HL 11: Focus Session: Quantum Emitters in 3D Semiconductors

Quantum emitters in 3D semiconductors play a crucial role in many applications. In this focus session, we focus on the latest developments for their use in quantum technologies. In addition to the well-known NV center in diamond, there are a number of other defect centers in various semiconductor systems that hold great potential for quantum sensing, quantum cryptography, and/or quantum information technology. Today's research focuses on the discovery of new centers, their properties, synthesis, and their microscopic origin. For the latter, ab initio methods are often used, and the material systems span silicon, nitrides, carbides, and other semiconductors with large band gaps.

Organized by Carsten Ronning and Jan Meijer

Time: Monday 15:00–18:15 Location: POT/0251

Invited Talk HL 11.1 Mon 15:00 POT/0251
Quantum Repeater Hardware made from Silicon Carbide — •Jörg Wrachtrup — Center for Applied Quantum Technologies, University of Stuttgart

Distributing entanglement via quantum repeaters is a formidable challenge. Memory-based approaches require quantum emitters that couple strongly to optical fields, and at the same time demand stationary qubits with excellent coherence properties. Colour centres in solids meet these requirements remarkably well and are therefore leading contenders in the field. However, existing solutions are either technically demanding or result in limited network efficiency.

Silicon carbide (SiC) offers several advantages over current approaches. Most notably, SiC is a wafer-scale material with excellent nanophotonic properties and hosts defects with outstanding spin coherence. In this talk, I will highlight recent progress in incorporating colour centres into nanophotonic structures and achieving efficient photon extraction. In addition, the electron spins of these colour centres can be coupled to nuclear spin qubits with exceptional coherence properties. I will discuss this coupling and its use as quantum memories for repeaters.

Invited Talk HL 11.2 Mon 15:30 POT/0251
Diamond based quantum sensing for drug testing — •Romana Schirhagl — University Medical Center Groningen, Groningen, the Netherlands

Free radical generation plays a key role in the mechanisms of action of many different drugs. Additionally, free radical generation offers a powerful biomarker to quantify the drug efficacy. However, free radicals are difficult to measure since they are short lived and reactive. Diamond based quantum sensing offers a possible solution to this problem. We have demonstrated recently that we can predict which drugs might work in clinical samples. Here we can either measure stress responses [1] (as for instance caused by anti-cancer drugs or anti-biotics) or reduction of oxidative stress [2] (as caused by anti-inflammatory drugs, certain inhibitors or anti-oxidants). We tested synovial fluid from rheumatoid arthritis and osteoarthritis patients. We can clearly differentiate the two groups which differ in their responsiveness to Piroxicam. Such ex-vivo measurements can be used for diagnostic purposes, to predict the effectiveness of a drug or to elucidate its mechanism of action. In my talk I will show different examples of how quantum sensing can be used in drug development. 1 Tian, Y., Nusantara, A.C., Hamoh, T., Mzyk, A., Tian, X., Perona Martinez, F., Li, R., Permentier, H.P. and Schirhagl, R., 2022. ACS Applied Materials & Interfaces, 14(34), pp.39265-39273. 2 Sigaeva, A., Shirzad, H., Martinez, F.P., Nusantara, A.C., Mougios, N., Chipaux, M. and Schirhagl, R., 2022. Small, 18(44), p.2105750.

Invited Talk HL 11.3 Mon 16:00 POT/0251
The oxygen-related ST1 centre in diamond: a room temperature coherently controllable electron spin — •Sebastien Pezzagna — Applied Quantum Systems, Universität Leipzig, Leipzig, Germany

The development of quantum information and technologies has rapidly evolved from the beginning of the century. Nowadays, there exists a variety of defects and host crystals which are suitable for applications in quantum computing, sensing or communication, such as the nitrogen-vacancy (NV) centre in diamond. However, the reliable and scalable employment of such a system requires the ability to produce it on demand together with a deep understanding of its optical and spin properties, as well as charge states and close by environment.

In this presentation, we will discuss the so-called ST1 centre in diamond, one of the few defect centres possessing a coherently controllable electron spin at room temperature. We will first show how we could identify the nature of the ST1 centre and how it can then be produced on demand. We will then emphasize the large spin readout contrast and charge state stability which characterise the ST1 centre, and how this compares to the well-known NV centre. Finally, we will highlight the peculiarities of the ST1 centre, supported by optical spectroscopy and by investigations of the hyperfine interactions with surrounding carbon-13 nuclear spins and with the oxygen-17 nuclear spin within the centre itself.

15 min. break

Invited Talk HL 11.4 Mon 16:45 POT/0251
Silicon quantum emitters emitting in the optical telecommunication range for scalable quantum photonic circuits — •Yonder Berencén — Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, 01328 Dresden, Germany

Silicon has recently emerged as a promising host for single-photon emitters operating at telecom wavelengths, offering a pathway toward scalable quantum photonic technologies on a CMOS-compatible platform. In this invited talk, I will provide an overview of the most relevant intrinsic and extrinsic-based quantum emitters in silicon, including the W, G, T, and C centers as well as erbium. I will discuss their optical and spin properties, deterministic creation via broad-beam ion implantation and focused ion beam implantation, and recent progress toward realizing spin-optical interfaces in the optical telecom bands. Particular emphasis will be placed on single-emitter spectroscopy, demonstration of optically detected magnetic resonance (ODMR) in silicon at telecom wavelengths, and the integration opportunities enabled by silicon*s mature photonic and electronic fabrication ecosystem. Finally, I will outline a roadmap toward fully monolithic silicon quantum photonic integrated circuits that combine single emitters with on-chip photonic routing and a groundbreaking approach for silicon-based single-photon detectors at the telecom range.

Invited Talk HL 11.5 Mon 17:15 POT/0251
Advances in materials processing for quantum sensing — •Adam Gali — HUN-REN Wigner Research Centre for Physics, Budapest, Hungary — Budapest University of Technology and Economics, Budapest, Hungary

For more than a decade, our first-principles studies have suggested that neutral divacancy defects in silicon carbide (SiC) could provide such an alternative. These defects can be excited in the infrared and emit in the second biological window, making them intrinsically attractive for biological sensing. The next step is to engineer the SiC surface and introduce shallow divacancy species suitable for nanoscale sensing. Under ambient conditions, however, SiC readily oxidizes and forms a high density of optical and paramagnetic defects at the interface, necessitating new materials-processing strategies. We have shown with first-principles calculations that the ODMR contrast of divacancy centers can be enhanced through strain engineering, a prediction verified experimentally by our collaborators. Additionally, we proposed replacing the native oxide with carbon-chain terminations to prevent oxidation. Our simulations revealed that such surfaces serve as ideal hosts for shallow divacancy quantum sensors capable of detecting external paramagnetic species [1]. This theoretical proposal has since been experimentally demonstrated by our collaborators, paving the way toward non-invasive, room-temperature quantum sensor devices.

[1] Non-invasive bioinert room-temperature quantum sensor from

silicon carbide qubits, Pei Li et al., Nature Materials, 24, 1913 (2025).

HL 11.6 Mon 17:45 POT/0251

Generation of Vacancy-Based Colour Centres in 4H-Silicon Carbide for Quantum Nanophotonics with Optically Active Spins — •Leonard K.S. Zimmermann[1,2], Jonah Heiler[1,2], Samuel C. Eserin[3], Matthias Rupp[1], Ella B. Schneider[3], Jean-Nicolas Audinot[1], Steven K. Clowes[3], Ben N. Murdin[3], Stephan Kucera[1], and Florian Kaiser[1,2] — [1]Luxembourg Institute of Science and Technology (LIST), Esch-sur-Alzette, Luxembourg — [2]University of Luxembourg, Esch-sur-Alzette, Luxembourg — [3]Advanced Technology Institute, University of Surrey, United Kingdom

Silicon carbide (SiC) has emerged as a promising colour centre platform for scalable quantum systems based on nanophotonics and -electronics. Integration into nanophotonic circuits requires sub-micron three-dimensional positioning control of colour centres, achievable via ion implantation to create vacancies followed by thermal annealing. Spin-optical quantum coherence properties vary significantly with implantation parameters. We present initial results from an ongoing implantation-annealing study for generating VSi and VSiVC colour centres in 4H-SiC. Helium and Neon are implanted with varied doses at different energies, and different annealing processes for colour centre formation are investigated. We summarise single-emitter yield and show basic spin coherence measurements for the different processes. Our study highlights parameters necessary for optimal generation conditions of colour centres in 4H-SiC.

HL 11.7 Mon 18:00 POT/0251

Controlled generation of color centers in MBE-grown AlN for quantum photonics applications — •Meysam Saeedi[1], Duc V. Dinh[1], Andrey N. Anisimov[2], Mingyun Yuan[1], Georgy V. Astakhov[2], and Alberto Hernández-Mínguez[1] — [1]Paul-Drude-Institut für Festkörperelektronik, Leibniz-Institut im Forschungsverbund Berlin e.V., 10117 Berlin, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, 01328 Dresden, Germany

The large electronic band gap of aluminium nitride (AlN), its compatibility with CMOS technology, and the presence of defect centers acting as quantum light sources in the visible spectral range, make this material attractive for applications in integrated quantum photonics. In this contribution, we demonstrate the controlled generation of optically active defect centers in AlN thin films grown on 4H-SiC by molecular beam epitaxy (MBE). To this end, we compare the photoluminescence (PL) spectra of pristine AlN samples grown under both N-rich and Al-rich conditions with their corresponding PL spectra after H-ion irradiation and annealing. We show that achieving high-purity single-photon emitters in samples grown under N-rich conditions is hindered by a broad background PL, primarily arising from native oxygen-related defect complexes already present in as-grown samples. However, the PL background is reduced by more than one order of magnitude by turning the MBE growth conditions from N-rich to Al-rich regimes. These results outline a clear pathway toward the engineering of integrated, high-purity quantum emitters in epitaxial AlN.