physical mechanism for spin polarisation in the NV^- centre.

This raises the tantalising possibility of engineering "designer" colour centres for specific applications. For instance, the neutral NV^0 centre is known to have a metastable level between its ground and excited states. Manipulating it to open the intersystem crossing from this level back to the ground state would likely give rise to optically induced spin polarisation, opening a second solid-state optically-controlled qubit in diamond.

HL 95.8 Fri 11:30 H14

Detecting and Polarizing Nuclear Spins in Diamond — •Jochen Scheuer[1], Paz London[2], Jianming Cai[3], Ilai Schwarz[3], Alex Retzker[4], Martin B. Plenio[3], Masayuki Katagiri[5,6], Tokuyuki Teraji[6], Satoshi Koizumi[6], Junichi Isoya[5], Ran Fischer[2], Liam McGuinness[1], Boris Naydenov[1], and Fedor Jelezko[1] — [1]Institut für Quantenoptik, Universität Ulm, Ulm, Germany — [2]Department of Physics, Technion, Israel Institute of Technology, Haifa, Israel — [3]Institut für Theoretische Physik, Universität Ulm, Ulm, Germany — [4]Racah Institute of Physics, The Hebrew University of Jerusalem, Jerusalem, Israel — [5]Graduate School of Library, Information and Media Studies, University of Tsukuba, 1-2 Kasuga, Tsukuba, Ibaraki, Japan — [6]National Institute for Materials Science, Tsukuba, Ibaraki, Japan

Control and measurement of nuclear spins is essential for medicine, chemistry and physics, but the sensitivity of conventional measurement schemes is limited due to low thermal polarization of nuclei under ambient conditions. We use an electron-nuclear double resonance technique, known as Hartmann-Hahn double resonance, to demonstrate experimentally polarization of single and multiple nuclear spins in a room temperature solid. By transferring polarization from an optically cooled electron spin associated with the nitrogen-vacancy (NV) defect, to carbon nuclei we are able to control spin bath dynamics. This work opens new possibilities for different fields of science, from control over decoherence and use of mesoscopic ensemble of nuclear spins as qubits to enhancement of contrast in magnetic resonance imaging.

HL 95.9 Fri 11:45 H14

Tailoring the Diamond: Microwave structures surrounding nano-fabricated solid immersion lenses registered to single emitters in diamond on demand — •Luca Marseglia[1], Florian Striebel[1], Andreas Häussler[1], Boris Naydenov[1], Jan Meijer[2], and Fedor Jelezko[1] — [1]Institut für Quantenoptik, Universität Ulm, Albert-Einstein-Allee 11, 89081 Ulm - Germany — [2]Ruhr-Universität Bochum, Universitätsstraße 150, 44801, Bochum, Germany.

The negatively charged Nitrogen Vacancy color center (NV) is a spin active defect with a long spin lifetime at room temperature. It is a three level system whose value of the ground state spin can be driven by applying a small microwave field making a NV centre a good candidate as qubit for quantum information purpose. To exploit the splitting of the ground state of the NV the control and the precision of a microwave field applied on a single NV is crucial. So we have successfully coupled the NV to a microwave structures, made of metal, lithographically deposited on the diamond, applying high intensity microwave field improving the addressing of the spin and the driving of the Rabi oscillation of the NV. Besides to directly improve the coupling efficiency from a planar surface we formerly developed a technique to fabricate solid immersion lenses (SILs), using Focus Ion Beam (FIB) system, who geometrically avoid any refraction at the diamond-air interface. Eventually we will create a microwave structure, placed precisely on the nanofabricated SIL coupled to the colour centre. These integrated structures will allow us to handle the spin of the NV centre with very high precision and microwave field intensity.

HL 95.10 Fri 12:00 H14

Coherent Control of a ^{13}C NV$^-$ center — •Burkhard Scharfenberger[1], William J. Munro[2], and Kae Nemoto[1] — [1]National Institute of Informatics, 2-1-2 Hitotsubashi, Chiyoda-ku, Tokyo 101-8430, Japan — [2]NTT Basic Research Laboratories, NTT Corporation, 3-1 Morinosato Wakamiya, Atsugi, Kanagawa 243-0198, Japan

We investigate the theoretically achievable fidelities for coherently controlling an effective three qubit system consisting of a negatively charged NV center in diamond coupling via an hyperfine interaction to one nearby ^{13}C nuclear spin using only micro- and radio wave pulses. With its long coherence times and comparatively simple optical accessibility, already the 'bare' NV^- center has an interesting potential in quantum computing related applications. Although a number of experiments have already been conducted using NV centers with one or more ^{13}C nearby, fidelities achieved are limited not only by experimental inaccuracies but a lack of theoretical understanding of the system dynamics. We seek to redress this by fully modelling the NVC systems behaviour in the ground state manifold, including all hyperfine interactions (between N and V as well as C and V) and dissipation where parameters are taken from previous experimental work as well as theoretical ab-initio studies. We show that for close-by carbons, the strong hyperfine interaction leads to unwanted mixing of levels which ultimately limits fidelities in single-qubit driving and entanglement generation to less than 99% in the experimentally interesting weak magnetic fields regime.

HL 95.11 Fri 12:15 H14

Resolving individual spin defects in diamond beyond the diffraction limit by exploiting their charge state dynamics — •Nabeel Aslam, Matthias Pfender, Gerald Waldherr, Philipp Neumann, and Jörg Wrachtrup — 3. Physikalisches Institut, Universität Stuttgart, Germany

The nitrogen-vacancy center in diamond is an electron and nuclear spin system that shows exceptionally good coherence properties at room temperature. This makes it a promising system for the implementation of quantum information processing. Furthermore the ability to sense magnetic and electric fields on the nanometer scale has been demonstrated for NV defects. Individual spin detection and initialization is performed optically by a confocal microscope which fails in resolving individual defects with a distance smaller than the diffraction limit. Here we demonstrate a novel microscopy method that is able to exploit the stochastically switching between different charge states achieving resolutions of 10 nm, well below the diffraction barrier. Compared with targeted switching based methods like STED this method applies at least five magnitudes lower laser power for a certain resolution. This is in fact a great improvement for the future use of nanodiamonds as biomarkers in cells with nanometer resolution. Even better resolutions can be achieved by combining this method with spin state manipulation.

HL 95.12 Fri 12:30 H14

Investigations on nitrogen-vancancy center creation and its physical properties — •Denis Antonov[1,2], Gabriel Bester[2], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Max-Planck-Institut für Festkörperforschung, Heisenbergstr. 1, 70569 Stuttgart, Germany

The negatively charged nitrogen-vacancy (NV^-) center embedded in extended and nanoscale diamond structures is a promising candidate for quantum information processing (QIP), magnetometry and even for biomarkers. A basic requirement for these applications is a precise prediction of the placement and a detailed understanding of the physical properties of the NV^- center. Using a range of simulation techniques we consider the formation of NV^- centers from the statistical standpoint, before performing accurate calculations for the optical properties of individual NV^- centers. In particular, we investigate the channeling effect during shallow implantations in molecular dynamics and Monte Carlo simulations. Furthermore, a combination of a spin-polarized atomic effective pseudopotential and a configuration interaction approache is used to obtain many body effects in the excitonic spectra.