Q 14: Quantum Metrology and Sensing (joint session QI/Q)

Time: Monday 17:00–18:45 Location: HS VIII

Invited Talk Q 14.1 Mon 17:00 HS VIII

Precision measurement with nanoscale resolution — •Joerg Wrachtrup — University of Stuttgart, Center for Applied Quantum Technologies, 70569 Stuttgart — Max Planck Insitute for Solid State Research, Stuttgart, Germany

Solid state quantum sensors quantitatively measure a variety of parameters on nanometer length scales. In the talk I will show and discuss measurements on correlated electron materials. Recently we were e.g. measuring magnetic order in 2D twisted magnetic monolayers to uncover their Moiré periodicity of magnetization. It turns out that at specific twist angles new magnetic phases beyond the Moiré wavelength emerge which can be interpreted by a gradual modulation of anisotropy parameters. We also probe superconductivity in the 2D limit. We observe fractional vortices in two dimensional 2D NbSe2 superconductors. A close inspection reveals vortex dynamics leading to enhanced dephasing of the quantum spin probe. Our results hint at charge dynamics related to the unconventional band structure of the material.

Q 14.2 Mon 17:30 HS VIII

A comprehensive study of various optically pumped magnetometer schemes — •Marco Decker[1,2], Rafael Rothganger De Paiva[1,3], and René Reimann[1] — [1]Quantum Research Center, Technology Innovation Institute, Abu Dhabi, UAE — [2]Department of Physics and Research center OPTIMAS, RPTU Kaiserslautern-Landau — [3]Universidade Federal do ABC, Santo Andre, Sao Paulo, Brazil

Highly precise and accurate magnetic field sensing has real-world applications in non-destructive testing [1], biomedical imaging [2], and positioning and navigation [3]. Optically pumped magnetometers (OPMs) have proven to be a highly suitable choice to meet the requirements of these applications [4]. In this work, we present a comprehensive study of various OPM schemes and evaluate their feasibility for multiple use cases.

Comparing measurement schemes from published works is challenging due to varying gas mixtures, laser setups, and shielding conditions. We systematically evaluate the free induction decay (FID), nonlinear magneto-optical rotation (NMOR), Bell-Bloom, and other setup types, tested with Cs-133 vapor for various buffer gases and coatings. After comparing sensitivity, bandwidth, and dynamic range, we assess the suitability of these schemes for different deployment scenarios.

[1] S. Youssef, Journal of Nondestructive Testing 21, 19390 (2016); [2] P. K. Mandal, Front. Comput. Neurosci. 12 (2018); [3] A. J. Canciani, AFIT, Dissertation, https://scholar.afit.edu/etd/251 (2016); [4] D. Budker and M. Romalis, Nature Physics 3, 227-234 (2007)

Q 14.3 Mon 17:45 HS VIII

Spin Quantum Magnetometry and Gradiometry: Towards clinical applications in unshielded environments — •Magnus Benke, Jixing Zhang, Michael Kübler, Yihua Wang, Anjana Karuvayalil, and Jörg Wrachtrup — 3rd Physics Institute, University of Stuttgart, Stuttgart

Highly sensitive magnetometers are an essential tool for material analysis and medical applications. The Nitrogen Vacancy (NV) centers in diamond provides a promising candidate for a quantum sensor offering high sensitivity together with an exceptional spatial resolution while operating at ambient conditions. Current comparable technology also only has a limited dynamic range which makes it susceptible to background magnetic noise outside of shielded environments. The NV sensor with its broad dynamic range does not suffer from this limitation and can be used to form a gradiometric sensor array of two or more magnetometers to cancel any background fields. This enables unshielded measurements of small magnetic fields orders of magnitude smaller than the surrounding environment.

In this work we present a DC-broadband magnetometer with improved sensitivity reaching a photon shot noise limit of sub-pT/$\sqrt{\text{Hz}}$ using a CW-ODMR (Continuous-Wave Optically Detected Magnetic Resonance) measurement scheme. With two of these highly sensitive magnetometers, we build a gradiometer and achieved a reduction of an artificial background signal by 40 times without decreasing an applied test signal. These advancements open the door to magnetic field-related clinical applications in unshielded environments.

Q 14.4 Mon 18:00 HS VIII

Enhancing NV-center magnetometer sensitivity for quantum sensing using flux concentrators — •Anjana Karuvayalil[1], Jixing Zhang[1], Michael Kübler[1], Stephan Erlhoff[2], Magnus Benke[1], Yi hua Wang[1], Pascal Schmidt[1], Andrej Denisenko[1], Cheuk Cheung[1], and Jörg Wrachtrup[1] — [1]3rd Institute of Physics, University of Stuttgart — [2]Max Planck Institute, Stuttgart

Magnetic field sensing is a critical tool in fields such as geophysics, medical science, and magnetic field mapping. Existing magnetic field sensors, including OPMs and SQUIDs, provide high sensitivity but often come with limitations such as complexity or operational constraints. This work highlights the nitrogen-vacancy (NV) center-based magnetometer for its exceptional quantum properties making it more reliable for quantum sensing. The NV-center magnetometer achieved photon shot noise-limited sensitivity in the sub-picotesla range. This sensitivity can be further enhanced by incorporating flux concentrators near the diamond. These flux concentrators, designed and optimized using high permeable materials like MnZn and Permalloy, are capable of amplifying weak magnetic fields and significantly improving the effective sensitivity of the magnetometer. They are precisely machined to integrate seamlessly into the experimental setup. Continuous-Wave Optically Detected Magnetic Resonance (CW ODMR) is employed for measurements, with results showing that the use of flux concentrators leads to a 16-fold enhancement in sensitivity. This approach helps the detection of weak biosignals from muscles, the heart, and the brain.

Q 14.5 Mon 18:15 HS VIII

Activation of metrologically useful genuine multipartite entanglement — •Róbert Trényi[1,2,3,4], Árpád Lukács[1,4,5], Paweł Horodecki[6,7], Ryszard Horodecki[6], Vértesi Tamás[8], and Géza Tóth[1,2,3,4,9] — [1]Dept. of Th. Phys., UPV/EHU, Bilbao, Spain — [2]EHU Quantum Center, UPV/EHU, Bilbao, Spain — [3]DIPC, San Sebastián, Spain — [4]HUN-REN Wigner RCP, Budapest, Hungary — [5]Dept. of Math. Sci., Durh. Univ., UK — [6]Int. Cnt. for Theory of Quant. Tech., UG, Gdansk, Poland — [7]Fac. of Appl. Phys. and Math., Nat. Quant. Inf. Cnt., GUT, Gdansk, Poland — [8]HUN-REN Inst. for Nucl. Research, Debrecen, Hungary — [9]IKERBASQUE, Bilbao, Spain

Quantum states with metrologically useful genuine multipartite entanglement (GME) outperform all states without GME in metrology. States reaching the maximal utility in metrology all belong to this convex set of quantum states. With our proposed scheme, we can identify a broad class of practically important states that possess metrologically useful GME in the case of several copies, even though in the single copy case these states can be non-useful, i.e., not more useful than separable states. Thus, we essentially activate quantum metrologically useful GME. We discuss how our findings are related to error correction. We also analyze the iterative method applied to maximize the metrological usefulness for a given quantum state. In particular, we carry out an optimization of the metrological performance over possible local Hamiltonians with a see-saw method.

Q 14.6 Mon 18:30 HS VIII

Simulators of Quantum Dissipative systems — •Durga Dasari, Jixing Zhang, and Joerg Wrachtrup — 3. Physics Institute, University of Stuttgart, Stuttgart, GERMANY

Multipartite quantum correlations play a central role in our understanding of many-body physics, as they make them classically hard to compute. This difficulty is stimulating great efforts to quantum simulate these systems, i.e. to solve their dynamics using a highly controlled quantum spin system. Quantum simulators based on large spin ensembles can massively increase the Hilbert space, as control and readout happen globally. Equally, with controlled dissipation and decoherence, they can be ideal candidates to simulate open-quantum systems which are computationally more demanding when compared to Hamiltonian systems that are currently simulated. It is now an open question to demonstrate that the control is still sufficient to show a quantum advantage in these large systems, to simulate complex quantum many-body dynamics such that classical methods are systematically outperformed. In this talk we will show how such dissipative Quantum simulators can be realized in central spin systems theoretically, and present some initial experimental studies using the dipolar-coupled NV center ensembles in diamond.