HL 6: Materials and Devices for Quantum Technology I

Time: Monday 15:00–18:45 Location: H13

HL 6.1 Mon 15:00 H13

First-Principles Investigation of NV Centers in Silicon Carbide Polytypes — •Timur Biktagirov, Uwe Gerstmann, and Wolf Gero Schmidt — Universität Paderborn, Paderborn, Germany

Optically addressable spin defects in semiconductors offer versatile platforms for quantum applications, including computing, communication, and sensing. Among these, nitrogen-vacancy (NV) centers in silicon carbide (SiC) polytypes have emerged as a promising class of quantum defects, analogous to the NV center in diamond. In contrast to diamond, SiC is a technologically mature material with large-scale production capabilities, advanced doping techniques, and compatibility with CMOS fabrication methods. Additionally, the emission wavelengths of NV centers in SiC lie in the near-infrared range, making them particularly suitable for applications in single-photon emission. In this work, we discuss recent advancements in the ab initio investigation of NV centers in the 4H, 6H, and 3C polytypes of SiC. Simulating the magneto-optical properties of these spin centers, which are crucial for quantum applications, requires a detailed and accurate description of both the host material and the embedded defect. Accordingly, we demonstrate how supercell density functional theory (DFT) and recent implementations based on DFT can be employed to model key properties, including intra-defect optical transition energies, electron-electron and electron-nuclear spin interactions, and electron-phonon coupling. These theoretical insights provide a foundation for optimizing NV centers in SiC for next-generation quantum technologies.

HL 6.2 Mon 15:15 H13

tunable superconductivity in Ga-doped SixGe1-x via ion implantation and flash lamp annealing — •yu cheng[1,2], yi li[1,2], oliver steuer[1], mao wang[3], artur erbe[1,2], manfred helm[1,2], shengqiang zhou[1], and slawomir prucnal[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, Dresden, Germany — [2]TU Dresden, Dresden, Germany — [3]Laboratory of Micro-Nano Optics, College of Physics and Electronic Engineering, Sichuan Normal University, Chengdu, PR China

Group-IV superconducting semiconductors offer promising opportunities for scalable superconductor-semiconductor platforms in quantum computing. However, realizing a superconducting phase in semiconductors requires doping concentrations beyond the metal-insulator transition (MIT). Achieving such high doping levels in silicon (Si) and germanium (Ge) is challenging due to the limited solid solubility of acceptors in these materials. Various advanced techniques have been developed to overcome this problem, such as gas immersion laser doping or ns-pulsed laser melting [1]. Here, we explore tunable superconducting states in Ga-hyperdoped SixGe1-x alloys by applying ion implantation followed by ms-range flash lamp annealing. We observed that the critical temperature depends on the Ge-concentration. Samples with the highest Ge content demonstrate the transition temperature (Tc) of 1.2 K, attributed to increased Ga solubility, while samples with 70% of Si shows Tc around 100 mK. Notably, all samples achieved carrier concentrations over solid solubility, illustrating the effects of hyperdoping on superconductivity.

HL 6.3 Mon 15:30 H13

Direct printing of microlenses on hexagonal boron nitride to improve light outcoupling — •Daniel Klenkert[1,2], Paul Konrad[2], Andreas Sperlich[2], Vladimir Dyakonov[2], and Jens Ebbecke[1] — [1]1Technology Campus Teisnach Sensor Technology, Deggendorf Institute of Technology, 94244 Teisnach — [2]Experimental Physics 6, Julius-Maximilians-University Würzburg, 97074 Würzburg

Optically active defects in hexagonal boron nitride (hBN) have attracted wide research interest in the field of quantum technology. Solid immersion lenses can be employed in order to increase light outcoupling and thus the external quantum efficiency (EQE) of such defects. These lenses are, however usually created by etching them into the surface of the host material, which makes them rather unsuitable for 2D materials such as hBN.

Here we present an alternative approach: direct printing of polymer microlenses onto hBN using the two-photon polymerization technique. This strategy is not limited to bulk crystals, but can also be applied to thin films. Using a ceramic hybrid polymer with low fluorescence and high optical transparency, hemispherical lenses were directly printed on macroscopic hBN crystals and on thin flakes to demonstrate the feasibility and EQE enhancement of this approach.

HL 6.4 Mon 15:45 H13

Dynamical reorientation of spin multipoles in silicon carbide by transverse magnetic fields — •Alberto Hernández-Mínguez[1], Alexander V. Poshakinskiy[2], Michael Hollenbach[3], Paulo V. Santos[1], and Georgy V. Astakhov[3] — [1]Paul-Drude-Institut für Festkörperelektronik, Berlin, Germany — [2]ICFO-Institut de Ciències Fotòniques, Castelldefels, Spain — [3]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany

The long-lived and optically addressable high-spin state of the negatively charged silicon vacancy (V_{Si}) in silicon carbide makes it a promising system for applications in quantum technologies. Most studies of its spin dynamics have been performed under external magnetic fields applied along the symmetry axis of the V_{Si} center. Here, we show that the application of a weak magnetic field perpendicular to the symmetry axis leads to a non-trivial behavior of the optically detected magnetic resonances (ODMRs) caused by the dynamical reorientation of the spin multipole under optical excitation. Particularly, we observe the inversion of the quadrupole-spin polarization in the excited state and the appearance of a dipole-spin polarization in the ground state. The latter is much higher than the thermal polarization and cannot be induced solely by optical excitation. Our theoretical model reproduces well all sharp features in the ODMR spectra and shine light on the complex dynamics of spin multipoles in these kinds of solid-state systems.

[1] A. Hernández-Mínguez *et al.*, Phys. Rev. Appl. **22**, 044021 (2024)

HL 6.5 Mon 16:00 H13

The hBN defects database for quantum applications — •Chanaprom Cholsuk[1,2], Asli Cakan[1,2], Sujin Suwanna[3], and Tobias Vogl[1,2,4] — [1]Department of Computer Engineering, School of Computation, Information and Technology, Technical University of Munich, 80333 Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany — [3]Optical and Quantum Physics Laboratory, Department of Physics, Faculty of Science, Mahidol University, Bangkok 10400, Thailand — [4]Abbe Center of Photonics, Institute of Applied Physics, Friedrich Schiller University Jena, 07745 Jena, Germany

Hexagonal boron nitride (hBN) has emerged as a solid-state platform for hosting a variety of defects for quantum applications. Identifying optimal defects for specific quantum applications has been challenging as some defects exhibit similar properties while others encounter strain. Comprehensive properties are therefore required. This work addresses this gap by utilizing density functional theory and open quantum system approaches to thoroughly characterize the properties of 257 defects and evaluate their potential for quantum emitter and quantum memory applications. This enables matching defects with suitable quantum applications. Furthermore, all findings are compiled into an accessible online database at https://h-bn.info, allowing one to compare our calculated optical fingerprints with experiments and other simulations. Consequently, this work enriches hBN defect resources, supporting progress in quantum technologies and defect identification.

HL 6.6 Mon 16:15 H13

Scanning NV center thermometry — Elias Sfeir[1], Maxime Rollo[1], Yoann Baron[2], Felipe Favaro de Oliveira[3], Gediminas Seniutinas[3], Marcelo Gonzàlez[3], Mathieu Mathieu[3], Patrick Maletinsky[3,4], Jean-Baptiste Jager[5], Jean-Michel Gérard[5], Vincent Jacques[1], •Aurore Finco[1], and Isabelle Robert-Philip[1] — [1]Laboratoire Charles Coulomb, Université de Montpellier, CNRS, Montpellier, France — [2]Univ. Grenoble Alpes, CEA, LETI, Grenoble, France — [3]Qnami, Muttenz, Switzerland — [4]Department of Physics, University of Basel, Basel, Switzerland — [5]Univ. Grenoble Alpes, CEA, Grenoble INP, IRIG, PHELIQS, Grenoble, France

Scanning NV center microscopy relies on a single nitrogen-vacancy (NV) defect in diamond as a quantum sensor for scanning probe experiments. It is now routinely used as a powerful magnetometry technique, and its functionalities can be extended to temperature measurements by exploiting the temperature dependence of the NV electron spin resonance (ESR) frequency. In this work, we show how to simultaneously map the Joule heating and the Oersted field generated by an electrical current flowing through a semiconductor nanowire with a scanning NV center microscope. Our results highlight that the component of the magnetic field perpendicular to the NV center quantization axis competes with the effect of temperature on the NV ESR frequency, making quantitative temperature measurements challenging. Therefore, we finally propose solutions to improve the overall performances of the technique through the design of optimized diamond probes.

15 min. break

HL 6.7 Mon 16:45 H13

Luminescence of electron and ion beam irradiated hBN — •Jan Böhmer, Annkathrin Köhler, Christian T. Plass, and Carsten Ronning — Friedrich Schiller University, Jena, Germany

Defect centers in solid state materials have emerged as promising candidates for quantum emitters. Here, hexagonal boron nitride (hBN) has attracted much interest as an interesting material for the realization of room temperature single photon emitters (SPEs). Emitting defects can be specifically created by irradiation of hBN flakes and nanoparticles with (focused) electron and ion beams, which allows to modify the luminescence properties of the hBN samples and fabricate targeted localized SPEs. The effects of the irradiation on the luminescence spectrum were investigated using micro photoluminescence (μPL). The nature and applicability for SPEs were determined by $g_{(2)}$-autocorrelation measurements as a function of the irradiation parameters.

HL 6.8 Mon 17:00 H13

Strain-induced tuning of quantum emitters in hexagonal boron nitride — •Tjorben Matthes[1,2], Anand Kumar[1,2], Mohammad Nasimuzzaman Mishuk[1,2], and Tobias Vogl[1,2] — [1]Department of Computer Engineering, TUM School of Computation, Information and Technology, Technical University of Munich, 80333 Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany

In this talk, we will show our recent progress in controlling the emission characteristics of our single photon emitters in hexagonal boron Nitride (hBN).

We have previously demonstrated our results on the polarisation characteristics of both the absorption and the emission characteristics of our single photon emitters. By conducting a statistical analysis of a large array of emitters, we found some unexpected results that indicate a shift of the emission axes in one direction compared to the crystal axes. We suspected a strain induced by the exfoliation process as the cause. We, therefore, conduct now further tests deliberately inducing strain into the hBN flakes in which the emitters are embedded.

HL 6.9 Mon 17:15 H13

Impact of a magnetic field on low-temperature photoluminescence of indium-doped silicon — •Kevin Lauer[1,2], Mario Bähr[1], Richard Grabs[1], Frank Long[1,3], Martin Kaleta[1], Andreas Frank[1], Thomas Ortlepp[1], Katharina Peh[2], Noah Stiehm[2], Rüdiger Schmidt-Grund[2], Dirk Schulze[2], and Stefan Krischok[2] — [1]CiS Forschungsinstitut für Mikrosensorik GmbH, Erfurt, Germany — [2]Technische Universität Ilmenau, Institut für Physik, Ilmenau, Germany — [3]Universität Göttingen, Göttingen, Germany

Acceptor-interstitial silicon (ASi-Sii)-defects [1] were proposed to be responsible for a gain loss in low-gain avalanche detectors (LGAD) and for an efficiency loss in silicon solar cells. Recently, it was speculated that this defect category could be relevant for silicon-based quantum technology, as well. To advance the understanding of these defects in silicon with respect to their potential use as qubits, low-temperature photoluminescence (PL) measurements are performed while subjecting the sample to magnetic fields. Silicon samples with and without indium doping were treated by a temperature quenching step to generate ASi-Sii-defects. The ASi-Sii-defect generation was done using a local laser quenching method as well as using a Bunsen burner with subsequent water quenching. As expected, the integrated PL intensity increased after this generation process. While the sample is subjected to magnetic fields, the integrated PL intensity changes significantly. Differences between samples with and without indium doping will be discussed. [1]K. Lauer et al., Phys. Status Solidi A, 219 (2022) 2200099

HL 6.10 Mon 17:30 H13

Fabrication, characterization and deformation of Si/SiGe membranes for spin qubit devices — •Lucas Marcogliese[1], Ouviyan Sabapathy[1], Rudolf Richter[2], Dominique Bougeard[2], and Lars R. Schreiber[1,3] — [1]JARA-FIT Institute for Quantum Information, Aachen, Germany — [2]University of Regensburg, Regensburg, Germany — [3]ARQUE Systems GmbH, Aachen, Germany

The energy separation between the two lowest lying energy states in silicon, known as valley splitting, has been shown to have a significant impact on dephasing times, readout and shuttling fidelities of spin qubits in Si/SiGe. Greater control over the strain tensor field may be decisive for deterministic valley splitting enhancement in the presence of alloy disorder. Here, we demonstrate the fabrication of SiGe/Si/SiGe quantum well membranes suspended by the handle wafer via wet etching. Relying on SiGe as an etch stop, the robust and reproducible process yields membranes down to micrometer thicknesses. Raman maps confirm that etching preserves epitaxial tensile strain in the quantum well. Remarkably, they reveal that the in-plane strain components generated by the cross-hatch pattern typical of Si/SiGe heterostructures on bulk substrates disappear on etched membranes. To probe their elastic properties, the membranes are stressed by loading with a profilometer stylus at room temperature. We envision the Si/SiGe membrane as a flexible scientific platform for investigating novel, advanced valley splitting enhancements techniques, required for scalable Si/SiGe quantum computing with electron spins.

HL 6.11 Mon 17:45 H13

Design and optimization of bimodal cavities coupled to multi-level quantum systems — •Oscar Camacho Ibarra, Jan Gabriel Hartel, Atzin Ruiz Perez, Sonja Barkhofen, and Klaus Jöns — PhoQS Institute, CeOPP, and Department of Physics, Paderborn University, Paderborn, Germany

Photonic integrated cavities are essential building blocks for qubit-controlled switches, routers, and gates in quantum networks and quantum information processing. These devices rely on the integration of multi-level quantum systems coupled to multiple photonic modes inside a cavity. Thus, the present work introduces a systematic workflow for the design of bimodal cavities by employing one-dimensional crossed photonic crystal nanobeam cavities with non-zero cavity lengths. By optimizing three key parameters*the periodicity, a single feature size of the hole shape, and the central cavity length*we establish a robust methodology for designing crossed nanobeam cavities. This approach supports configurations with either matching or mismatched resonance frequencies, offering flexibility for diverse quantum applications. References [1]* Mikkel Heuck, Kurt Jacobs and Dirk R. Englund. Controlled-Phase Gate Using Dynamically Coupled Cavities and Optical Nonlinearities. Phys. Rev. A 109, 062620 (2024). [2]* Luiz O. R. Solak, Daniel Z. Rossatto, and Celso J. Villas-Boas, Universal quantum computation using atoms in cross-cavity systems. Phys. Rev. A 109, 062620 (2024).

HL 6.12 Mon 18:00 H13

In Situ Defect Density Determination of Spin Defects in Hexagonal Boron Nitride — Atanu Patra[1], •Paul Konrad[2], Andreas Sperlich[2], Timur Biktagirov[3], Thinh Tran[4], Igor Aharonovich[4], Sven Höfling[1], and Vladimir Dyakonov[2] — [1]Technische Physik, Julius-Maximilians-University Würzburg, 97074 Würzburg — [2]Experimentelle Physik 6, Julius-Maximilians-University Würzburg, 97074 Würzburg — [3]Lehrstuhl für Theoretische Materialphysik, Universität Paderborn, 33095 Paderborn, Germany — [4]School of Mathematics and Physical Sciences, University of Technology Sydney, Ultimo, NSW 2007, Australia

In recent years, the negatively charged boron vacancy (V_B^-) spin defects in hexagonal boron nitride (hBN) caught attention for their sensitivity to environmental parameters such as magnetic field, temperature, and pressure, making them ideal for quantum sensing. The optical emission from these defects, crucial for applications, depends on their density, which could -so far- not be determined directly for thin flakes. Our study identifies distinct Raman modes alongside the E_{2g} peak in defect-enriched hBN. Polarization-dependent Raman measurements reveal that these modes arise from atomic vibrations associated with the V_B^- defects. Additionally, we corroborate this result by density functional theory. We investigate the interdependent relationship between the vibronic states and defect density and obtain a universally applicable method to directly determine the absolute spin-defect density in flakes by Raman spectroscopy alone.

HL 6.13 Mon 18:15 H13

Electric-circuit realization of the Floquet-SSH-Model — •Christine Barko[2], Alexander Stegmaier[1], Alexander Fritzsche[1], Riccardo Sorbello[1], Martin Greiter[1], Hauke Brand[2], Maximilian Hofer[2], Udo Schwingenschlögl[3], Roderich Moessner[4,5], Ching Hua Lee[6], Alexander Szameit[5,7], Andrea Alù[8,9], Tobias Kiessling[2,5], and Ronny Thomale[1,5] — [1]Physikalisches Inst. (TP1), Universität Würzburg, Würzburg, Germany — [2]Physikalisches Inst. (EP3), Universität Würzburg, Würzburg, Germany — [3]Physical Science and Engineering Division, King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia — [4]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, Dresden, Germany — [5]Würzburg-Dresden Cluster of Excellence ct.qmat, Würzburg, Germany — [6]Department of Physics, National University of Singapore, Singapore — [7]Institute of Physics, University of Rostock, Rostock, Germany — [8]Photonics Initiative, Advanced Science Research Center, City University of New York, New York, USA — [9]Physics Program, Graduate Center, City University of New York, New York, USA

We build Floquet-driven capactive circuit networks to realize topological states of matter in the frequency domain. We find the Floquet circuit network equations of motion to reveal a potential barrier which effectively acts as a boundary in frequency space. By implementing a Su-Shrieffer-Heeger Floquet lattice model and measuring the associated circuit Laplacian and characteristic resonances, we demonstrate how topological edge modes can nucleate at such a frequency boundary.

HL 6.14 Mon 18:30 H13

Erbium dopants in nanophotonic resonators — •Andreas Gritsch, Alexander Ulanowski, Stephan Rinner, Johannes Früh, Jakob Pforr, and Andreas Reiserer — Technical University of Munich, TUM School of Natural Sciences and Munich Center for Quantum Science and Technology (MCQST), 85748 Garching, Germany

Optically addressable spin qubits are pristine candidates for large-scale quantum networks [1] and modular quantum computing architectures [2]. Erbium dopants are the only emitter with a coherent optical transition in the minimal-loss-band of optical fibers. In silicon, erbium integration is compatible with industrial-grade nanofabrication processes [4]. In nanophotonic resonators efficient spin-photon interfaces can be realized, in which about ten single dopants can be resolved with Purcell enhancement up to 177. Their spin state can be initialized and read out with a combined fidelity of 87%. This spin further exhibits a second-long lifetime and a Hahn-echo coherence time of 48 s [4]. We further investigate the optical coherence and the spectral multiplexing capabilities in our silicon devices, which allows a detailed comparison to our experiments with YSO membranes integrated into Fabry-Perot resonators [5].

[1] A. Reiserer, Rev. Mod. Phys. 94, 041003 (2022). [2] S. Simmons, PRX Quantum 5, 010102 (2024). [3] S. Rinner, et al., Nanophotonics 12 (2023). [4] A. Gritsch, et al., arXiv:2405.05351 (2024), Nat. Commun., (in press). [5] A. Ulanowski, et al., Advanced Optical Materials 12 (2024).