MA 15: Focus Session: Quantum Sensing with Solid State Spin defects I (joint session TT/MA)

The electron spins of defects in solid state materials show remarkable quantum coherence, making them excellent sensors. Recent advances in material engineering and measurement techniques lead to continuous improvements in the sensitivity and resolution of established single spin sensors such as the Nitrogen-Vacancy center in diamond, and the development of new defect sensors in materials such as Silicon Carbide and hexagonal Boron Nitride. In condensed matter physics, such sensors are often being used for exploring the structure of magnets, superconductors, topological phases, etc. This focus session will highlight most of the recent experimental and theoretical advances, current challenges, and emerging directions, focusing both on the improvements of the defects themselves, and their use for exploring novel phenomena in condensed matter physics.

Coordinators: Aparajita Singha (TU Dresden), Uri Vool (Max Planck Institute for Chemical Physics of Solids)

Time: Tuesday 9:30–12:45 Location: HSZ/0003

Topical Talk MA 15.1 Tue 9:30 HSZ/0003
Exploring nanoscale van der Waals magnetism using single spin microscopy — •Patrick Maletinsky — Basel University, Departement of Physics, Klingelbergstrasse 82, 4056 Basel

Atomically thin van der Waals (vdW) magnets provide a unique platform to explore magnetism in the ultimate two-dimensional limit [1]. Their weak interlayer coupling, tunable anisotropy, and gate sensitivity enable engineering of magnetic order and spin textures at the atomic scale. However, their small magnetic moments, nanoscale domains, and complex coupling make them difficult to probe experimentally [2].

I will present recent progress in understanding vdW magnetism using single-spin magnetometry based on nitrogen-vacancy centers in diamond. This quantum-sensing technique enables nanoscale imaging of magnetic order, phase transitions in few-layer systems under ambient and cryogenic conditions. I will show how this approach reveals microscopic mechanisms of magnetism in layered materials and uncovers phenomena such as "lateral exchange bias" and spin-reorientation transitions in ultrathin magnets [3,4].

I will conclude with an outlook on how quantum sensors can advance the study of correlated and topological magnetism in vdW materials [5], and how combining them with strain, gating, or optical control may enable designer spintronic and magnonic systems.

[1] Science 363, 706; Nat. Nanotechnol. 14, 408 [2] Science 364, 973 [3] Nat. Commun. 15, 6005 [4] Nat. Commun. 16, 9725 [5] Nat. Rev. Phys. 6, 753

Topical Talk MA 15.2 Tue 10:00 HSZ/0003
Optically addressable spin defects in two-dimensional materials — •Vladimir Dyakonov — Julius-Maximilians-Universität Würzburg, 97074 Würzburg, Germany

Two-dimensional (2D) materials have emerged as the new playground for quantum photonics devices. Among them, hexagonal boron nitride (hBN) is an interesting candidate, mainly because of its crystallographic compatibility with different 2D materials, but also because of its ability to harbour optically active defects generating single photons. The negatively charged boron vacancy was the first intrinsic, optically addressable spin defect in hBN that allows coherent control at room temperature, as reported in 2020. [1] Although other types of spin centers have been found in this material since then, this spin-1 color center remains the only one with a clearly elucidated structure. Practical applications of hBN spin centres as intrinsic magnetic field, temperature, etc. sensors in van der Waals heterostructures are hence envisioned. To further boost the quantum sensing applications of this spin defect in hBN, we investigated the dynamics of the intermediate state, because it is likely to trap electrons for a certain time, which affects the subsequent sensing protocol when the pulsed magnetic resonance experiment is designed.[2] Finally, we found that spin defects exhibit a direct correlation between Raman features and PL intensity, which allowed us to develop an all-optical method for determining the absolute spin defect density in flakes. [3]

[1] A. Gottscholl et al., Nat. Mater. 19, 540 (2020)
[2] P. Konrad et al., arXiv:2503.22815 [quant-ph] (2025)
[3] A. Patra et al., Adv. Funct. Mater. e17851 (2025).

Topical Talk MA 15.3 Tue 10:30 HSZ/0003
Nitrogen vacancy centers in diamond as novel sensing and imaging tool for magnetic nanostructures, in life science and chemistry — Sebastian Westrich[1], Nikhita Khera[1], Emma Resmann[1], Ephraim Spindler[1], Kristin Kühl[1], Alena Erlenbach[1], Mathias Weiler[1], Georg von Freymann[1], Artur Widera[1], Maria Wächtler[2], Stefanie Müller-Schüssele[3], and •Elke Neu-Ruffing[1] — [1]Department of Physics and Research Center Optimas, RPTU Kaiserslautern Landau, Erwin-Schrödinger-Straße 56 67663 Kaiserslautern — [2]Institut für Physikalische Chemie, Christian-Albrechts-Universität zu Kiel — [3]Department of Biology, RPTU Kaiserslautern Landau

Nitrogen vacancy centers (NV centers) locally probe magnetic fields, electric fields and temperature. Advantages of NV sensors include their sensitivity for fluctuating magnetic fields, which can be harnessed e.g. to detect free radicals. Additionally, near field based energy transfer serves as sensing resource to detect optically-active dipoles in close proximity. The talk will summarize our work on using scanning NV-based magnetometry to characterize magnetic nanostructures, including calibrating the scanning NV's position with respect to the sample. We highlight work on imaging frustrated magnetic systems (spin ice) as well as magnetic structures obtained via Direct Laser Writing. As another route towards broadening the field of applicability, we demonstrate for the first time near field energy transfer between NV centers and a naturally occuring fluorophore, namely chlorophyll. We furthermore explore routes to employ NV centers as sensor in photocatalysis.

15 min. break

Topical Talk MA 15.4 Tue 11:15 HSZ/0003
Electron spin, nuclear spin, and optical properties of transition-metal defects in silicon carbide with perspectives for quantum technologies — •Guido Burkard — Department of Physics and IQST, University of Konstanz, 78457 Konstanz, Germany

Transition-metal (TM) defects in silicon carbide (SiC) have emerged as a promising solid-state platform for quantum technologies, particularly because certain species, such as vanadium, provide optical emission in the telecom band and thus enable efficient spin-photon interfaces and quantum memories. In parallel, high-spin nuclei in solids are attracting growing interest for quantum information processing due to their long coherence times and intrinsically large Hilbert spaces, which support advanced protocols in quantum communication, measurement-based quantum computing, and quantum sensing, as well as explorations of fundamental quantum phenomena. A scalable route toward quantum networking relies on modular devices that combine an optically addressable electronic spin with one or more nuclear-spin qudits. We present a theoretical framework for TM defects in SiC. We model the spin and optical structure of a single active 3d electron, revealing how crystal fields and spin-orbit coupling modify selection rules, the g-tensor, and Rabi dynamics. We derive the effective hyperfine interaction within the spin-orbit-induced Kramers doublets and analyze nuclear-electron state transfer. Building on these insights, we propose a driven, dissipative protocol for robust nuclear-spin polarization and investigate how strain engineering can tailor electronic levels, optical Λ systems, and spin initialization pathways.

Topical Talk MA 15.5 Tue 11:45 HSZ/0003
Statics and dynamics of complex magnetic states in mi-

crostructures — •Aurore Finco — Laboratoire Charles Coulomb, CNRS and University of Montpellier, Montpellier, France

Scanning NV center microscopy is a versatile technique allowing both the mapping of static magnetic textures [1] and of microwave fields, which can be generated for example by spin waves. Here I will focus on the investigation of microstructures.

I will first show how we can use magnetoelectric coupling in the antiferromagnetic multiferroic bismuth ferrite to pattern a thin film using electric field and create whirling textures of both electric polarization and magnetization [2].

In a second part, I will discuss ferromagnetic microstructures, in the room-temperature van der Waals magnet Fe_5GeTe_2, demonstrating the stabilization of vortices [3], and in permalloy, which hosts either a S state or a vortex. In this material and when choosing the appropriate dimensions for the microstructures, spin wave modes with frequencies in the vicinity of 2.87 GHz are present and can therefore be probed and imaged. Through the handedness of the stray field that these spin wave mode produce, we can even discriminate between several modes with similar frequencies.

[1] Finco and Jacques, APL Materials 11, 100901 (2023)
[2] Chaudron et al, Nature Materials 23, 905 (2024)
[3] Sfeir et al, Physical Review Materials 9, 114003 (2025)

MA 15.6 Tue 12:15 HSZ/0003

Probing Vortex Dynamics in 2D Superconductors with Scanning Quantum Microscope — •Malik Lenger[1], Sreehari Jayaram[1], Lucas Pupim[2], Ruoming Peng[1], Mathias Scheurer[2], Jurgen Smet[3], and Jörg Wrachtrup[1,3] — [1]3rd Institute of Physics, University Stuttgart, Stuttgart, Germany — [2]Institute for Theoretical Physics III, University Stuttgart, Stuttgart, Germany — [3]Max Planck Institute for Solid State Research, Stuttgart, Germany

Magnetic dynamics at the nanoscale provide crucial insight into the behavior of superconductors. Using single-spin scanning quantum microscopy, we probe vortex dynamics in the two-dimensional superconductor NbSe2. Our measurements reveal a disordered vortex glass phase that melts near the critical temperature and displays cooling-rate-dependent configurations. Surprisingly, magnetic noise persists well below Tc, with a strength that increases at lower temperatures - contrary to expectations. This behavior, detected via spin decoherence, points to an intrinsic origin driven by competition between supercurrent density and thermal fluctuations. Our results establish single-spin microscopy as a powerful platform for investigating fluctuations in 2D superconductors.

MA 15.7 Tue 12:30 HSZ/0003

Quantum sensing of a synthetic 3D spin texture — •R. J. Peña Román[1,2,3], S. Maity[1,2], F. Samad[4,5], S. Josephy[6], A. Morales[6], S. Chattopadhyay[1,3], A. Kákay[4], K. Kern[2,7], O. Hellwig[4,5], and A. Singha[1,2,3] — [1]IFMP, Dresden University of Technology — [2]Max Planck Institute for Solid State Research — [3]Wurzburg-Dresden Cluster of Excellence (ct.qmat) — [4]Institute of Ion Beam Physics and Material Research, Helmholtz-Zentrum Dresden-Rossendorf — [5]Insititute of Physics, Chemnitz University of Technology — [6]QZabre AG, Zurich — [7]Institute de Physique, École Polytechnique Fédérale de Lausanne

Multilayered synthetic antiferromagnets (SAFs) are artificial three-dimensional (3D) architectures engineered to create novel, complex, and stable spin textures. Magnetic imaging of the spin texture is a crucial step for achieving tailored material performance and new functionalities. However, the deterministic detection of the magnetic textures and their quantitative characterization at the nanoscale remains challenging. Here, we use nitrogen-vacancy scanning probe microscopy under ambient conditions to perform quantitative vector-field magnetometry in a multilayered SAF. We demonstrate distinct fingerprints emerging from spin noise and constant stray fields, providing insights into the structure of domains and domain walls, as well as into magnetic noise associated with thermal spin waves. Combined with modern machine learning approaches, this work opens up new possibilities for quantitative magnetometry in materials with tailored and complex 3D spin textures.