HL 38: Materials and Devices for Quantum Technology II

Time: Thursday 9:30–12:45 Location: POT/0051

HL 38.1 Thu 9:30 POT/0051

Shadow masks for all-in-situ fabrication of InAs nanowire Josephson junctions — •Christian Schäfer, Lennart Grosch, Yurii Kutovyi, Nils von den Driesch, Thomas Schäpers, and Alexander Pawlis — PGI 9 / PGI 10 / JARA-FIT, Forschungszentrum Jülich, 52428 Jülich, Germany

Josephson junctions based on semiconductor/superconductor hybrid structures offer unique features for quantum circuits, such as gate-controllable supercurrent and quantized Andreev bound states. Clean interfaces between nanowire and superconductor are essential to leverage both effects, driving the development of in-situ contact fabrication. Shadow wall epitaxy offers both, a scalable and all-in-situ solution for nanowire growth and contact formation. Micrometer-high pre-fabricated walls shadow the molecular beams of In and As depending on their relative orientation. Since As on its own has a low sticking coefficient and In forms isolated droplets, partially shadowed regions are insulating and do not form InAs crystals. Despite the significant lattice mismatch between InAs and the GaAs substrate, we observe growth of lateral 1D-nanowires between walls spaced less than one micrometer. The same mask can additionally be used to perform selective deposition of any superconductor. We explore different mask designs to optimize electrical device isolation, nanowire growth, and junction geometry. Since no transfer or post-processing after growth is necessary, associated defects and degradation are avoided. Shadow wall epitaxy enables scalable in-situ fabrication of InAs nanowire junctions.

HL 38.2 Thu 9:45 POT/0051

Semiconductor−superconductor membranes for nanoelectronic devices — •Thies Jansen[1], Christian Reichl[2], and Thomas Sand Jespersen[1,3] — [1]Technical University of Denmark, Anker Engelunds Vej 101 2800 Kongens Lynby — [2]ETH Zürich Laboratorium für Festkörperphysik — [3]Center for Quantum Devices Niels Bohr Institute, University of Copenhagen

Semiconductor-superconductor hybrid materials have become the workhorse platform for quantum devices, owing to their clean and highly transparent semiconductor-superconductor interfaces. Indium arsenide−aluminum (InAs-Al) nanowires and quantum wells are currently the dominant material systems, each offering distinct advantages: nanowires allow transfer to arbitrary substrates, while quantum wells provide two-dimensional design flexibility. Here, we introduce a new platform that combines the strengths of both systems: a semiconductor-superconductor membrane. We present the fabrication of these membranes and their initial electrical characterization through low-temperature transport measurements. The membranes are gate-tunable, and their material properties closely resemble those of both InAs nanowires and InAs quantum wells.

HL 38.3 Thu 10:00 POT/0051

Secondary electron detector for deterministic single ion implantation — •Priyal Dadhich, Nico Klingner, and Gregor Hlawacek — Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf(HZDR), Dresden, Germany

Fault tolerant quantum computers based on donor-ion solid-state qubits require highly localized placement of single donors. To achieve this, we are developing a new setup for deterministic single-ion implantation in a FIB. To detect each implanted ion, we aim to use the secondary electrons (SEs) emitted during ion impact. A windowless silicon drift detector (SDD), biased up to +10 kV, accelerates and collects these SEs. The resulting electron-hole pairs allow us to quantify the number of emitted electrons via pile-up analysis. A critical challenge for this detection approach is the intrinsic SE emission probability. As governed by Poisson statistics, the average SE yield strongly affects detection confidence. Current work examines material-dependent absolute SE yields and practical methods to enhance SE emission while maintaining efficient extraction. Given the low SE yield per impact, optimizing the extraction geometry is crucial. A C++ simulation code using the ion-optics library IBSIMU [1] has been developed for this customised problem, to maximize SE collection and study backscattering, including possible methods to recollect backscattered electrons.
References: [1] T Kalvas et. al. Rev. of Sci. Inst., 81(2), 2010.

HL 38.4 Thu 10:15 POT/0051

Spin-orbit-enabled realization of arbitrary two-qubit gates on moving spins — •David Fernández-Fernández[1], Yuta Matsumoto[2], Lieven M.K. Vandersypen[2], Gloria Platero[1], and Stefano Bosco[2] — [1]Instituto de Ciencia de Materiales de Madrid, CSIC, Spain — [2]QuTech and Kavli Institute of Nanoscience, Delft University of Technology, The Netherlands

Shuttling spin qubits across semiconductor quantum dot arrays is emerging as a key primitive for scalable quantum information processing, enabling on-chip inter-node quantum communication and modular architectures. By analyzing the shuttling of two spin qubits towards each other using a conveyor-mode protocol, we show that controlling only two experimentally accessible parameters, the shuttling velocity and the waiting time at minimum interdot separation, is sufficient to synthesize a broad class of entangling gates. Moderate SOI provides direct access to both CPHASE(θ) and SWAP$^{\alpha}$ families, as well as native fermionic-simulation gates, all with fidelities above 99.99% neglecting decoherence. We further quantify gate accessibility through a Weyl-chamber analysis and demonstrate that strong SOI or engineered helical magnetic fields can unlock nearly complete ($\sim$ 99.98%) coverage of all locally inequivalent 2Q operations, including quantum gates such as the Berkeley gate. This work provides a realistic and scalable route toward single-step 2Q gates on mobile spin qubits, with immediate implications for distributed quantum computing, quantum simulation, and shuttling-assisted error-correcting architectures.

HL 38.5 Thu 10:30 POT/0051

Topological Superconductivity in the Presence of Contact Potentials — •Leonard Kaufhold — Institute for Theoretical Physics, Cologne, Germany

The research on Majorana bound states (MBS) has brought forth a multitude of proposed platforms and devices that are, in principle, capable of realizing such states as topological edge modes. These devices usually rely on the superconducting proximity effect induced in semiconductors with strong spin-orbit coupling or, more recently, in topological insulators. The material interface however induces another effect that can be as much as one order of magnitude larger than the electronic band gap at the surface. Due to the mismatch of work functions between the materials, a dipole layer forms at the interface, effectively creating a contact potential that modifies the electronic band structure far beyond the minimal models typically used to describe the formation of MBS. In this presentation, we will focus on different nanowire-based architectures consisting of a topological insulator in contact with an s-wave superconductor, and discuss on a theoretical level the effect of contact potentials on the formation and stability of MBS. We further outline under which parameter conditions these interface-induced effects become experimentally relevant.

HL 38.6 Thu 10:45 POT/0051

Hexagonal Germanium Nanowires as a Spin Qubit Platform — •Anirban Das[1], Baksa Kolok[1,2], Daniel Varjas[1,3], and Andras Palyi[1,2] — [1]Department of Theoretical Physics, BME, Budapest, Hungary — [2]HUN-REN-BME-BCE QTRG, BME, Budapest, Hungary — [3]IFW Dresden and Würzburg-Dresden Cluster of Excellence ct.qmat, Dresden, Germany

Hexagonal germanium (2H-Ge) offers strong spin-orbit interaction and optical activity, making it an appealing platform for semiconductor spin qubits. Recent progress in growing hexagonal Si_xGe_{1-x} nanowires enables controlled geometries suitable for quantum devices. In contrast to cubic Si or Ge, 2H-Ge supports direct band-gap transitions, opening a pathway towards a novel spin-photon interface.

We study the electronic and spin properties of 2H-Ge nanowires using a multiband k·p Hamiltonian describing low-energy states near the Γ point. By discretizing the model with open boundaries, we construct nanowires oriented perpendicular to the c-axis and compute their band structure. We analyze confinement-induced gap variations and the influence of transverse electric fields, from which we extract Rashba coefficients. Magnetic fields are included via a Peierls substitution to investigate anisotropic spin responses. The resulting effective g-tensor shows strong directional dependence, revealing regimes favorable for qubit operation in hexagonal Ge nanowires.

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15 min. break

HL 38.7 Thu 11:15 POT/0051

Low-Loss LNOI PIC Components for Quantum Interference Applications — •Mohammad Malik[1,2,3], Simon Palitza[1,2,3], and Carsten Schuck[1,2,3] — [1]Department for Quantum Technology, University of Münster — [2]Center for NanoTechnology - CeNTech, Münster — [3]Center for Soft Nanoscience - SoN, Münster

Lithium niobate on insulator (LNOI) exhibits significant potential as a platform for integrated photonics owing to its strong electro-optic response, broad transparency window, and intrinsic nonlinear properties. For on-chip quantum key distribution (QKD) and related quantum photonic applications, the precise fabrication of photonic integrated circuit (PIC) components with minimal loss and high fidelity remains a key challenge. Here, we demonstrate directional couplers (DCs) and multimode interferometers (MMIs) that achieve a 50/50 splitting ratio with insertion losses below 1.5 dB at a wavelength of 1550 nm. These results are obtained using in-house fabrication techniques, including electron-beam lithography and inductively coupled plasma reactive ion etching, enabling accurate and reproducible realization of crucial PIC components. Building on these results, we will discuss progress towards integrating superconducting nanowire single-photon detectors (SNSPDs) on the LNOI platform for realizing on-chip Hong-Ou-Mandel interference as required for integrated quantum technology applications, including measurement device independent QKD.

HL 38.8 Thu 11:30 POT/0051

Scalable and individual control of Si qubits via magnetic skyrmions — •Leander Reascos[1], Raluca Boltje[1], Kai Litzius[1], Felix Büttner[1,2], and Mónica Benito[1] — [1]Institute of Physics, University of Augsburg, 86159 Augsburg, Germany — [2]Helmholtz-Zentrum Berlin für Materialien und Energie, 14109 Berlin, Germany

Scalable, precise control of spin qubits is essential for large-scale quantum processors with millions of qubits. Electron-spin qubits in semiconductor quantum dots are promising due to their small size, high fidelities, long coherence times, and CMOS compatibility. However, current electric-dipole spin resonance (EDSR) schemes rely on static micromagnets, which suffer from fabrication-induced inhomogeneities and limited tunability. We propose using gate-tunable nanoscale magnetic skyrmions as on-chip magnetic field sources to replace micromagnets. By controlling skyrmion geometry, the local magnetic field at a quantum dot can be tuned post-fabrication to adjust both the qubit frequency and the EDSR driving gradient. Using micromagnetic simulations and analytical modeling, we show how skyrmion geometry maps directly onto the qubit's Zeeman splitting and Rabi frequency. These results highlight skyrmion-based control as a promising route towards scalable, frequency-selective spin-qubit architectures with enhanced tunability.

HL 38.9 Thu 11:45 POT/0051

Strain modulation in Germanium: an overview for quantum applications — •Meera None[1], Ignatii Zaitsev[1], Davide Spirito[2], Patricio Farrell[3], Christian Merdon[3], Yiannis Hadjimichale[3], Daniel Fritsch[4], Marvin Hartwig Zoellner[1], and Costanza Lucia Manganelli[1] — [1]IHP-Frankfurt (Oder)-Germany — [2]BC-Materials-Leioa, Spain — [3]WIAS-Berlin — [4]Zuse-Berlin

Germanium (Ge) is a promising platform for hole-based quantum devices due to its high hole mobility, strong spin-orbit coupling, and compatibility with CMOS technology. We investigate strain engineering in an ideal structure with two silicon nitride (SiN) stressors on a Ge substrate, using FEM to study how stress level, stressor height, and design influence mechanical deformation. The resulting strain tensors, including often neglected shear components, are inserted into a fully coupled 6x6 Bir-Pikus Hamiltonian to compute heavy hole (HH) and light hole (LH) band shifts under uniaxial and biaxial stress. Our results show tunable HH-LH splitting from 36 to 165 meV for SiN stressors between 1 and 4 GPa, demonstrating that SiN stressors offer a practical, scalable route to engineer Ge band structure for quantum wells and hole spin qubits.

HL 38.10 Thu 12:00 POT/0051

Optical probing of strain fields in isotopically pure Si-28 using donor-bound excitons — •Nico Eggeling[1], Phillip Külper[1], N.V. Abrosimov[2], Jens Hübner[1], and Michael Oestreich[1] — [1]Leibniz Universität Hannover, Germany — [2]IKZ Berlin, Germany

The successful demonstration of all optical qubits in isotopically pure Si-28 utilises the donor-bound exciton transition of phosphorus dopants [1]. As a current obstacle for large-scale implementation, the challenge remains to harness inhomogeneities resulting from simple imperfections in the crystal lattice, over dopant-dependent lattice deformations, to even the hydrostatic pressure due to the sample's own weight or adjacent interfaces. We present results from spatially resolved measurements of the donor-bound exciton, revealing a distinct strain distribution in a bulk Si-28 sample at cryogenic temperatures. These are explained in the context of the Pikus-Bir formalism for silicon [2], leading to strain estimates that are well matched to the known extrinsic factors.

[1] E.Sauter, PhD Thesis (2022)
[2] Loippo et al., Phys. Rev. Mater. 016202 (2023)

HL 38.11 Thu 12:15 POT/0051

Development of heavy noble gas field ion sources using an iridium coated single crystalline tungsten emitter — •Amina Zid[1,2], Gregor Hlawacek[1], Nico Klingner[1], Arnaud Houel[2], and Anne Delobbe[2] — [1]Institute for Ion Beam Physics and Material Research, Helmholtz-Zentrum Dresden-Rossendorf — [2]ORSAY PHYSICS, 95, 3ème Avenue - ZA Saint-Charles, 13710 Fuveau, France

Gas Field Ion Sources (GFIS) provide high brightness, high current density and excellent spatial resolution[1]. Conventional GFIS use light noble gases: helium enables 0.5 nm imaging resolution, while neon allows high-resolution milling beyond Liquid Metal Ion Source (LMIS) capabilities. However, low maximum current limits material removal rates, and the light ions cause deep implantation and bubble formation, reducing efficiency for large-volume or high-aspect-ratio milling. To overcome these limits, we investigate GFIS operation in a Focused Ion Beam (FIB) using heavier noble gases.

Additionally an iridium-coated tungsten tip is investigated. Iridium forms the strongest bond with tungsten[2], enabling higher electric fields and thus higher stable beam currents. Our emitter operates from a single emission point rather than the typical trimer used in Helium Ion Microscopy. This work presents the first FIB performance evaluation of this emitter with argon and xenon, including comparison to helium and neon-based GFIS.

[1] Höflich, K. et al., Applied Physics Reviews 2023; G. Hlawacek & A. Gölzhäuser (Eds.), Helium Ion Microscopy, Springer, 2016.
[2] Oshima, C. et al., Surface Science and Nanotechnology 2018.

HL 38.12 Thu 12:30 POT/0051

Finding the kinked propagation of the I3 defect in hexagonal silicon using a machine-learned potential — •Jolijn Dellevoet — Eindhoven University of Technology, Eindhoven, The Netherlands

Hexagonal silicon-germanium (hex-SiGe) alloys have recently emerged as promising direct-bandgap semiconductors suitable for on-chip optical communication, offering a path to reduce heat production in microchips. Currently, the hex-SiGe crystal is grown in core-shell nanowire structures, but their crystal quality is hindered by the formation of I3 defects. During growth, these defects nucleate and can propagate into otherwise pristine crystal. This propagation has been observed experimentally but not reproduced in atomistic simulations, leaving the underlying mechanism unclear. This presentation reveals, at atomic resolution, a kinking mechanism that enables the I3 defect boundary to propagate within hex-Si. This mechanism and its corresponding energy landscape are obtained by using the nudged elastic band (NEB) method in combination with the machine-learned PACE potential. Although the calculations are currently limited to Si systems, future studies could focus on extending the calculations to SiGe systems. The temperature and boundary length dependence of the transition rate can ultimately be used to optimize growth conditions of the hex-SiGe core-shell nanowires.