HL 50: Materials and devices for quantum technology III

Time: Friday 9:30–13:00 Location: POT 251

HL 50.1 Fri 9:30 POT 251

3D magnetic resonance tomography of nitrogen vacancy centers with sub-10nm resolution — •Mohammad T Amawi[1,2], Andrii Trelin[1], You Huang[1], Georg Braunbeck[2], Francesco Poggiali[1], and Friedemann Reinhard[1] — [1]Institute for Physics, Quantum Technology, University of Rostock, Germany — [2]Physics Department, Technical University of Munich, Germany

We present a device for three-dimensional magnetic resonance tomography with nanoscale resolution, and apply it to image the spatial position of a nitrogen-vacancy center (NV) cluster in bulk diamond. Three orthogonal magnetic field gradients, generated from currents in microfabricated gold conductors, are used to create a position-specific Larmor frequency of the NV ground state spins. Measuring this frequency by pulsed optical-microwave spectroscopy, we determine the position of each NV center in 3D.

I will report on fabrication of the device, based on a liftoff process and maskless lithography, as well as the geometry required to create three orthogonal magnetic fields. The measurement protocol for 3D imaging will be discussed, as well as hardware and software means to reduce the shot-to-shot field variation, caused by electrical noise, down to 0.1%. This level of stability enabled us to demonstrate 3D imaging with around 5 nm spatial resolution. I will conclude with an outlook addressing how the resolution can be further improved by reducing the dimensions of the micro wires, and how it could be extended to image spins deposited on the diamond surface.

[1] Arai, K. et al. Nat. Nanotechnol. 10 (2015)

HL 50.2 Fri 9:45 POT 251

3D printing as an enabling tool for quantum technologies — •Pavel Ruchka[1], Ksenia Weber[1], Sina Hammer[2], Carlos Jimenez[3], Simon Thiele[3], Johannes Drozella[3], Tim Langen[2], Alois Herkommer[3], and Harald Giessen[1] — [1]4th Physics Institute, Research Center SCoPE and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]5th Physics Institute and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [3]Institute of Applied Optics (ITO) and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 9, 70569 Stuttgart, Germany

Nowadays, a lot of effort is given to making quantum technologies more usable for day-to-day life. This involves many aspects, such as developing quantum computers with a large number of qubits, creating quantum gates with high fidelity, and establishing a large-scale communication links with quantum repeaters. Miniaturizing such quantum devices remains nevertheless a highly relevant issue. For this, the 2-photon polymerization (2PP) based 3D printing comes in handy. In this talk, we present several miniature 3D printed optical and mechanical components, which enable the optical trapping of atoms and coupling quantum emitters and detectors to fibers or chips. These devices have an exceptionally compact footprint and a comparably high efficiency. With the ease of production of such components, 2PP can be scaled for the future requirements of highly compact and efficient quantum devices.

HL 50.3 Fri 10:00 POT 251

Spatially controlled fabrication of telecom single-photon emitters in Si by focused ion beam implantation — •Nico Klingner[1], Michael Hollenbach[1,2], Nagesh Jagtap[1], Lothar Bischoff[1], Ciaran Fowley[1], Ulrich Kentsch[1], Gregor Hlawacek[1], Artur Erbe[1], Nikolay Abrosimov[3], Manfred Helm[1], Yonder Berencen[1], and Georgy Astakhov[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, 01328 Dresden, Germany — [2]Technische Universität Dresden, 01062 Dresden, Germany — [3]Leibniz-Institut für Kristallzüchtung (IKZ), 12489 Berlin, Germany

Single photon emitters (SPE) are the starting point and foundation for future photonic quantum technologies. We present the laterally controlled fabrication of single G and W centers in silicon that emit in the telecom O-band. We utilized home built gold-silicon liquid metal alloy ion sources (LMAIS) in a focused ion beam (FIB) system to perform mask-free implantation of 40 keV Si ions from 6 to 500 ions per spot. Analysis and confirmation of SPEs has been done in a home-build cryo-photoluminescence setup. We will demonstrate a success rate of more than 50% and upscaling to wafer-scale. We will also provide an insight and overview on the LMAIS technology and an outlook on other potential applications of FIB implantation. arXiv:2204.13173

HL 50.4 Fri 10:15 POT 251

Plasma studies by optical emission spectroscopy for phosphorus doped diamond — •Felix Hoffmann[1], Nicola Lang[1], Philipp Reinke[2], Peter Knittel[1], and Volker Cimalla[1] — [1]Fraunhofer Institute for Applied Solid State Physics, Tullastraße 72, D-79108 Freiburg, Germany — [2]Quantum Brilliance GmbH, Industriestraße 4, D-70565 Stuttgart, Germany

While p-doping of diamond by Boron is a well-controlled process, n-doping by Phosphorus (P) remains challenging due to its low solubility and big covalent radius in comparison to carbon. The control of plasma conditions and the understanding of its influence on growth parameter is crucial for single crystal diamond growth by microwave plasma assisted chemical vapor deposition (MPCVD) [1]. Hydrogen-methane plasmas with dopant-carrier gases have been analyzed with respect to kinetic gas temperature (of the C2 band) and radical concentration by optical emission spectroscopy (OES) under various experimental conditions such as excitation power, operating pressure and gas concentrations [2]. Here we present results of P-doped diamond growth using the carrier gas trimethylphosphine (TMP) and point out the influence of TMP on plasma properties and its relation to growth parameter of P-doped {111} diamond grown by MPCVD.

[1] V. Mortet et al. Diamond and Related Materials, 2022, 124, 108928

[2] Mikhail Aleksandrovich Lobaev et al. Phys. Satus Solidi A, 2019, 216, 1900234

HL 50.5 Fri 10:30 POT 251

Modifying dipole selection rules in cuprous oxide Rydberg excitons — •Annika Neubauer and Harald Giessen — 4th Physics Institute, University of Stuttgart

Excitons in cuprous oxide have large binding energies, which implies that different principal quantum number state excitons can be created as they are energetically not spaced too closely to each other nor to the ionization continuum. High principal quantum number Rydberg excitons in cuprous oxide are macroscopic quantum systems with spatial extensions in the several hundreds of nm up to several μm range. This implies, that excitation with a focused light beam leads to a large overlap of light and matter wavefunctions and should lead to an enhanced optical transition.

We are going to show that the dipole selection rules in cuprous oxide Rydberg excitons can be manipulated via excitation with orbital angular momentum light or via the quadrupole field of plasmonic antennas. Both such light fields posses a strong field gradient or an additional angular momentum. This way, different angular momentum quantum number state excitons can be switched on and off, which is attractive for quantum state engineering. The mesoscopic size of cuprous oxide Rydberg excitons also implies that already μm-sized structures lead to mesoscopic quantum size effects. This can be advantageous for the realization of quantum technologies, such as optical switching applications, based on cuprous oxide Rydberg excitons.

HL 50.6 Fri 10:45 POT 251

Strong coupling of a single quantum dot to a tunable plasmonic nanogap antenna at room temperature using a novel scanning probe technique — •Michael A. Becker[1], Hsuan-Wei Liu[1,2], Burak Gurlek[1,2], Korenobu Matsuzaki[1], Randhir Kumar[1], Stephan Götzinger[2,1], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany — [2]Friedrich Alexander University of Erlangen-Nürnberg, Schloßplatz 4, 91054 Erlangen, Germany

In the strong coupling regime of cavity quantum electrodynamics, the spectrum of an isolated quantum system hybridizes with a mode of a resonator. At room temperature, coupling to the environment leads to a fast dephasing of the transition dipole, and strong near-field enhancements in plasmonic nanoantenna geometries need to be exploited to reach the strong light-matter coupling regime. For an efficient coupling, the antennas need to be placed within a few nanometer with respect to the individual emitters. Here, we exploit our novel and simple press-roll scanning probe technique (PROscan) capable of performing high-precision optical near-field measurements with remarkable stability. We demonstrate an open nanogap antenna that can be tuned in resonance with the exciton transition of a single quantum dot. With this approach, we drive the system from the weak to the strong light-matter coupling regime, evidenced by a vacuum Rabi splitting. Our results elucidate the complex interplay between the nanoantenna's mode volume and the physics of its eigenmode.

30 min. break

HL 50.7 Fri 11:30 POT 251

Optimal quantum control of Si/SiGe spin qubits in a Quantum bus architecture — •Akshay Menon Pazhedath[1], Alessandro David[1], Lars R. Schreiber[2], Hendrik Bluhm[2], Tommaso Calarco[1], and Felix Motzoi[1] — [1]Peter Grünberg Institute-Quantum Control (PGI-8), Forschungszentrum Jülich GmbH, D-52425 Jülich, Germany — [2]JARA-FIT Institute for Quantum Information, Forschungszentrum Jülich GmbH and RWTH Aachen University, Aachen, Germany

Quantum bus architecture based on electron spin-shuttling is a promising candidate for scalable quantum computing, as the number of control lines required to control the spin remains constant irrespective of the length of the device. A gated Si/SiGe quantum well with a carefully placed micro-magnet acts as an addressable qubit system in such an architecture. We investigate the feasibility of performing single qubit operations using optimal quantum control techniques. Spin decoherence due to interaction with the valley degree of freedom in the Si/SiGe heterostructure is identified as a potential decay mechanism and optimal pulses are engineered to maximize single qubit state transfer and unitary operation fidelities, so that the operations are compliant with the fault tolerant error threshold.

HL 50.8 Fri 11:45 POT 251

Generating spatially distributed entanglement as a resource for novel quantum computing paradigms on a platform of coupled microcavities — •Marc Bostelmann, Steffen Wilksen, Frederik Lohof, and Christopher Gies — Institute for Theoretical Physics and Bremen Center for Computational Material Science, University of Bremen, Bremen, Germany

Spatially distributed entanglement is important for the realization of novel quantum-photonic applications in quantum computing and quantum machine learning. We consider photonic arrays made from quantum emitters in optically coupled microcavities as hardware platform for entanglement generation. These offer a large degree of tunability with the possibility of site-selective optical excitation. We present a scalable numerical scheme for the determination of excitation parameters to generate different classes of multipartite entangled states, and a quantum bath engineering approach to create entanglement in the steady-state [arXiv:2211.13639].

HL 50.9 Fri 12:00 POT 251

Towards the Development of Cryogenic Integrated Power Management Units — •Alfonso Rafael Cabrera Galicia — Forschungszentrum Jülich GmbH Wilhelm-Johnen-Straße 52428 Jülich

Integrated Circuits (ICs) in cryogenic environments are expected to allow the development of scalable quantum computers consisting of thousands of physical quantum bits (qubits). However, since these ICs require undistorted power supply for optimal performance, the development of Power Management Units (PMUs) capable of cryogenic operation is also needed for the quantum computing systems scalability. To develop such PMUs, it is necessary to understand the cryogenic electrical behavior of its components. Therefore, this talk will present the measurement results obtained from an exploratory cryogenic DC characterization of some of the passive and active components belonging to a commercial 22nm FDSOI IC technology.

HL 50.10 Fri 12:15 POT 251

Physical Integration of Cryogenic Control Electronic Together with a Spin Qubit Sample at mK Temperatures — •Lea-Marie Schreckenberg[1], Patrick Vliex[1], René Otten[2], and Stefan van Waasen[1,3] — [1]Central Institute of Engineering, Electronics and Analytics, Electronic Systems, Forschungszentrum Jülich GmbH, Jülich, Germany — [2]JARA Institute for Quantum Information, Forschungszentrum Jülich GmbH and RWTH Aachen University, Aachen, Germany — [3]Faculty of Engineering, Communication Systems, University of Duisburg-Essen, Germany

A universal quantum computer requires the control and read out of millions of physical quantum bits (qubits). Due to wiring limitation in current state-of-the-art dilution refrigerators scaling up to millions of qubits with room-temperature electronics is challenging. Integrated Circuits (ICs) operating next to the qubits will help solving this scalability problem but require novel approaches for cryogenic circuits. This talk will focus on the physical design layer of the integration of a custom-designed 65nm CMOS low-power digital to analog converter (DAC) for qubit bias together with a spin qubit sample. In total, eight DAC channels are integrated at the mixing chamber stage of a dilution refrigerator and are operated at milli-kelvin temperatures. Additionally, engineering aspects regarding the sample space setup, cryostat wiring and the tight density are pointed out.

HL 50.11 Fri 12:30 POT 251

Design of power efficient digital low-dropout circuit for quantum computers — •Swasthik Baje Shankarakrishna Bhat[1], Alfonso Rafael Cabrera Galicia[1], Arun Ashok[1], Patrick Vliex[1], Andre Zambanini[1], Christian Grewing[1], and Stefan van Waasen[1,2] — [1]Forschungszentrum Jülich GmbH, Germany — [2]Universität Duisburg-Essen

Quantum computing is an approach to enable new computing paradigms with qubits as the computing elements that require individual tuning. A limitation in current setups is the number of controllable qubits. To scale the number of qubits, a close integration of control circuits close to the qubits in the cryogenic environment is required. However, to deal with these cryostats* minimal thermal power budget, ultra-low power dissipation is required, also for biasing circuits.

This contribution presents the design and simulation results of a power-efficient digital low-dropout regulator developed with a commercial 22nm FDSOI technology. It is expected that the circuit will enable on-chip biasing for future quantum computers based on Cryogenic Electronics operating at 4 K. Unlike its Analog counterpart integrated Digital LDO is not prone to process and mismatches delivering high efficiency at the same time The circuit concept and the system model investigation performed via Matlab-Simulink will be showed, as well as the expected circuit performance.

HL 50.12 Fri 12:45 POT 251

Design of Ultra-Low Power High Speed Communication Interface From Cryogenic to Room Temperature Electronics — •Ege Onat, Jonas Bühler, Christian Grewing, and Stefan van Waasen — Central Institute of Engineering, Electronics and Analytics, ZEA-2: Electronic Systems, Forschungszentrum Jülich GmbH

The objective of this research is to transfer high-speed data from deep cryogenic temperatures to room temperature while aiming for the lowest achievable power consumption in the cryostat. Quantum computers are operated inside dilution refrigerators under deep cryogenic temperatures and they need additional circuitry to ensure fault-free operations. Heating of the qubits caused by additional electronics degrades the system performance. Due to the limited power budget of the dilution refrigerators, each circuit should be designed considering power consumption. In contrast, the higher temperature stage can manage a higher power budget than the stage with the qubits. In this research, low-power data transmission methods for quantum computer applications are investigated and an asymmetric communication interface is designed and implemented. To achieve the asymmetric interface, only a varactor is placed into the cryogenic stage. To measure the capacitance on the room temperature stage, a capacitance readout circuitry is designed. It converts the capacitance into a measurable output such as voltage, frequency, or digital data. By implementing this interface, the data is carried on capacitance rather than voltages, which minimizes the power consumption at the transmitter compared to widely implemented communication interfaces.