QDiamond 2025
Mátraháza Academic Scholar Resort, Hungary
February 24-27, 2025

QDiamond 2025 - Program					
	Mon., Feb. 24	Tue., Feb. 25	Wed., Feb. 26	Thu., Feb. 27	
08:00-09:15	Dominik Bucher	Christian Degen	Fedor Jelezko	Dmitry Budker	08:00-09:15
09:15-10:30	Gavin Morley	Tim Taminiau	Michael Trupke	Ania Jayich	09:15-10:30
10:30-11:00	**coffee break**		**coffee break**		10:30-11:00
11:00-12:15	Carlos Meriles	Adam Gali	Alex Retzker	Toeno van der Sar	11:00-12:15
12:15-13:30	**lunch**		**lunch**		12:15-13:30
13:30-14:45	Cristian Bonato	Tanja Weil	Milos Nesladek	Nabeel Aslam	13:30-14:45
14:45-16:00	Fazhan Shi	Patrick Maletinsky	Steven Prawer	Ren-Bao Liu	14:45-16:00
16:00-16:30	**coffee break**		**coffee break**		16:00-16:30
16:30-17:45	Amit Finkler	Shimon Kolkowitz	Nathalie de Leon	Vincent Jacques	16:30-17:45
18:30	**dinner**				18:30

New developments in sensing with diamond electron and nuclear spins

Ashok Ajoy, UC Berkeley, ashokaj@berkeley.edu

I will present our experiments leveraging electron and nuclear spins out of equilibrium to build sensitive, deployable chemical sensors. These sensors utilize ^{13}C nuclei in diamond which are optically hyperpolarized to levels thousands of times greater than thermal equilibrium. These nuclei also exhibit extended coherence lifetimes ($T_2' > 800$ seconds), enabling their use in a range of applications. These include serving as sensitive quantum sensors for detecting time-varying magnetic fields, enhanced imaging agents, and for creating optically rewritable, nanometer-scale spin textures. They also provide a novel platform for exploring non-equilibrium physics.

By incorporating them in nanoparticle form, we demonstrate the versatility of these sensors, deploying them in diverse environments such as manufactured materials, single-cells, and living plants, and in flowing microdroplet emulsions. In these dynamic settings, we show the potential for sensitive chemical assays. Finally, we show the ability to extend this approach to a broader class of materials harnessing chemical synthesis.

Exploring nanoscale NMR with NV centers: quantum memories, nanostructures, and 2D superconductors

Nabeel Aslam, U. Leipzig, nabeel.aslam@uni-leipzig.de

In this talk, I will present recent advances in NV center-based nanoscale sensing and spectroscopy, with a focus on overcoming key limitations through the integration of single nuclear spins and tailored nanostructures. In the first part, I will discuss how single nuclear spins coupled to NV centers act as quantum memories, enabling enhanced functionality in diverse applications. Specifically, I will highlight their role in nanoscale NMR spectroscopy to achieve high spectral resolution and in hybrid systems where they enable coherent storage of phase information. In the latter case, we demonstrate how nuclear spins maintain quantum coherence, even while the NV center spin is exposed to dynamic magnetic gradient fields generated by micromagnets on mechanical resonators. The second part will center on our development of the nanowell platform in diamond, designed to confine liquid-state samples and address diffusion limitations in NV-based nanoscale NMR spectroscopy. By integrating NV centers within these nanowells, we achieve improved NMR detection efficiencies and precise sample colocalization, which could pave the way for practical applications of nanoscale NMR in biochemistry and molecular analysis. Finally, I will discuss the application of NV-based nanoscale NMR to study the pairing symmetry in 2D superconductors, using niobium diselenide ($NbSe_2$) as a model system. Conventional NMR spectroscopy was performed on bulk $NbSe_2$ to investigate electronic behavior across the charge density wave (CDW) and superconducting phases, serving as a reference. Building on this, exfoliated $NbSe_2$ flakes were transferred onto diamond surfaces and studied optically. We examined the spin properties of NV centers beneath the flakes to assess their suitability for nanoscale NMR in such systems. These findings demonstrate the versatility of NV centers for advancing both fundamental research and practical applications.

Adaptive learning for quantum sensing

Cristian Bonato, Heriot-Watt University, c.bonato@hw.ac.uk

In this talk, I will describe our work in spin quantum sensors enhanced by machine learning [1].

I will describe our effort to develop "smart" spin-based quantum sensors that self-optimise themselves, in real-time, to operate in the regime of maximum sensitivity [2-5]. I will present an adaptive approach, based on Bayesian inference, to estimate the key decoherence timescales (T_1, T_2^* and T_2) and the corresponding decay exponent for a single qubit, using information gained in preceding experiments. This approach reduces the time required to reach a given uncertainty by a factor up to an order of magnitude, depending on the specific experiment, compared to curve fitting data taken on a pre-determined parameter range. I will further discuss our ongoing work on the estimation of multiple parameters, through variational Bayesian inference approaches, and its application to the optimisation of nanoscale magnetic resonance experiments [6]. Smart quantum architectures, that self-optimise themselves to automatically operate with optimal settings, will significantly facilitate the adoption of quantum technologies by non-expert users.

To conclude, I will describe some recent work on developing an algorithm, based on Markov-chain Monte Carlo, to automatically construct Lindblad master equation models for Markovian open quantum systems, from experimental data [7]. While we benchmark the algorithm on experimental data on two optical quantum dots, our approach is very general and can be deployed to the characterisation of novel unknown quantum systems. We envision the algorithm to suggest to the experimenter possible alternative models that they might not have thought about when designing the experiment, and to help them ensure that the proposed theoretical mechanisms are the only possible interpretation of the experimental data.

[1] V. Gebhart et al., Nat. Rev. Phys. 5, 141 (2023)

[2] C. Bonato et al., Nat. Nanotechnol. 11, 247-252 (2016)

[3] H. Dinani et al., Phys. Rev. B 99, 125413 (2019)

[4] I. Zohar et al., Quantum Sci. Technol. 8, 035017 (2022)

[5] M. J. Arshad et al., Phys. Rev. Appl. 21, 024026 (2024)

[6] R. Budakian et al., Nanotechnology 35, 412001(2024)

[7] S. Wallace et al., arXiv 2410.17942 (2024)

NV-diamond-based magnetic resonance techniques for probing chemistry

Dominik Bucher, TU Munich, dominik.bucher@tum.de

Nitrogen vacancy (NV) centers in diamond have emerged as a versatile platform for nano- and microscale sensing applications. In this talk, I will highlight our recent advances in the use of NV centers for nano- and microscale NMR spectroscopy and microscopy in chemical analysis. In the first part of my talk, I will discuss nanoscale magnetic resonance techniques for probing surfaces and interfaces with applications in materials science and catalysis. In the second part, I will discuss microscale NV-NMR and present recent results including NV-NMR in microfluidic systems, microscale diffusion measurements, and the development of wide-field optical magnetic resonance microscopy. The remaining obstacles of this novel technology and future goals will be discussed in the concluding part.

Cryogenic color center quantum light microscope and other tools to play with diamond

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We are commissioning a new instrument built for us by attocube for color center research that incorporates a closed-cycle cryostat for the operation from 1.7 to 350 K, a 5 T×2 T×2 T vector magnet, wide-field, confocal, and magnetooptical Kerr effect detection modalities, sample scanning, and other features. I will discuss the physics we plan to do with this instrument as well as microwave-free magnetometry techniques and some of their recent applications.

Nanoscale covariance magnetometry with diamond quantum sensors

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Correlated phenomena play a central role in condensed matter physics, but in many cases there are no tools available that allow for measurements of correlations at the relevant length scales (nanometers - microns). We have recently demonstrated that nitrogen vacancy (NV) centers in diamond can be used as point sensors for measuring two-point magnetic field correlators. NV centers are atom-scale defects that can be used to sense magnetic fields with high sensitivity and spatial resolution. Typically, the magnetic field is measured by averaging sequential measurements of single NV centers, or by spatial averaging over ensembles of many NV centers, which provides mean values that contain no nonlocal information about the relationship between two points separated in space or time. We recently proposed and implemented a sensing modality whereby two or more NV centers are measured simultaneously, from which we extract temporal and spatial correlations in their signals that would otherwise be inaccessible. We demonstrate measurements of correlated applied noise using spin-to-charge readout of two NV centers and implement a spectral reconstruction protocol for disentangling local and nonlocal noise sources. This novel quantum sensing platform will allow us to measure new physical quantities that are otherwise inaccessible with current tools, particularly in condensed matter systems where two-point correlators can be used to characterize charge transport, magnetism, and non-equilibrium dynamics.

Toward time-resolved quantum sensing

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Over five years have passed since the last QDiamond conference. In this talk, I will discuss some of the efforts we undertook during this time, including work towards adding time resolution to quantum sensors, a revisit of the optical stability of near-surface NV defects, new directions in diamond probe fabrication, and applications of scanning magnetometry to various condensed-matter systems.

Using NVs for nanoscale MRI

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Nanoscale magnetic resonance imaging (nanoMRI) has been proposed and shown originally by Dan Rugar [1] and was demonstrated using the nitrogen-vacancy center in diamond [2]. In both approaches, the method of creating the necessary high magnetic field gradient makes use of a permanent magnet, which prevents one from using this technique with state-of-the-art quantum sensing pulse sequences (due to mixing of the eigenstates).

Inspired by the magnetic resonance force microscopy community [3], our approach makes use of a quartz tip, which is coated with a gold wire reaching all the way to its apex (see figure). The magnetic field gradient created in this way can be turned on and off at will, allows for a spectral separation as high as 1 μG/nm, and can be moved around in proximity with the sample using atomic-force feedback.

I will present the fabrication process, followed by an in-depth analysis of the resulting gradient properties, and explain how this apparatus can be used to perform MRI on single molecules [4]. Finally, I will also present an unexpected but extremely useful property of this magnetic-gradient-on-a-tip, namely the concentration of field lines at the position of the NV, leading to a six-fold increase in Rabi periods.

Combined with other methods developed in our group [5-7], which I will also overview, such on-demand magnetic field gradients are set to enable the use of quantum sensors as practical tools for nanoscale magnetic resonance imaging of molecules.

[1] D. Rugar et al., Nature 430, 329-332 (2004)

[2] M. Grinolds et al., Nat. Nanotechnol. 9, 279 (2014)

[3] W. Rose et al., Phys. Rev. X 8, 011030 (2018)

[4] L. Schein-Lubomirsky et al., arXiv 2409.17690

[5] D. Yudilevich et al., Phys. Rev. Appl. 18, 054016 (2022)

[6] I. Zohar et al., Quantum Sci. Technol. 8, 035017 (2023)

[7] D. Yudilevich et al., New J. Phys. 25, 113042 (2023)

Defect qubits in realistic environment from first principles

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Most of the defect qubits in diamond is negatively charged so they require nitrogen donors to stabilize the desired charge state of the defect qubits. Since the ionization energies of these defects are deep they are not freely ionized at room temperature so the exchange of carriers occurs at extremely long timescales in dark unless the nitrogen donors reside close to the defect qubits. Furthermore, all the known defect qubits in diamond are dopant-vacancy complexes. If these defects are created by irradiaton techniques then residual vacancy clusters may reside close to the defect qubits. As a consequence, the observed defect qubits in diamond are rarely well isolated and the interaction of the defect qubits with the nitrogen donors or the vacancy clusters affects their qubit operation, e.g., spin relaxation and coherence times, spectral diffusion, and other properties. Illumination applied to control of the qubits may initiate photoionize these defects and induce charge transfer between them.

We developed models to accurately simulate and compute this complex environment by means of first principles calculations. We applied our method to understand cryogenic quantum sensing or the role of electrolyte in the enhancement of spin relaxation time of the near-surface nitrogen-vacancy center. We further develop a microscopic theory for the spectral jumps and diffusion of inversion symmetric defect qubits. We show that illumination creates fixed charges close to the defect qubits which induce a “built-in” electric field with explaining previous observations. Furthermore, we show for the silicon-vacancy center that it likely incorporates together with nitrogen donors during the chemical vapor deposition of diamond. We find that the interplay between these defects mediates the photocurrent signal from quasi single silicon-vacancy defects in their optically inactive double negative charge state.

Quantum sensing with spin defects in hexagonal boron nitride

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Quantum sensors based on optically-active spin defects in semiconductors have found a broad variety of applications, in both basic and applied science, due to their unprecedented combination of sensitivity, spatial resolution and ability to operate under a wide range of experimental conditions. While the most prominent example is undoubtedly the nitrogen-vacancy (NV) center in diamond, the exploration of alternative spin defects and host materials remains an active field of research worldwide. In this context, the negatively-charged boron vacancy (V_B) center in hexagonal boron nitride (hBN) is currently attracting a growing interest for the development of quantum sensing and imaging technologies on a two-dimensional (2D) material platform. This point defect, which can be readily created by various irradiation methods, has a spin triplet ground level whose electron spin resonance frequencies can be measured optically under ambient conditions and strongly depends on external perturbations. In this talk, I will describe our recent research work aimed at developing quantum sensing foils based on V_B centers in hBN.

Sensing with NV centers: from one spin to many spins

Ania Bleszynski Jayich, UC Santa Barbara, ania@physics.ucsb.edu

Nitrogen vacancy (NV) center spins in diamond are well-established as leading quantum sensors for probing a variety of magnetic phenomena at the nano- and micro-scales. However, experiments to date have primarily leveraged either single NV centers or ensembles of non-interacting NV centers. Here I discuss experimental progress towards leveraging strongly-interacting spin ensembles for enhanced quantum sensing. In particular, I discuss the synthesis of strongly interacting ensembles, their characterization using the decoherence dynamics of the spins themselves, and schemes to engineer metrologically useful entangled states.

Scaling up diamond spin qubits

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Optically active spin qubits in diamond have recently emerged as a candidate material for a range of quantum-based applications, including quantum information processing, quantum communication and quantum sensing. In this talk, we will show the realisation of a spin-based solid-state architecture for a scalable quantum register consisting of strongly dipolarly coupled electron spins associated with NV centres and nuclear spins. Elements of quantum networks and quantum light-matter interface enabled by single GeV colour centres will be presented.

Scalable parallel measurement and control over individual nitrogen-vacancy centers in diamond

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The nitrogen-vacancy (NV) center in diamond has been widely adopted as a quantum sensor, and is now even used in undergraduate instructional labs as a model quantum system. However, despite its ubiquity and popularity, basic properties of the NV center remain poorly understood. In addition, most work has been restricted to measurements of one NV center at a time, or to globally averaged measurements of ensembles of many of NV centers. In this talk I will first present a recent experimental and theoretical study of temperature and spin-state-dependent spin-phonon relaxation rates in the electronic ground state spin-triplet of NV centers in diamond, and will discuss how these new insights could lead to magnetometers with enhanced sensitivity. I will also explain how these results led us to a simple, analytical, physically motivated expression for the temperature dependence of the zero-field splitting of the NV center electronic ground state, with applications to nanoscale thermometry. I will then present our experimental demonstration of spatiotemporal magnetic field correlation measurements with pairs of NV centers, including the ability to distinguish between global and local noise sources, and the capability to measure signals of interest using free precession times beyond the apparent single NV coherence time in certain regimes. Finally, I will present a new experimental platform we have developed for simultaneously manipulating and independently measuring dozens of single NV centers in parallel.

Quantum nonlinear spectroscopy via a single spin quantum sensor

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The correlators of a quantum system that can be extracted by classical nonlinear spectroscopy reflect how the quantum system evolves under a classical force. When a quantum sensor is coupled to a quantum system, the effect can be viewed as either the quantum system is driven by the force from the sensor, or the sensor is affected by the noise from the system. The "delayed choice" in quantum mechanics makes it possible to select which of these two "worldviews" is realized by setting the initial state of the sensor before the coupling and selecting a basis to measure the sensor after the coupling. This way, the quantum nonlinear spectroscopy (QNS) can obtain $2^{(N-1)}$ different types of correlators after N shots of interrogation between the sensor and the system, while the classical nonlinear spectroscopy in the same order can determine one type of correlators. In the sense that the scope of accessible correlators by quantum sensing is exponentially larger than those by the classical method, the QNS represents a kind of quantum supremacy in the realm of sensing and metrology. The QNS can be realized using correlations of sequential weak measurements or synthesized quantum channels. I will explain the concept of QNS and several applications, including the classical-noise-free detection of quantum objects, distinction between classical and quantum noises, and approaches to studying non-Gaussian fluctuations in critical quantum many-body systems.

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Opportunities, puzzles, challenges in the photophysics of diamond color centers

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Quantum two-level systems offer attractive opportunities for sensing and imaging — especially at the nanoscale. In the almost twenty years since its inception, this idea [1] has evolved from proof of concept [2] to a mature quantum technology [3-5], with applications spanning physics, materials engineering, and life sciences.

In this talk, I will present our recent findings on the photophysical properties of diamond color centers for nanoscale quantum sensing under cryogenic conditions. For the Nitrogen-Vacancy (NV) center, we identified previously unexplored spin-mixing excited state level anticrossings at specific strain and magnetic field combinations [6], where NV spin initialization and readout are impaired. While these features limit magnetometry performance, our fully quantitative model of NV photophysics [6] and its temperature-dependent extension [7] provide new insights into the NV's electronic structure and enable novel sensing schemes, such as all-optical NV electrometry.

Additionally, I will discuss our work on Silicon-Vacancy (SiV) centers in diamond, advancing them as all-optical magnetometers for operation in extreme conditions, including Tesla-range magnetic fields and sub-Kelvin temperatures. We demonstrated deterministic creation of shallow SiV centers with lifetime-limited optical lines [8] and achieved SiV charge state control via laser-induced surface oxidation of diamond [9].

Beyond their fundamental significance in understanding color centers in wide-bandgap semiconductors, these results inform optimal sensing strategies for NV magnetometry and open new avenues in quantum sensing, particularly for probing strongly correlated electron systems.

[1] B. Chernobrod and G. Berman, *J. Appl. Phys.*, **97**, 014903 (2005).

[2] G. Balasubramanian et al., *Nature*, **455**, 648 (2008).

[3] P. Appel et al., *Rev. Sci. Instrum.*, **87**, 063703 (2016).

[4] N. Hedrich et al., *Phys. Rev. Appl.*, **14**, 064007 (2020).

[5] www.qnami.com

[6] J. Happacher et al., *Phys. Rev. Lett.*, **128**, 177401 (2022).

[7] J. Happacher et al., *Phys. Rev. Lett.*, **131**, 086904 (2023).

[8] J. Zuber et al., *Nano Lett.*, **23**, 10901 (2023).

[9] Z.-H. Zhang et al., *Phys. Rev. Lett.*, **130**, 166902 (2023).

Quantum sensing of mesoscale electric couplings between point charges in diamond

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Color centers in semiconductors are being actively explored as a platform for quantum information science and nanoscale sensing but most attention thus far has been centered on the spin and optical degrees of freedom. Using the nitrogen-vacancy (NV) center in diamond as a paradigm, this presentation will survey recent results showcasing instead the use of electric interactions in the form of direct Coulombic couplings with proximal traps or photogenerated carriers. Specifically, we will discuss how to leverage statistical correlations in the spectral fluctuations of optical transitions in sub-diffraction NV clusters to pinpoint the relative three-dimensional positions of interacting NVs as well as the location and charge sign of surrounding traps. We will also describe the use of single-shot charge readout to monitor single events of hole capture in negatively charged NVs, a process made possible through the formation of transient Rydberg states featuring radii approaching 1 μm. These results create opportunities for new sensing modalities of electric fields with increased sensitivity, and for establishing interactions between color centers over a spatial range exceeding that possible via magnetic couplings.

Nitrogen-vacancy centres in diamond and nanodiamond for magnetometry and towards a test of quantum gravity

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We have built a fibre-coupled diamond magnetometer achieving a sensitivity of 30 pT/$\sqrt{\text{Hz}}$ in the frequency range from 10-500 Hz [1]. This is the most sensitive fibre-coupled diamond magnetometer apart from one using magnetic flux concentrators. We use this to monitor moving machinery and detect damage in steel [2]. To improve our ability to detect damage in steel we have demonstrated the first tensor gradiometry using a diamond sensor [3]. We have also driven our magnetometer around on the road [4].

In separate experiments, we diamagnetically levitate individual microdiamonds in vacuum, towards tests of fundamental physics. We aim to use a spin superposition of a nitrogen-vacancy (NV) centre to put the microdiamond into a superposition of being in two places at once [5,6]. This version of Schrödinger's cat would be able to test theories of wavefunction collapse. This is the first step of a much more ambitious experiment to test if gravitational effects can be in a quantum superposition: can gravity entangle things [7]? The NV centres in the nanodiamonds we have developed for this have the longest spin coherence times and the longest longitudinal spin relaxation times which will make them useful for quantum sensing [8,9].

[1] S. M. Graham et al., Phys. Rev. Appl. 19, 044042 (2023)

[2] L. Q. Zhou et al., Phys. Rev.Appl. 15, 024015 (2021)

[3] A. J. Newman et al., Phys. Rev. Appl. 21, 014003 (2024)

[4] S. M. Graham et al., Diam. Relat. Mater. 152, 111945 (2025)

[5] M. Scala et al., Phys. Rev. Lett. 111, 180403 (2013)

[6] B. D. Wood, S. Bose & G. W. Morley, Phys. Rev. A 105, 012824 (2022)

[7] S. Bose et al., Phys. Rev. Lett. 119, 240401 (2017)

[8] B. D. Wood et al., Phys. Rev. B 105, 205401 (2022)

[9] J. E. March et al., Phys. Rev. Appl. 20, 044045 (2023)

Reviewing the Electrical Spin State Readout: Solid-state and Quantum Physics

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In this talk we review the photelectric spin readout applied to diamond NV spins. Since our first work on this topic [1], despite its potential [2,3] such as lower shot noise limits and scalability [2,3], the performance of this approach is still by far not optimal. This includes difficulties in achieving reproducible readout both for single NVs or ensembles and the signal and charge state stability. Addressing these issues from the point of view solid-state and defect physics is the primary goal of this talk. In the second part of the talk we review the current-state of the art of quantum protocols, applied on photoelectric readout, and solutions for single qubit and enable driving and readout, qubit gates and application to sensing and prospects for entanglement-based sensing.

[1] E. Bourgeois et al., Nat. Commun. 6, 8577 (2015)

[2] P. Siyushev, M. Nesladek et al., Science 363, 728-731 (2019)

[3] M. Gulka, D. Wirtitsch et al., Nat. Commun. 12, 4421 (2021)

Quantum control for sensing and hyperpolarisation

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In this lecture I will present our recent work on the development of families of nuclear spin hyperpolarisation sequences which find applications in both, dynamic nuclear polarisation based on colour centers in diamond and para-hydrogen induced polarisation thanks to a mathematical equivalence between the two settings.

Techniques for the optimization of diamond surfaces for quantum applications

Steven Prawer, University of Melbourne, s.prawer@unimelb.edu.au

The diamond surface plays a crucial role in controlling the properties of quantum emitters in the near surface region. Various UHV techniques, such as XPS, UPS, NEXAFS, and confocal microscopy can be used to monitor the properties of the surface in the search for the optimum parameters for surface treatments. Here we show that measurements of the electrochemical properties of the surface in solution provides a surprisingly simple, but highly sensitive method to find the optimal parameters for surface treatments. We use the technique to compare various methods commonly used to terminate the diamond surface with oxygen and find that annealing in flowing oxygen for 24 hours provides the best surface termination. We interpret these results in terms of the effects of residual sp^2 defects on the surface on the electronic band structure in the near surface region.

Techniques for the optimization of diamond surfaces for quantum applications

Alex Retzker, Hebrew University of Jerusalem, retzker@phys.huji.ac.il

Decoherence and imperfect control are crucial challenges for quantum technologies. Common protection strategies rely on noise temporal autocorrelation, which is not optimal if other correlations are present. We developed and demonstrated experimentally a strategy that utilizes the cross-correlation of two noise sources [1]. We achieve a tenfold coherence time extension by destructive interference of cross-correlated noise, improve control fidelity, and surpass the state-of-the-art sensitivity for high frequency quantum sensing, significantly expanding the applicability of noise protection strategies.

In the second part of my talk, I will discuss a strategy that we have developed [2] to reach the ultimate precision limit. The ultimate precision limit in estimating the Larmor frequency of N unentangled rotating spins is well established, and is highly important for magnetometers, gyroscopes and many other sensors. However, this limit assumes perfect, single addressing, measurements of the spins. This requirement is not practical in NMR spectroscopy, as well as other physical systems, where a weakly interacting external probe is used as a measurement device. In this talk I will show that in the framework of quantum nano-NMR spectroscopy, in which these limitations are inherent, the ultimate precision limit is still achievable using control and a finely tuned measurement.

[1] A. Salhov et al., Phys. Rev. Lett. 132, 223601 (2024)

[2] D. Cohen et al., npj Quantum Inf. 6, 83 (2020)

Microscale magnetic resonance spectroscopy with an optimal sensitivity spin sensor in diamond

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Quantum sensing with Nitrogen-Vacancy (NV) centers has opened a new way for magnetic resonance spectroscopy of a single molecule at a few nanometers. For both of nanoscale NMR and single-molecule ESR, shallow NV centers in diamond are needed, while its property is heavily effected by the surface noise. Usually we should balance the distance from surface and the quantum features of NVs. In this talk, I will firstly introduce our results on optimal magnetic sensitivity of a single NV center and how to improve it step by step. The best sensitivity of a single shallow NV center is achieved as 0.6 nT/$\sqrt{\text{Hz}}$, while the distance is roughly 30 nanometers from the diamond surface. Using NV centers, in-situ NMR and ESR technology have been developed and used to characterize the materials property at nanoscale.

[1] J. Du, F. Shi, X. Kong, F. Jelezko, J. Wrachtrup, Rev. Mod. Phys. 96, 025001 (2024)

[2] Z. Zhao et al., Sci. Adv. 10, eadp9228 (2024)

[3] Z. Huang, et al., submitted (2024)

[4] Z. Qin, et al., Nat. Commun. 14, 6278 (2023)

[5] Z. Zhao, et al., Natl. Sci. Rev. 10, nwad100 (2023)

[6] S. Chen, et al., Nano Lett. 23, 2636-2643 (2023)

[7] T. Xie, et al., Phys. Rev. Lett. 130, 030601 (2023)

Detecting and controlling the dynamics of coupled spin systems in diamond

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In this talk, I will discuss some of our latest efforts in using single NV centers to detect, control and exploit the dynamics of coupled spin systems in diamond. In particular, I will discuss: (1) the coherence of NV centers in high-purity isotopically engineered diamonds, (2) experiments that directly probe the spin bath dynamics that underlie the NV spin coherence, and (3) how we can program complex Hamiltonians into large coupled nuclear spins systems surrounding an NV center.

Prospects for applications of spin centres in crystals

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While the development of spin centres for quantum technology is in full swing, their widespread adoption is still on the horizon, and several challenges remain to be overcome on this path. I will summarize some of these challenges and discuss possible solutions. The nitrogen-vacancy (NV) centre in diamond has spearheaded this pursuit, chiefly towards devices for quantum sensing. Their sensitivity is in part limited by the spin contrast and by the collection of photoluminescence [1]. I will describe progress on electrical readout of NV centres, which allows to circumvent lossy optical collection and instead leverages highly efficient collection of charge carriers during the spin-dependent ionization cycle, with a view to dramatically enhanced state readout [2]. This method furthermore provides a clear path towards integration with microelectronic circuits, for which I will present a first implementation [3]. A method to control and read out scalable arrays of sensors based on NV centres will be discussed. Lastly, I will briefly introduce a defect in silicon carbide which is of interest for quantum communication and computation. Vanadium in SiC has emerged as a strong candidate for these applications [4–9]: It has a strong optical transition at 1.3 μm, compatible with optical fiber networks, a long-lived electron spin, and is hosted in a material that is available with high quality at an industrial scale. Our investigations have resulted in significant advances in our understanding of this remarkable system, the control of its electron spin, and the development of photonic interfaces for quantum networks [10].

[1] D. Wirtitsch et al., Phys. Rev. Research 5, 013014 (2023)

[2] M. Gulka et al., Nat. Commun. 12, 4421 (2021)

[3] D. Wirtitsch et al., arXiv 2403.03090 (2024)

[4] L. Spindlberger et al., Phys. Rev. Applied 12, 014015 (2019)

[5] C. M. Gilardoni et al., New J. Phys. 23, 083010 (2021)

[6] B. Tissot et al., Phys. Rev. Research 4, 033107 (2022)

[7] T. Astner et al., Quantum Sci. Technol. 9, 035038 (2024)

[8] P. Koller et al. (submitted, 2025)

[9] P. Cilibrizzi et al., Nat. Commun. 14, 8448 (2023)

[10] J. Fait et al., Appl. Phys. Lett. 119, 221112 (2021)

Magnetic imaging of spin waves and supercurrents using spins in diamond

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Spin waves are collective excitations of the spins in magnetic materials. They play an important role in the thermodynamics of magnetic materials and are promising signal carriers in classical and quantum information devices. In this talk, I will introduce spin-wave imaging based on electronic sensor spins in diamond [1,2] – a magnetic resonance technique that enables studying spin waves underneath optically opaque materials [3]. I will then describe experiments on the interaction of spin waves with normal and superconducting metals [4]. For normal metals, Ohmic dissipation dominates the diamagnetic response to the stray magnetic fields of the spin waves, leading to spin-wave damping. In contrast, the dissipationless diamagnetism of superconductors renormalizes the spin-wave dispersion, resulting in spin-wave refraction that is tunable by electric currents, magnetic fields, and temperature. The results indicate that superconductors provide opportunities for realizing tunable, low-damping spin-wave optical devices that could be used for microwave-control in classical or quantum circuits.

[1] F. Casola, T. van der Sar, A. Yacoby, Nat. Rev. Mater. 3, 17088 (2018)

[2] I. Bertelli et al., Sci. Adv. 6, eabd3556 (2020)

[3] I. Bertelli et al., Adv. Quantum. Technol. 4, 2100094 (2021)

[4] M. Borst et al., Science 382, 430–434 (2023)

From Nanodiamond Synthesis to Intracellular Stimulation and Sensing

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Nanodiamonds with lattice defects have emerged as photostable emitters and nanoscale sensors in cell biology. However, nanodiamonds with narrow size distributions and defined lattice defects are still challenging to synthesize. We report the preparation of narrowly dispersed nanodiamonds with different lattice defects and their surface functionalization, which is essential for cellular experiments. Our strategy is to equip nanodiamonds with a functional shell that allows the stimulation and nanoscale sensing of physical parameters and reactive species inside living cells. In living cells, a multitude of biological reactions occur in a concurrent manner, giving rise to an inhomogeneous distribution of different species, temperatures, radicals, and pH at the nanoscale. The local and quantitative detection of these intracellular signals and molecules, including transient reactive structures with limited lifetimes, is of paramount importance. Current methodologies that allow quantification at the nanoscale are frequently constrained to strict conditions such as low temperature or vacuum and are not suitable for living systems. We propose surface-functionalized nanodiamond sensors capable of manipulating and probing critical parameters in situ within the living cell. This approach offers a novel means to elucidate cellular responses to intracellular changes, which could facilitate deeper insights of cell-based diseases and treatments.

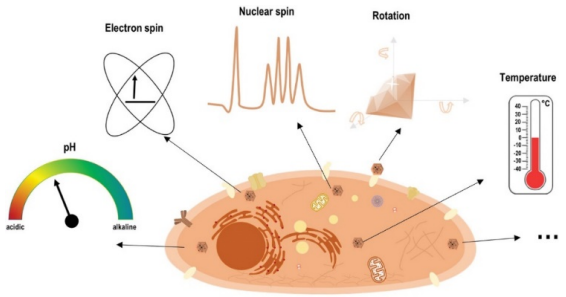

Figure 1: Detecting and manipulating intracellular signals

[1] Q. Lu et al., J. Amer. Chem. Soc. 146, 7222-7232 (2024)

[2] Y. Wu & T. Weil, Adv. Sci. 9, 2200059 (2022)

[3] Y. Wu et al., J. Amer. Chem. Soc. 144, 12642–12651 (2022)

[4] Y. Wu et al., Nano Lett. 21, 3780–3788 (2021)

Probing material properties with nanoscale spin quantum microscopy

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Solid state quantum sensors quantitatively measure a variety of parameters on sub-micron length scales. Material properties related to magnetic fields can be specifically well probed. In my talk I will discuss various application examples. Recently we were measuring magnetic order in 2D twisted magnetic monolayers to uncover a Moiré periodicity. 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 observe fractional vortices in low dimensional 2D $NbSe_2$ superconductors. A close inspection reveals vortex dynamics leading to enhanced dephasing of the NV probe. We interpret our results by the unconventional band structure of the material.