TUE 12: Quantum Sensing and Decoherence: Contributed Session to Symposium III

Time: Tuesday 14:15–16:00 Location: ZHG105

TUE 12.1 Tue 14:15 ZHG105

Inelastic electron-light interaction probed by holographic scanning transmission electron microscopy — •Nora Bach[1,2], Tim Dauwe[1,2], Murat Sivis[1,2], and Claus Ropers[1,2] — [1]Max Planck Institute for Multidisciplinary Sciences, Göttingen, Germany — [2]4th Physical Institute, University of Göttingen, Germany

In an ultrafast transmission electron microscope (UTEM), inelastic scattering between free electrons and optical near fields allows for coherent manipulations of the electron quantum state [1]. Recently, different techniques have been developed to reveal the near-field phase imprinted onto the electron wave function, but offer only limited variability in tailoring the electron-light interactions and require a highly coherent electron source [2,3]. In this contribution, we introduce scanning transmission electron microscopy with spatially separated coherent electron probes [4] for the full imaging of complex optical near fields at relaxed coherence requirements. In the far field, these electron probes interfere to form a hologram from which we reconstruct phase shifts induced both by elastic scattering processes and by stimulated inelastic interactions. By superimposing multiple parallel interactions, our approach can be extended to tailoring of the electron spectral distribution beyond what is achievable with a single interaction.

[1] Feist et al., Nature 521, (2015)
[2] Gaida et al., Nature Communications 14, (2023)
[3] Gaida et al., Nature Photonics 18 (2024)
[4] Fehmi et al., Journal of Physics D: Applied Physics 51 (2018)

TUE 12.2 Tue 14:30 ZHG105

A nonlinear extension of crystallography - X-ray-optical wavemixing on valence charges — •Dietrich Krebs — Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

As we celebrate 100 years of Quantum Physics, the field of x-ray crystallography simultaneously approaches its 111th anniversary. Both fields are closely intertwined - with innumerable advances in solid-state and quantum physics being propelled by crystallography's outstanding ability to determine the structure of matter microscopically. Yet, crystallography itself never quite progressed into the quantum realm. Instead, it largely remains a method rooted in concepts of classical waves and (spherical) charge densities.

In this talk, we outline how ideas from nonlinear optics and the use of modern x-ray free-electron lasers (XFEL) help to extend crystallography to the next order, namely nonlinear crystallography. Basing this extension on x-ray-optical wavemixing, it offers atomic-scale resolution - similar to regular x-ray crystallography - combined with the spectroscopic sensitivity of optical techniques. We present our results from a recent XFEL-experiment, which demonstrate the feasibility of nonlinear crystallography on laser-excited diamond. In particular, we showcase the 3D-reconstruction of the newly accessible valence-response function, which agrees well with our theoretical predictions from nonrelativistic Quantum Electrodynamics.

TUE 12.3 Tue 14:45 ZHG105

Measurement of electron wave phase shifts with Angstrom spatial resolution to analyse electric double layers — Jonas Lindner[1], Ulrich Ross[1,2], Tobias Meyer[1], Sung Sakong[3], Axel Gross[3], Michael Seibt[2], and •Christian Jooss[1] — [1]Institute of Materials Physics, University of Goettingen, Germany. — [2]4th Institute of Physics, Solids and Nanostructures, University of Goettingen, Germany — [3]Institute of Theoretical Chemistry, University Ulm, Germany

Using phase shifting off-axis holography in a transmission electron microscope (TEM), phase shift measurements of electron waves with 1 Angstrom spatial resolution and $2\pi/452$ phase sensitivity was achieved. The detection of phase shifts is then applied to the measurement of atomic scale electric potentials of electric double layers at electrode water interfaces. The effect of inelastic scattering due to gas ambient on electron coherence is studied. The achieved progress in spatial resolution and phase detection allows us to observe ordered water layers at the dynamic state of a platinum (111) surface as well as water reorganization under applied electric potentials. The obtained projected electric potential of water dipole layers is quantitatively compared to ab-initio molecular dynamics simulations. The experimental results reveal an extended ordered water region. The bias-dependent reorientation of molecular dipole network gives new insights into the atomic scale electric field at Helmholtz layers and its impact on proton-coupled electron transfer at interfaces. Finally, we discuss general conclusions on quantum coherence of scattered matter waves.

TUE 12.4 Tue 15:00 ZHG105

Quantum Sensing with a Strongly Driven Spin — •Dhruv Deshmukh and Joachim Ankerhold — Institute for complex quantum systems, Ulm University, Germany

Quantum systems, when exposed to suitably-tuned strong time-periodic fields, may exhibit subharmonic dynamics, the most prominent case being that of period doubling. In this presentation, we introduce conditions required for period k-tupling dynamics to manifest in the simplest paradigmatic quantum system, namely, a single driven two-level system [1]. Experimental observations, with a driven NV centre, verifying period doubling and higher multiplicities up to period quintupling are showcased [2]. Building upon these results, we show how the period k-tupling dynamics can be used for quantum metrology with a few specific examples. First, we explain how the period doubling dynamics of a driven NV centre depends upon its temperature based zero-field splitting, making it a promising tool for thermometry. Next, we also show how the special case of period-1 dynamical freezing may be used for vector magnetometry due to its direction dependent sensitivity on magnetic field [1]. We also briefly discuss the possibilities of detecting neighbouring nuclear spins through their effect on the driven NV centre dynamics.

Research Articles (to be published soon): [1] Period k-tupling in Driven Two-Level Systems (Dhruv Deshmukh and Joachim Ankerhold) [2] Observation of period doubling and higher multiplicity in a driven single-spin system (Dhruv Deshmukh, Raúl B. González, Roberto Sailer, Ressa S. Said, Fedor Jelezko and Joachim Ankerhold)

TUE 12.5 Tue 15:15 ZHG105

Sensing Spins on Surfaces and Following them into Chemical Bonds with Scanning Probe Microscopy — •Dmitriy Borodin — IBS Center for Quantum Nanoscience, Seoul, South Korea

Spins on surfaces have been recently proposed as a promising qubit platform and also for atomic-scale quantum sensing. Control and readout are enabled by single atom electron spin resonance via scanning tunneling microscopes (ESR-STM).

In this work we show that quantum sensing can be enabled by following the electron spin resonance of a single molecule bound to the tip of a scanning probe microscope. We demonstrate that weak electrostatic and magnetic fields of single atomic objects can be quantified with sub-angstrom spatial resolution. The atomic-scale quantum sensor if universally applicable to conductive surfaces.

The spin lifetimes and phase coherence times (T1 and T2) of atomic spins on surfaces were so far limited by electron scattering with the metal - a limitation of STM based spin detection. Therefore, we have implemented sensing of single atom spins using the magnetic exchange force (MxF) between a magnetic tip and an ad-atom on the surface. Surprisingly, studying the spin-spin interaction we observe pattern that reflect the formation of a chemical bond between the surface bound atom and the magnetic atom at the tip.

TUE 12.6 Tue 15:30 ZHG105

Exploring Coherent Manipulation of Spin Systems via the Near-Field of a Modulated Electron Beam — •Thomas Spielauer[1], Matthias Kolb[1], Thomas Weigner[1], Johann Toyfl[1], Giovanni Boero[2], Dennis Rätzel[3], and Philipp Haslinger[1] — [1]VCQ, Technische Universität Wien, Atominstitut, Stadionallee 2, 1020 Vienna, Austria — [2]EPFL, BM 3110 Station 17, CH-1015 Lausanne, Switzerland — [3]ZARM, Universität Bremen, Am Fallturm 2, 28359 Bremen

Electron spin resonance (ESR) is a versatile analytical technique with broad applications in medicine, biology, and material science. While conventional ESR methods rely on magnetic field gradients or sophisticated resonator designs to provide spatial resolution, we explore an alternative approach utilizing the non-radiative near field of a modulated electron beam, implemented within a modified scanning electron microscope.

Our custom-built in-situ ESR platform allows us to investigate the interaction between the modulated electron beam and solid-state spin systems. Using a benchmark sample (Koelsch radical, α,γ-bisdiphenylene-β-phenylallyl) and a conventional ESR detection scheme, we observe signatures compatible with spin interactions driven by the collective non-radiative near field of the beam.

These findings establish a pathway toward coherent spin manipulation using a modulated, free-space electron beam, potentially enabling nanoscale spatial resolution for coherent quantum system control.

TUE 12.7 Tue 15:45 ZHG105

Direct imaging of magnetotransport at graphene-metal interfaces with a single-spin quantum sensor — •Chaoxin Ding, Marius Palm, Kevin Kohli, and Christian Degen — ETH Zurich, Zurich, Switzerland

Magnetotransport underlines many important phenomena in condensed matter physics, such as the Hall effect and magnetoresistance (MR) effect, and forms the basis for applications in magnetic memories and spintronic devices. Thus far, most magnetotransport studies have been based on bulk resistance measurements, without direct access to the nanoscale spatial transport pattern. Here, we discuss nanoscale quantum imaging of magnetotransport in a monolayer graphene with an embedded metal disc using a scanning nitrogen-vacancy magnetometer. By visualizing the current flow under an out-of-plane magnetic field around 0.5 T, we directly observe Lorentz-force-induced current deflection at the graphene-to-metal interface. As the carrier density in graphene increases, the current flowing through the graphene sheet is enhanced. In addition, we observe that the MR is more prominent in the ambipolar regime compared to the electron- or hole- doped regimes, which can be attributed to the intrinsic MR effect. Finally, we show that spatial current imaging uncovers non-uniform contact resistances along the circular graphene-metal interfaces, which cannot be easily identified by optical, electrical or topographic characterization.