Symposium Defect centers in diamond for applications in quantum optics and nanophotonics (SYDD)

veranstaltet vom
Fachverband Quantenoptik und Photonik (Q)

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Übersicht der Hauptvorträge und Fachsitzungen

(Hörsaal Audimax-B)

Hauptvorträge

SYDD 1.1	Fr	10:30–11:00	Audi-B	**Manipulation and nanopositioning of single NV centers** — •Ronald Hanson
SYDD 1.2	Fr	11:00–11:30	Audi-B	**Fabrication strategies for diamond based quantum devices** — •Steven Prawer
SYDD 1.3	Fr	11:30–12:00	Audi-B	**Controlling nonclassical emission of light in diamond** — •H. Weinfurter, J. Bahe, C.L. Wang, X.Q. Zhou, T. Kippenberg, A. Stiebeiner, A. Rauschenbeutel, J. Meijer
SYDD 2.1	Fr	14:00–14:30	Audi-B	**Experimental investigation of optically detected magnetic resonance of multiple and single NV spin in diamond** — Ngoc Diep Lai, Dingwei Zheng, Fedor Jelezko, •François Treussart, Jean-François Roch
SYDD 2.2	Fr	14:30–15:00	Audi-B	**Photonic crystal cavities - A basic element for scalable quantum electrodynamics with diamond N-V centers** — •Joseph Salzman, Igal Bayn
SYDD 2.3	Fr	15:00–15:30	Audi-B	**Engineered CVD diamond for spintronic applications** — •Daniel Twitchen, Matthew Markham

Fachsitzungen

SYDD 1.1–1.5	Fr	10:30–12:30	Audi-B	**Defect centers in diamond for applications in quantum optics and nanophotonics I**
SYDD 2.1–2.7	Fr	14:00–16:30	Audi-B	**Defect centers in diamond for applications in quantum optics and nanophotonics II**

SYDD 1: Defect centers in diamond for applications in quantum optics and nanophotonics I

Zeit: Freitag 10:30–12:30 Raum: Audi-B

Hauptvortrag SYDD 1.1 Fr 10:30 Audi-B

Manipulation and nanopositioning of single NV centers — •Ronald Hanson — Kavli Institute of Nanoscience, Delft University of Technology

Nitrogen-Vacancy (NV) defect centers in diamond are a promising system for spin-based applications in quantum information and communication. Here we present our recent results towards understanding and manipulating single NV spins, as well as controlling the position of individual NV centers with high precision. Although the NV center is studied intensively, there remain significant challenges in understanding its excited-state structure. We use single-spin resonant spectroscopy to observe the excited-state spin levels over a broad range of magnetic fields, yielding a direct measurement of the zero-field splitting, g-factor, transverse anisotropy splitting and hyperfine coupling in the orbital excited state [1]. Second, we study and manipulate the NV spin coherence time. By tuning the NV spin*s environment we find strikingly different behavior [2], leading to important insights into decoherence. Measurements as a function of temperature show that polarization of the spins in the environment fully eliminates their decohering effect [3]. Finally, we will present our first results towards controllably selecting, picking up, moving and positioning single NV centers with ∼10 nm precision.

[1] G. D. Fuchs et al., Phys. Rev. Lett. **101**, 117601 (2008)
[2] R. Hanson et al., Science **320**, 352 (2008)
[3] S. Takahashi et al., Phys. Rev. Lett. **101**, 047601 (2008)

Hauptvortrag SYDD 1.2 Fr 11:00 Audi-B

Fabrication strategies for diamond based quantum devices — •Steven Prawer — University of Melbourne, School of Physics, Parkville, Victoria, 3010, Australia

We aim to unlock the enormous potential of the weird quantum world for a new generation of information processing devices which address important and unsolved problems in secure communications, high performance computing, data storage, simulation and imaging. Surprisingly, single crystal diamond, long known for its allure as a gemstone, displays unique quantum properties and these make it ideal for the fabrication of critical components which will be the building blocks of this new quantum technology. Indeed diamond is an ideal material for use in the fabrication of (i) single photon sources for quantum communications, (ii) photonic platforms for the investigation of quantum entanglement in solid state systems (iii) optical regenerators and non-linear quantum gates and (iv) room temperature photonic based magnetometers.

But the same properties that make diamond so attractive for these applications also make it very hard to fabricate into devices. In this talk, I will describe the methods we have developed for fabricating diamond nanocrystals with desired properties and sculpting mirrors, waveguides and cavities directly into single crystal diamond by using a combination of implantation, focused ion beam milling and electrochemical etching.

The first devices based on these technologies are entering the market for applications in ultrasecure communications. But the future holds even more exciting prospects for diamond devices in quantum computing and nanoscale imaging of biological processes in real time.

Hauptvortrag SYDD 1.3 Fr 11:30 Audi-B

Controlling nonclassical emission of light in diamond — •H. Weinfurter[1], J. Bahe[1], C.L. Wang[1], X.Q. Zhou[2], T. Kippenberg[2], A. Stiebeiner[3], A. Rauschenbeutel[3], and J. Meijer[4] — [1]L.-M. Universität München, Sektion Physik, Schellingstr. 4/III, D-80799 München — [2]Max-Planck-Institut f. Quantenoptik, Hans-Kopfermann.Str. 1, D-85748 Garching — [3]Universität Mainz, Staudingerweg 7, D-55128 Mainz — [4]Ruhr-Universität Bochum, Universitätsstr. 150, D-44801 Bochum

The development of reliable devices to generate single photons is crucial for applications in quantum cryptography, as well as for fundamental quantum optics experiments. But the quality and yield of colour center based sources is intrinsically limited by broad bandwidth, shelving states, or the high index of refraction of diamond. Here we report on several attempts to improve the performance, like doping of diamond to control the charge state of single SiV centers, usage of solid immersion lenses, and coupling defects in nano crystals to the evanescent field of microdisk cavities or of tapered fibers.

SYDD 1.4 Fr 12:00 Audi-B

Towards optical interfaces for color centers in diamond — Roland Albrecht, Janine Riedrich-Moeller, Elke Neu, David Steinmetz, Christian Hepp, and •Christoph Becher — Fachrichtung 7.3 (Technische Physik), Universität des Saarlandes, Campus E 2.6, 66123 Saarbrücken

In recent years color centers in diamond have attracted significant interest for applications in quantum information. For many of these applications, e.g. quantum networks, it is essential to couple single color centers to a cavity mode with high quality-factor Q and small modal volume in order to coherently manipulate, readout and transfer the center's quantum state. We follow two different routes towards realization of such optical interfaces: coupling to microcavities based on fiber mirrors or microcavities defined within diamond-based photonic crystals (PhC). The fiber based Fabry-Perot cavities consist of a flat mirror onto which diamond nanocrystals are deposited by spin coating and a fiber mirror where a concave impression has been produced on the fiber facet by laser machining. We demonstrate cavities with lengths of a few microns and finesse of about 300, sufficient for observing modified spontaneous emission. In addition, we present optimized designs based on Fourier- and real space analysis of PhC defect cavity structures. By careful variation of the field envelope, vertically radiated power can be suppressed and the Q-factor can be improved significantly up to $Q \approx 320000$ at a modal volume of $V = 0.35(\lambda/n)^3$. We discuss routes for fabrication of diamond-based PhC cavities.

SYDD 1.5 Fr 12:15 Audi-B

Imaging magnetometry using single spins in diamond — •Gopalakrishnan Balasubramanian, Julia Tisler, Roman Kolesov, Fedor Jelezko, and Joerg Wrachtrup — 3. Physikalisches Institute, Universitaet Stuttgart, Germany

Single Nitrogen-Vacancy color centers in diamond are gaining popularity because of its exceptional optical and spin properties. The single spin of the defect can be manipulated optically, providing a efficient way to entangle single electron spins and couple nuclear spins qubits in diamond. Long spin coherence time of these single defects finds application as sensitive magnetic field probes. Using engineered diamond we can achieve ultrahigh sensitivity using which we will be able to detect a single external electron or nuclear spin.[1] Controlled creation of these color centers inside nanodiamonds offers diverse applications. By attaching these single spins to the tip of a scanning probe, we were able to perform sensitive scanning probe magnetometry at nanoscale.[2] Improving this device by using quantum grade diamond and synchronized NMR pulse sequences we would have the ability to perform nanoscale NMR/MRI of single molecules.

[1] Maze, J. R. et al. Nanoscale magnetic sensing with an individual electronic spin in diamond. Nature 455, 644-647(2008).

[2] Balasubramanian, G. et al. Nanoscale imaging magnetometry with diamond spins under ambient conditions. Nature 455, 648-651(2008).

SYDD 2: Defect centers in diamond for applications in quantum optics and nanophotonics II

Zeit: Freitag 14:00–16:30 Raum: Audi-B

Hauptvortrag SYDD 2.1 Fr 14:00 Audi-B

Experimental investigation of optically detected magnetic resonance of multiple and single NV spin in diamond — Ngoc Diep Lai[1], Dingwei Zheng[1], Fedor Jelezko[2], •François Treussart[1], and Jean-François Roch[1] — [1]Laboratoire de Photonique Quantique et Moléculaire, Ecole Normale Supérieure de Cachan and CNRS UMR 8537, 94235 Cachan cedex, France — [2]3. Physikalisches Institut, Universität Stuttgart, 70550 Stuttgart, Germany

We investigate electron spin resonance of single Nitrogen-Vacancy (NV) color center in a diamond nanocrystal (size ∼50 nm) and resonances of multiple NV centers laying in their four possible directions in a bulk diamond crystal. The magnetic resonance frequencies vary differently depending on the amplitude and the orientation of the applied magnetic field with respect to spins in each direction. While the orientations of NV spins in a bulk diamond is known from crystal axis, a single NV spin in a nanocrystal is randomly oriented, depending on deposition on the substrate. We report a double measurement method to accurately determine the orientation of an arbitrary single spin, by varying the amplitude and the orientation of an external magnetic field. In addition, we found that the lifetime of a single NV center or the average lifetime of multiple NV centers also varies with the external magnetic field. This lifetime variation can be explained by the mixing between $m_S = 0$ and $m_S = \pm 1$ electron spin states, as a function of the applied magnetic field. Lifetime-based detection appears to be an efficient method to increase the contrast of magnetic resonance. This result is of importance for applications such as spin-resonance-based magnetometry.

Hauptvortrag SYDD 2.2 Fr 14:30 Audi-B

Photonic crystal cavities - A basic element for scalable quantum electrodynamics with diamond N-V centers — •Joseph Salzman and Igal Bayn — Technion, The Israel Institute of Technology, Haifa, Israel 32000

Impurity atoms in diamond (such as the N-V center), exhibit unique spin properties that can be turned into efficient units of quantum information technology. 2D Photonic Crystal Structures in diamond are being considered as an attractive architecture for the control and manipulation of atom-photon coupling. This implementation requires the capability to couple the optical emission of the impurity atom to a cavity with a sharp spectral resonance. In addition, the Photonic crystal (PC) architecture provides integral scalability, a very important property for quantum information applications. In this talk we review recent progress in diamond PC nanocavities. We discuss the challenges in reaching high Q values in diamond and in low-ϵ materials in general. We present both semi-analytical and 3D Finite-Difference-Time-Domain (FDTD) computations, deriving the geometry of an ultra high-Q nanocavity with $Q \approx 1.3 \cdot 10^6$ with $V_m = 1.77 \cdot (\lambda/n)^3$. Then, we describe photonic crystal cavity fabrication in mono-crystalline diamond using high energy Ion Implantation, and Focused-Ion-Beam (FIB) milling.

Hauptvortrag SYDD 2.3 Fr 15:00 Audi-B

Engineered CVD diamond for spintronic applications — •Daniel Twitchen and Matthew Markham — Element Six Ltd, King's Ride Park, Ascot, Berkshire SL5 8BP, UK

There has been rapid progress in understanding of the NV centre in diamond in the last few years. This defect centre has many desirable properties as a solid state qubit. This paper will focus on the progress made in growing synthetic diamond using chemical vapour deposition (CVD) with a specific emphasis ono point defect and isotropic control.

SYDD 2.4 Fr 15:30 Audi-B

Deterministic ultracold ion source targeting the Heisenberg limit — •Kilian Singer, W. Schnitzler, R. Fickler, N.M. Linke, and F. Schmidt-Kaler — Universität Ulm, Institut für Quanteninformationsverarbeitung, Albert-Einstein-Allee 11, D-89069 Ulm

We have realized a universal deterministic single ion source on the basis of an ion trap applicable to a wide range of elements and molecules [1,2]. Initially, cold $^{40}Ca^+$ ion crystals are trapped within a segmented linear trap. Those ions are then deterministically extracted and detected with an efficiency of 90% at a distance of 29cm. For single ion extraction we measured a mean velocity of 19.47km/s with a 1σ-spread of only 6.3m/s and a beam divergence of 600μrad. We have also demonstrated the extraction of mixed ion crystals containing other dopant ions. Ion ray-tracing simulations predict that it is possible to focus down the ion beam to nm resolution with a simple Einzel-lens. This technique can e.g. be applied to generate color centers in diamond or to implant P into Si. Both systems provide a possible way for the realization of a solid state quantum computer [3,4]. In addition, the electrical properties of semiconductor devices can be greatly enhanced by the deterministic implantation of single ions [5].

[1] J. Meijer et al., Appl. Phys. A **83**, 321 (2006)
[2] J. Meijer et al., Appl. Phys. A **91**, 567 (2008)
[3] F. Jelezko et al., Phys. Rev. Lett. **93**, 130501 (2004)
[4] B. Kane, Nature **393**, 133 (1998)
[5] T. Shinada et al., Nature **437**, 1128 (2005)

SYDD 2.5 Fr 15:45 Audi-B

Plasmon-enhanced single photon emission from a nano-assembled metal-diamond hybrid structure at room-temperature — •Schietinger Stefan, Michael Barth, Tim Schröder, Thomas Aichele, and Oliver Benson — Nano-Optik, Institut für Physik, Humboldt-Universität zu Berlin, Hausvogteiplatz 5-7, 10117 Berlin, Germany

The controlled coupling of single quantum emitters to metal nanoantennas is one of the most promising, yet challenging tasks in current plasmonic research. It enables directional single photon emission with enhanced rate even for broad-band emitters. Here, we demonstrate the controlled coupling of a single NV-center in a nanodiamond to gold nanoparticles via manipulation with an AFM. While the excitation as well as the radiative emission rate are enhanced by an order of magnitude, the single photon character of the emission is preserved. Our approach provides a route towards novel hybrid systems as building blocks for complex nanophotonic and/or plasmonic devices stable even at room-temperature.

SYDD 2.6 Fr 16:00 Audi-B

ODMR of NV centres in nano-diamonds covered with N@C_{60} — •Rolf Simon Schoenfeld[1,2], Kati Huebener[1,2], Juliane Kniepert[1], Christoph Oelmueller[1], and Wolfgang Harneit[1,2] — [1]Institut für Experimentalphysik, Freie Universität Berlin, Arnimallee 14, D-14195 Berlin — [2]Abteilung SE2, Hahn-Meitner-Institut Berlin GmbH, Glienicker Str. 100, D-14109 Berlin

We report on experiments to detect electron spins in the molecular system N@C_{60} indirectly by coupling them to single electron spins in diamond. The spin of single nitrogen-vacancy centres in nano-diamonds can be routinely measured using optically detected magnetic resonance (ODMR) in a confocal microscopy setup. Line splittings compatible with expectations are sometimes seen in the ODMR spectra. Direct comparison of spectra on individual nano-diamonds before and after coverage with fullerenes however gave no clear evidence that the spin-spin coupling was due to N@C_{60}.

SYDD 2.7 Fr 16:15 Audi-B

Nickel doping of nitrogen enriched CVD-diamond for the production of single photon emitters — •M. Wolfer, A. Kriele, O. Williams, H. Obloh, C.-C. Leancu, L. Kirste, and C.E. Nebel — Fraunhofer Institute for Applied Solid State Physics, Tullastr. 72, D-79108 Freiburg

In contrast to well understood nitrogen-vacancy (NV) centers, incorporation and properties of nickel-nitrogen (NiNx)-centers in diamond are not understood. In this work we report about the controlled doping of diamond with nickel into diamond by different doping methods using plasma CVD growth. As substrates we use single-, poly- and nanocrystalline diamonds. These substrates are overgrown in a H2/CH4 plasma to a thickness of typically 20 to 300 nm, using nickel/nitrogen addition during growth. As Ni-doping sources we used i) gaseous nickelocene, ii) nickel-powder and iii) nickel wire. We apply optical emission spectroscopy (OES) during growth to investigate and control Ni addition. Applied solid state characterizations are SIMS, Raman scattering and photoluminescence spectroscopy. The exposure of Ni to the plasma gives strong emission intensities at 341 nm as detected by OES. Ni in diamond shows however only weak emissions in the regime 790 to

900 nm which is attributed to the non optimized Ni-N formation. To enhance the density of active NiNx centers, thermal annealing experiments have been applied up to 1400 °C to stimulate N diffusion. The deduced results will be compared with data in the literature to reveal mechanisms of Ni center formation in diamond.