QI 20: Metrology and Sensing

Time: Friday 9:30–12:00 Location: BEY/0137

QI 20.1 Fri 9:30 BEY/0137

Nitrogen Vacancy center based gradiometry: Towards unshielded magnetic biosensing applications — •Magnus Benke, Jixing Zhang, Michael Kübler, Yihua Wang, and Jörg Wrachtrup — 3rd Physics Insitute, University of Stuttgart, Stuttgart

Magnetometers based on Nitrogen Vacancy (NV) centers in diamond offer high sensitivities and spatial resolution, as well as a broad dynamic range. These properties allow for unshielded measurements by combining two or more sensors into a gradiometric array to suppress common-mode noise. In this work we present a DC-broadband gradiometer, comprised of two magnetometers using a CW-ODMR (Continuous-Wave Optically Detected Magnetic Resonance) measurement scheme. With this array we were able to effectively reduce an artificial background signal by 45 times without attenuating an applied test signal. For further detailed analysis of the noise floor, we equipped the sensors with flux concentrators to identify the different noise contributions in the signal.

QI 20.2 Fri 9:45 BEY/0137

Model-free error mitigation in NV center magnetometry — •Dennis Herb[1], Miriam Resch[1], Mirko Rossini[1], Joachim Ankerhold[1,2], and Dominik Maile[1] — [1]Institute for Complex Quantum Systems, Ulm University, Germany — [2]Center for Integrated Quantum Science and Technology (IQST), Ulm-Stuttgart, Germany

Quantum sensing is an emerging field with the potential to outperform classical methods in both precision and spatial resolution. However, the sensitivity of the underlying quantum platform also makes them highly susceptible to their environmental noise. To address this issue, techniques from the field of quantum error mitigation have been used to improve measurement results from noisy device signals via post-processing. We present a novel mitigation technique for quantum sensors to efficiently reverse the effects of any noise source that can be described by a completely positive trace preserving map. The method neither requires tomography of the final density matrix after the sensing protocol nor an underlying noise-model. It leverages the knowledge acquired by a pre-characterization step of the device to automatically adapt to the complexity of the dissipative evolution and to indicate which sensing times τ are best suited for the most accurate results. This method represents a further step toward perfecting a new family of sensors with the smallest scale of resolution, enabling measurements at the molecular scale.

QI 20.3 Fri 10:00 BEY/0137

Part 1: Optically Addressable Molecular Spins at 2D surfaces — •Yan Tung Kong, XuanKai Zhou, Cheuk Kit Cheung, Ruoming Peng, and Jörg Wrachtrup — 3. Physikalisches Institut, University of Stuttgart, 70569 Stuttgart, Germany

Optically addressable surface spins constitute a long-sought goal in quantum sensing, offering a pathway to probe quantum phenomena with atomic-scale precision. Here, we introduce a novel architecture in which pentacene spin molecules are anchored onto two-dimensional hexagonal boron nitride (hBN) and self-align with the underlying lattice. This configuration yields robust optically detected magnetic resonance (ODMR) signals from 4 K to room temperature. We further demonstrate ensemble spin sensing of Fe3GaTe2 (FGT), as well as controlled positioning of Pc molecules. This work represents the first demonstration of a surface molecular spin sensor that integrates long coherence, optical addressability, and interfacial functionality, thereby enabling quantum sensing capabilities beyond those of conventional solid-state spin systems.

QI 20.4 Fri 10:15 BEY/0137

Part 2: Optically Addressable Molecular Spins at 2D surfaces — •Xuankai Zhou[1], Yan-Tung Kong[1], Cheuk Kit Cheung[1], Ruoming Peng[1], and Jörg Wrachtrup[1,2] — [1]3. Physikalisches Institut, University of Stuttgart, 70569 Stuttgart, Germany — [2]Max Planck Institute for Solid State Research, 70569 Stuttgart, Germany

Surface spins with coherent control hold the potential to quantum sensing revolution by nanoscale magnetic imaging. On the pentacene-hBN hybrid platform, we demonstrate distinguished coherence engineering alongside versatile functional sensing. By employing isotope purification and dynamical decoupling, the spin-coherence time is extended to $T_2 > 30$ μs and $T_{2,DD} > 300$ μs, already approaching the intrinsic triplet state lifetime limit. Meanwhile, it is also available for the platform to sense nearby proton nuclear signals and magnetic responses of two-dimensional magnets beneath hBN layer. This work represents the first demonstration of surface molecular spin sensor, integrating long coherence, optical addressability and interfacial functionality, thereby enabling quantum sensing beyond conventional solid-state spins.

QI 20.5 Fri 10:30 BEY/0137

Iterative optimization in quantum metrology and entanglement theory using semidefinite programming — Árpád Lukács[1,2,3], •Róbert Trényi[2,3,4,5], Tamás Vértesi[6], and Géza Tóth[3,4,2] — [1]Dept. of Math. Sci., Durh. Univ., UK — [2]HUN-REN Wigner RCP, Budapest, Hungary — [3]Dept. of Th. Phys., UPV/EHU, Bilbao, Spain — [4]EHU Quantum Center, UPV/EHU, Bilbao, Spain — [5]Dept. of Th. Phys., Univ. of Szeged, Hungary — [6]HUN-REN Inst. for Nucl. Research, Debrecen, Hungary

Metrological performance of a quantum state is measured by how much it can outperform all separable states in a metrological task. We present efficient optimization techniques to maximize this performance by searching for the optimal local Hamiltonian generating the unitary dynamics for a given bipartite initial state. We show that this is equivalent to maximizing the Quantum Fisher Information over a specific set of local Hamiltonians. This task is very difficult, as it involves maximizing a convex function over a convex set. We reformulate the problem in a bilinear way and optimize it using an iterative see-saw method, where each optimization step is solved via semidefinite programming. We further show that the same optimization framework can be adapted to problems in entanglement theory, such as identifying bound entangled states that maximally violate the Computable Cross Norm-Realignment criterion. Finally, we provide examples where two copies of a quantum state outperform a single copy, demonstrating metrological activation for certain small systems.

QI 20.6 Fri 10:45 BEY/0137

Localization and coherent control of 25 nuclear spins in Silicon Carbide — •Pierre Kuna[1], Erik Hesselmeier-Hüttman[1], Phillip Schillinger[1], Felix Gloistein[1], Viktor Ivády[2], Wolfgang Knolle[3], Jawad Ul-Hassan[4], Vadim Vorobyov[1], and Jörg Wrachtrup[1,5] — [1]3rd Institute of Physics, University of Stuttgart, Stuttgart, Germany — [2]Eötvös Loránd University, Hungary — [3]Department of Sensoric Surfaces and Functional Interfaces, Leibniz-Institute of Surface Engineering (IOM), Leipzig, Germany — [4]Department of Physics, Chemistry and Biology, Linköping University, Linköping, Sweden — [5]Max Planck Institute for solid state physics, Stuttgart, Germany

Nuclear spins coupled to optically addressable defects provide long-lived quantum memories[1] and scalable resources for quantum algorithms. For the V2 center in 4H-SiC, leveraging this potential requires precise knowledge of the surrounding nuclear-spin environment to refine DFT models and enable advanced multi-qubit algorithms[3,4].

We report ångström-level 3D localization of 25 naturally occurring 29Si and 13C spins around a single V2 center. Using correlation-spectroscopy SEDOR, Our work establishes a new state of the art in controlling nuclear spin cluster in 4H-SiC. By selecting multi-spin chains up to length four, we access and characterize new nuclear spins and reconstruct their couplings to the central electron and neighboring nuclei.

[1] M. Zhong, Nature 517, 177 (2015) [2] Abobeih, M.H., Nature 606, 884*889 (2022) [3] J. Randall*et al..Science374,1474-1478(2021)

30min. break

QI 20.7 Fri 11:30 BEY/0137

Charge sensing back-action on spin qubit readout using a micromagnet — •Sudipto Das[1], Domonkos Svastits[1,2], Aritra Sen[1], and Andras Palyi[1,3] — [1]Budapest University of Technology and Economics, Budapest, Hungary — [2]Qutility @ Faulhorn Labs, Budapest, Hungary — [3]HUN-REN-BME-BCE Quantum Technology Research Group, Budapest, Hungary

This work presents a theoretical framework for the charge-sensing readout of semiconductor spin qubits in double quantum dots. We explain the readout based on Pauli blockade spin-to-charge conversion and subsequent charge sensing via quantum point contact using the Qubit Measures Qubit model [1]. Our analysis focuses on n-type Silicon double quantum dots with micromagnets enabling resonant single-qubit control, explicitly accounting for the inhomogeneous micromagnet field and its modulation by charge-sensor shot noise.

Within this model, we quantify key readout errors-fidelity loss due to Zeeman-field modulation, mixedness of the post-measurement state, and leakage caused by perpendicular field fluctuations. We also incorporate the noise from charge sensors to understand its effect on readout. By studying their dependence on device parameters, including the orientation of the external magnetic field, we offer insights into readout performance optimization and readout sweet spots.

[1] D. Svastits, B. Hetényi, G. Széchenyi, J. Wootton, D. Loss, S. Bosco, and A. Pályi, Readout sweet spots for spin qubits with strong spin-orbit interaction, arXiv:2505.15878.

QI 20.8 Fri 11:45 BEY/0137

Quantitative inspection of quantum chips using SQUID-on-tip atomic force microscopy — •Daan B. Boltje[1], Jessalyn DeVine[1], Dalal Benali[1], Matthijs Rog[2], Tycho Blom[2], Milan P. Allan[3], Alessandro Bruno[4], Kaveh Lahabi[1,2], and Johannes Jobst[1] — [1]QuantaMap B.V., Leiden, The Netherlands. — [2]LION, Leiden University, The Netherlands. — [3]Faculty of Physics, LMU Munich, Germany. — [4]QuantWare B.V., Delft, The Netherlands.

The performance of quantum chips and the physics of quantum materials in general and are often dominated by local properties and or defects. Understanding those local properties requires microscopy that operates at cryogenic temperatures and that does not disturb the highly sensitive quantum effects it aims to reveal. In this talk, we will show measurements obtained with a tuning-fork, atomic force microscope (AFM) that integrates a nano-SQUID sensor on the tip. This design enables extremely short sensor-chip distances and robust height feedback in tapping-mode to prevent crashes, which would damage the SQUID sensor as well as the chip under study. It offers a non-invasive, purely electronic readout and magnetic sensitivity in and out-of plane. Frequency multiplexing permits simultaneous imaging of chip topography, magnetic fields, current flow and thermal dissipation on the nanoscale. We will show experiments from this novel microscope on magnetic and superconducting nanostructures of spin qubits and transmon quantum chips. We demonstrate how insights from this SQUID microscopy into material properties and local effects can be used to improve the quantum chips. [1] M. Rog et al. arXiv:2508.21575 (2025)