QI 28: Surface Atom and Color Center Spin Qubits

Time: Thursday 15:00–18:00 Location: HFT-FT 131

Invited Talk QI 28.1 Thu 15:00 HFT-FT 131

An atomic scale multi-qubit platform — •Hong Thi Bui[1,2], Yu Wang[1,2], Yi Chen[3], Christoph Wolf[1,2], Yujeong Bae[1,2], Andreas J. Heinrich[1,2], and Soo-hyon Phark[1,2] — [1]Center for Quantum Nanoscience, Institute for Basic Science (IBS), Seoul, Korea — [2]Ewha Womans University, Seoul, Korea — [3]International Center for Quantum Materials, Peking University, Beijing, China

Individual electron spins in solids present promising prospects as qubits in quantum science and technology. Nevertheless, scaling up their utilization has posed a longstanding challenge. The use of a scanning tunneling microscope (STM) for individual atom addressability and precise atom-by-atom positioning allows for a bottom-up design of functional quantum devices. In this work, we successfully achieved the atom-by-atom construction, coherent manipulation, and readout of coupled electron-spin qubits using an STM. To facilitate coherent control of "remote" qubits that are outside of the tunnel junction, we complemented each electron spin with a local magnetic field gradient generated by a nearby single-atom magnet [1]. The readout process was accomplished by using a sensor qubit within the tunnel junction and implementing pulsed double electron spin resonance [2]. This approach allowed for the demonstration of fast single-, two-, and three-qubit operations in an all-electrical fashion [2]. Our qubit platform at the Angstrom scale exemplifies quantum functionalities utilizing electron spin arrays assembled atom by atom on a surface.

References: [1] S. Phark et al. Adv. Sci. 10, 2302033 (2023). [3] Y. Wang et al. Science 382, 87-92 (2023).

QI 28.2 Thu 15:30 HFT-FT 131

Theoretical study of entangled-state generation and coherence in atomic spins using electron spin resonance with the scanning tunneling microscope. — Eric Switzer[1,2], Jose Reina-Gálvez[3], Géza Giedke[2], Talat Rahman[1], Christoph Wolf[3], and •Nicolas Lorente[4] — [1]University Central Florida, Orlando, Florida — [2]DIPC, San Sebastian, Spain — [3]QNS, Ewha Womans University, Seoul, Republic of Korea — [4]CFM (CSIC-EHU), San Sebastian, Spain

Experimental techniques using pulsed electron spin resonance (ESR) with scanning tunneling microscopy (STM) have uncovered a new method to generate entangled spin states using atomic sites prepared on a substrate [1]. In this work, we demonstrate the use of a newly developed NEGF-derived quantum master equation software [2-5] to model ESR-STM for realistic experimental conditions relevant to atomic-scale qubit systems. We predict changes in measured current on the STM tip within the time domain and correlate patterns in the current with the generation of a non-trivial entangled spin state. We also demonstrate the role of electron dynamics in the sequential regime on the coherence of the entangled state as a function of time. [1] Yu Wang et al. Science 382, 87 (2023) [2] J. Reina-Gálvez et al. Phys. Rev. B 100, 035411 (2019) [3] J. Reina-Gálvez et al. Phys. Rev. B 104, 245435 (2021) [4] J. Reina-Gálvez et al. Phys. Rev. B 107, 235404 (2023) [5] https://github.com/qphensurf/

QI 28.3 Thu 15:45 HFT-FT 131

Demonstration of coherent excitation in a tin-vacancy color center in diamond with the SUPER scheme — •Cem Güney Torun[1], Mustafa Gökçe[1], Thomas K. Bracht[2], Mariano Isaza Monsalve[1], Sarah Benbouabdellah[1], Özgün Ozan Nacitarhan[1], Marco E. Stucki[1,3], Gregor Pieplow[1], Tommaso Pregnolato[1,3], Joseph H.D. Munns[1], Doris E. Reiter[4], and Tim Schröder[1,3] — [1]Institute of Physics, Humboldt University of Berlin, Berlin, Germany — [2]Institute of Solid State Theory, University of Münster, Münster, Germany — [3]Ferdinand-Braun-Institute, Berlin, Germany — [4]Faculty of Physics, Technical University Dortmund, Dortmund, Germany

We present a new approach to generate coherent single photons using a technique named SUPER (Swing-UP of the quantum EmitteR population) on a tin-vacancy color center in diamond. Traditional methods rely on resonant excitation but face a major challenge in separating the excitation laser from emitted photons due to spectral overlap. SUPER, however, employs two-color nonresonant pulses to achieve full inversion to the excited state allowing effective spectral filtering.

The implementation of SUPER involves a specially designed spectral pulse engineering setup. This setup generates pulses with specific spectral shapes directed to a tin-vacancy center within a diamond nanopillar. This study marks the first application of SUPER to a color center in diamond, demonstrating coherent single photon emission with nonresonant pulses. The results, consistent with theoretical models, show promise for the exploration of ultrafast processes using these methods.

QI 28.4 Thu 16:00 HFT-FT 131

Scaling-up of NV Quantum Information Processors — •Jonas Breustedt and Martin Plenio — Institut für Theoretische Physik, Universität Ulm

Finding a working and scaleable quantum computation architecture is an important topic in current quantum information. Here, quantum information processors based on nitrogen-vacancy (NV) centers in diamond constitute one such possible architecture. One particular advantage is their compactness: At distances between NV centers of ∼10nm, even micrometer sized diamond arrays could host on the order of millions of NVs. However, this close proximity is also required for efficient inter-NV coupling and consequently poses a problem when combined with the optical readout schemes for NVs: Selective addressability of individual NVs becomes a challenging affair, due to readout pulses performing the same external perturbation on multiple NVs.

In this work, we study the effect of optical driving of a coupled 2-NV system. We then quantify how differences in local, i.e. NV specific, parameters can be employed to obtain selective addressability of NV centers even though both centers experience the same optical driving. Our goal is to derive parameter regimes for, in particular, NV distances and lattice strain in which NVs can still be accessed individually. Identifying these regimes would be an important step to scale-up NV quantum information processing platforms.

QI 28.5 Thu 16:15 HFT-FT 131

Quantum Optimal Circuit Compilation Algorithm for NV Centers — •Yaqing Xy Wang[1], Mees Hendriks[3], Felix Motzoi[1], Tommaso Calarco[1,2], and Matthias M. Müller[1] — [1]Peter Grünberg Institute,Quantum Control (PGI-8), Forschungszentrum Jülich GmbH, D-52425 Germany — [2]Dipartimento di Fisica e Astronomia "Augusto Righi" Viale Berti Pichat 6/2, Bologna, Italy — [3]CHARM Therapeutics Ltd., The Stanley Building, 7 St. Pancras Square, London, N1C 4AG, UK

This talk illustrates an approach to circuit compilation that is applicable to centrally coupled qubit network. The method serves as an end-to-end mapping between a desired unitary to control pulse on the physical platform. The decomposition of circuit unitary to sequence of gates originating in native terms of the platform Hamiltonian is achieved by a modified recursive Cartan Decomposition of the unitary. Moreover, A quasi-analytic pulse generation method is proposed for achieving native basis gates that bypasses the costly matrix exponentiation involved in numerical pulse optimization algorithms. The method is expected to demonstrate its time optimality on larger Hilbert spaces with a high level of qubit connectivity as well as for more arbitrary unitary objectives that arise in quantum simulation tasks, nonetheless on smaller systems it provides mathematically elegant solutions. In both scenarios, the proposed method is robust against the short dephasing time of the central ancilla qubit(NV center).

15 min. break

QI 28.6 Thu 16:45 HFT-FT 131

Continuous-Wave, Room-Temperature Masers, using NV-Centers in Diamond — •Christoph W. Zollitsch[1,2], Stefan Ruloff[1], Yan Fett[1], Haakon T. A. Wiedemann[1], Rudolf Richter[1], Jonathan D. Breeze[1,2], and Christopher W. M. Kay[1,3] — [1]Department of Chemistry, Saarland University, Saarbrücken, Germany — [2]Department of Physics \& Astronomy, University College London, London, UK — [3]London Centre for Nanotechnology, University College London, London, UK

The concepts of microwave amplification by stimulated emission of radiation (MASER) were developed in the late 1950s, in conjunction with its optical counterpart the laser. While lasers found applications in many fields the applications of masers were highly specialized. This was due to the extreme operating conditions of the first masers, requir-

ing cryogenic temperatures and high vacuum environments. However, the maser*s excellent low-noise microwave amplification as well as its ultra narrow linewidth make it an attractive candidate for a broad range of microwave applications. Here, we characterize the operating space of a diamond NV-center maser system. Key for the continuous emission of microwave photons is a level inversion, in addition to a high-quality, low mode-volume microwave resonator to enhance the spontaneous emission of the NV-centers. We investigate the performance of the maser system as a function of level inversion and resonator quality-factor and construct a phase diagram, identifying the parameter space of operation and discuss the optimal working points and pathways for optimization.

QI 28.7 Thu 17:00 HFT-FT 131

Strain Engineering for Transition Metal Defects in SiC — •Benedikt Tissot[1], Péter Udvarhelyi[2,3], Adam Gali[2,3], and Guido Burkard[1] — [1]Department of Physics, University of Konstanz, D-78457 Konstanz, Germany — [2]HUN-REN Wigner Research Centre for Physics, P.O. Box 49, H-1525 Budapest, Hungary — [3]Budapest University of Technology and Economics, Institute of Physics, Department of Atomic Physics, Műegyetem rakpart 3., 1111 Budapest, Hungary

Transition metal (TM) defects in silicon carbide (SiC) are a promising platform for applications in quantum technology as some of these defects, e.g. vanadium (V), allow for optical emission in one of the telecom bands. For other defects it was shown that straining the crystal can lead to beneficial effects regarding the emission properties. Motivated by this, we theoretically study the main effects of strain on the electronic level structure and optical electric-dipole transitions of the V defect in SiC. In particular we show how strain can be used to engineer the g-tensor, electronic selection rules, and the hyperfine interaction. Based on these insights we discuss optical Lambda systems and a path forward to initializing the quantum state of strained TM defects in SiC.

QI 28.8 Thu 17:15 HFT-FT 131

Coherence properties of NV-center ensembles coupled to an electron-spin bath in diamond — Reyhaneh Ghassemizadeh, Wolfgang Körner, •Daniel F. Urban, and Christian Elsässer — Fraunhofer Institute for Mechanics of Materials IWM, Freiburg, Germany

Nitrogen-vacancy (NV) centers in diamond are one of the promising solid-state-based qubit platforms. Quantum-technology applications in general require long coherence times for the qubit. However, the coherence time of NV centers is limited due to their coupling to the surrounding fluctuating environmental electronic and nuclear spins. In this study we use the cluster-correlation expansion (CCE) method to study the decoherence of ensembles of NV centers in a range of electron-spin bath-concentrations ρ of 0.1 - 100 ppm. We demonstrate the statistical ensemble averaging and compute the Hahn-echo coherence time (T_2) and the stretched exponential parameter as a function of ρ. Moreover, we perform a geometrical analysis in order to determine the effective dipolar interaction length depending on the bath concentrations. Our results provide a quantified description of the decoherence behaviour of NV ensembles as well as individual electron-spin bath-configurations that lead to a prolonged coherency of the NV center.

QI 28.9 Thu 17:30 HFT-FT 131

Performance of quantum registers in diamond in the presence of spin impurities — •Dominik Maile and Joachim Ankerhold — Institute for Complex Quantum Systems, Ulm University

The Nitrogen Vacancy Center in diamond coupled to addressable surrounding nuclear spins forms a versatile building block for future quantum technologies. While previous activities focused on sensing with only a single or very few spins in operation, recently multi-qubit registers have been successfully implemented for quantum information processing. Further progress requires a detailed understanding of the performance of quantum protocols for consecutive gate operations and thus, beyond established treatments for relaxation and dephasing. In this talk, we provide such a theoretical analysis for a small spin registers with up to four spins built out of NV and environmental constituents in presence of ensembles of impurity spins. Thereby, we discuss the tradeoff between fast control of the full register and the leakage of entanglement to unwanted spins in the environment. We also show perspectives on how to overcome present limitations.

[1] D.Maile and J.Ankerhold, arXiv:2211.06234 (2023)

QI 28.10 Thu 17:45 HFT-FT 131

Fidelity of photon-mediated entanglement between remote nuclear-spin multi-qubit registers — •Wolf-Rüdiger Hannes, Regina Finsterhoelzl, and Guido Burkard — Department of Physics, University of Konstanz, 78457 Konstanz, Germany

The nuclear spin environment of NV centers can be used to realize a multiqubit register, for which long-lived single-qubit states and high-fidelity electron-nuclear gates have been demonstrated [1]. For scalable quantum networking applications, linking registers in a photonic network is important, but has so far been realized with one nuclear spin per node only [2,3]. We theoretically analyze the requirements to extend the photonic architecture proposed by Nemoto et al. [4], which makes use of the intrinsic nitrogen spin, to multiple ^{13}C spins per node. In particular we analyze the case where decoherence-protected gates suggested in Ref. [1] are applied consecutively and estimate a fidelity for creating multiple remote Bell pairs between two nodes. One requirement is the correction of unconditional phases acquired by unaddressed nuclear spins during a decoupling sequence. Even though the currently achieved degree of control of ^{13}C spins might not be sufficient for large-scale devices, the two schemes are compatible in principle.

[1] C. E. Bradley, J. Randall, M. H. Abobeih et al., Phys. Rev. X 9, 031045 (2019). [2] N. Kalb, A. A. Reiserer, P. C. Humphreys et al., Science 356, 928 (2017). [3] E. Bersin, M. Sutula, Y. Q. Huan et al., arXiv:2307.08619 (2023). [4] K. Nemoto, M. Trupke, S. J. Devitt et al., Phys. Rev. X 4, 031022 (2014).