QI 5: Implementations: Solid state systems

Time: Tuesday 9:30–12:15 Location: H8

Invited Talk QI 5.1 Tue 9:30 H8

Towards universal quantum computation and simulation with NV centre in diamond — •Vadim Vorobyov — 3rd Physical Institute, University of Stuttgart

NV centre in diamond is a mature platform for quantum technologies having applications ranging from quantum sensing to quantum communication and quantum information processing. Numerous implementation of NV centres in coupe with relative simplicity of the experiment enabled implementation of the NV magnetometry within complementary analysis methods such as X ray spectrometers and high pressure diamond anvil cells scanning probe experiments enabled discovery of 2D antiferromagnetic domain walls and single layer magnetism in layered magnetic materials proving its firm niche among nanoscale quantum sensors.

For quantum information processing a well addressable, readable interacting qubits are essential. NV centre - as optically readable single electron spin forms an interface to nearby nuclear spin baths, allowing to realize a star shape central spin model. In this work we discuss the computational potential of such system and compare it to planar architecture adapted by superconducting qubit systems.

We perform a randomised benchmarking of a room temperature operational system and benchmark important building blocks for quantum information processing: QFT and Toffoli gates on a qubits and discuss their possible applications in quantum sensing.

QI 5.2 Tue 10:00 H8

Probing the quantum noise of metals and spin liquids with NV center spin qubits — Jun Yong Khoo[1,5], Falko Pientka[2,5], Patrick A. Lee[3], and •Inti Sodemann Villadiego[4,5] — [1]Institute of High Performance Computing, Agency for Science, Technology, and Research, Singapore — [2]Institut fur Theoretische Physik, Goethe-Universitat Frankfurt a.M. — [3]Department of Physics, Massachusetts Institute of Technology, Cambridge Massachusetts, USA — [4]Institut fur Theoretische Physik, Universitat Leipzig — [5]Max-Planck-Institut fur Physik komplexer Systeme

Finding tailored probes that allow to identify the presence of exotic fractionalized states in quantum materials is a major open challenge. Recently, spin qubits based on NV centers are emerging as a new tool to investigate the magnetic noise emanating from complex correlated materials.

Here we study the magnetic noise emerging from a U(1) spin liquid state with a spinon Fermi surface. We show that at low frequencies the noise from this state has the same distance and frequency dependence as a metal but is reduced by a dimensionless pre-factor controlled by the diamagnetic susceptibilities of emergent fractionalized particles in this state. We estimate that the regime to detect this behavior can be comfortably accessed by the typical NV center splittings of a few GHz and estimate that the expected T1 times for an NV center placed above candidate materials, such as the organic dmit and ET salts, monolayer 1T-TaS2/Se2, would range from several tens to a few hundred milliseconds.

QI 5.3 Tue 10:15 H8

Fidelities of quantum algorithms for a spin register in diamond in presence of magnetic impurities. — •Dominik Maile, Jürgen Stockburger, and Joachim Ankerhold — Institut für komplexe Quantensysteme, Universität Ulm, Germany

The Nitrogen Vacancy Center in diamond coupled to addressable surrounding nuclear spins forms a versatile building block for future quantum technologies. We theoretically study quantum information protocols of a small spin register built out of this constituents in presence of a common bath of impurity spins. Using a cluster correlation expansion, we predict the coherence and relaxation properties as well as the fidelities for different quantum algorithms. Further, we study the influence of the volume density and the geometry of the spin bath consisting of substitutional nitrogen atoms. Our investigations yield insight how to efficiently use such a platform for quantum information purposes in presence of unavoidable magnetic impurities.

QI 5.4 Tue 10:30 H8

Nitrogen vacancy centers in diamond membranes coupled to an optical microcavity — •Maximilian Pallmann[1], Kerim Köster[1], Jonathan Körber[3], Julia Heupel[2], Rainer Stöhr[3], Timon Eichhorn[1], Larissa Kohler[1], Cyril Popov[2], and David Hunger[1] — [1]Karlsruher Institut für Technologie — [2]Universität Kassel — [3]Universität Stuttgart

Color centers in diamond centers are very promising candidates for applications in quantum communication and metrology. The nitrogen vacancy center (NV) stands out due to its exceptional spin coherence properties. On the other hand, it suffers from rather bad optical properties due to significant phonon coupling, and only 3% of the emitted light belongs to the Zero phonon line (ZPL). This can be overcome by coupling the emitters to optical cavities, making use of the Purcell effect.

In our experiment, we integrate a diamond membrane to an open access fiber-based Fabry-Perot microcavity [1] to attain emission enhancement into a single well-collectable mode as well as spectral filtering. We investigate the influence of the diamond membrane on the optical properties of the cavity.

We present Purcell-enhanced ensemble-fluorescence of shallow-implanted NV centers and observe cavity-induced collective effects that lead to a bunching behavior in the emission.

[1] Heupel,Pallmann,Körber.Micromachines 2020, 11, 1080;

QI 5.5 Tue 10:45 H8

Cavity-free microwave spectral hole burning in ^{166}Er:Y_2SiO_5 below 1K — Anton Mladenov[1], Natalia Pankratova[2], Dmitriy Sholokhov[1], Vladimir Manucharyan[2], Pavel Bushev[1,3], and •Nadezhda Kukharchyk[1,4,5] — [1]Experimental physics, University of Saarland, Saarbruecken, Germany — [2]Department of Physics, Joint Quantum Institute and Center for Nanophysics and Advanced Materials, University of Maryland, College Park, USA — [3]JARA-Institute for Quantum Information (PGI-11), Forschungszentrum Jülich, Jülich, Germany — [4]Walther-Meißner-Institut, Bavarian academy of sciences, Garching, Germany — [5]Munich Center for Quantum Science and Technologies, Munich, Germany

Deterministic narrow spectral hole burning on a microwave transition would allow for realization of microwave atomic frequency combs (mwAFC). On the way towards realisation an mwAFC, we present our recent results in spectral hole burning in Er:Y_2SiO_5 crystal in cavity-free regime at the variation of magnetic field and at temperatures below 1 K.

15 min. break

QI 5.6 Tue 11:15 H8

Modelling and engineering cQED devices via effective Hamiltonians — •Boxi Li[1,2], Tommaso Calarco[1,2], and Felix Motzoi[1] — [1]Forschungszentrum Jülich, D-52425 Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, D-50937 Cologne, Germany

Deriving effective Hamiltonian models plays an essential role in quantum theory, with particular emphasis in recent years on control and engineering problems. To develop fast, high-fidelity operations on cQED devices, there are also increasing demands on modelling tools that go beyond the strong perturbative regime and accurately capture the dynamics.

To this goal, we present two symbolic methods for computing effective Hamiltonian models. The first method makes use of the Jacobi iteration and works without the assumptions of perturbation theory while retaining convergence. In the perturbation regime, it reduces to a variant of the Schrieffer-Wolff method, which takes advantage of a recursive structure and exponentially decreases the number of terms in the high-order expansion. Both methods consist of algebraic expressions and can be easily automated for symbolic computation.

Based on these methods, we perform (semi-)analytical calculations that compute the effective Hamiltonian. We investigate both the ZZ and the cross-resonance interaction in the quasi-dispersive regimes. By choosing a proper frame transformation, we show that one can develop control pulses to suppress noises such as leakage and dynamical ZZ crosstalk, improving upon the conventional perturbative calculation.

QI 5.7 Tue 11:30 H8

Demonstration of an integrated optomechanical microcav-

ity with a suspended frequency-dependent photonic crystal reflector — •Sushanth Kini M[1], Anastasiia Ciers[1], Juliette Monsel[1], Cindy Peralle[2], Shu Min Wang[1], Philippe Tassin[2], and Witlef Wieczorek[1] — [1]Dept of Microtechnology and Nanoscience, Chalmers University, Göteborg, Sweden — [2]Dept of Physics, Chalmers University, Göteborg, Sweden

Optical microcavities confine the light field on sub-wavelength length scales leading to stronger light-matter interactions. Using microcavities in cavity optomechanics, which explores the interaction between an optical cavity and mechanical motion, one drastically increases the optomechanical interaction. In our work, we use this concept in on-chip optomechanical microcavities fabricated from AlGaAs heterostructures. In our realization, the mechanically-compliant element is a suspended photonic crystal (PhC) reflector slab, whose distance to a distributed Bragg reflector (DBR) mirror is less than the optical wavelength. We demonstrate a precise control over the microcavity resonance wavelength by varying the PhC hole radius, notably keeping cavity length constant. Importantly, we demonstrate that the frequency dependence of the optical reflectivity of the PhC slab modifies the optomechanical effects compared to a conventional optomechanical system. In the future, this integrated optomechanical microcavity platform offers novel capabilities in manipulating mechanical motion, such as offering more efficient cooling schemes or the capability to generate mechanical squeezing in the ultra-strong coupling regime.

QI 5.8 Tue 11:45 H8

Quantum reservoir computing with coupled cavity arrays — •Frederik Lohof, Niclas Götting, and Christopher Gies — Institute for Theoretical Physics, University of Bremen, Bremen

Arrays of coupled cavities with embedded semiconducting quantum dots are a potential platform for the realization of a photonic quantum reservoir computer. The quantum reservoir paradigm is intriguing as it can be realized with preexisting technology and does not rely on fine-tuning of the system parameters as it is the case with gate-based quantum computing. Crucially, the performance of a quantum reservoir relies on a sampling of the exponentially increasing phase-space dimension. We provide theoretical benchmarks on how the topology of a quantum reservoir influences the reservoir's performance and discuss prospects for implementing quantum reservoir computing on a platform of arrays of semiconducting microcavities.

QI 5.9 Tue 12:00 H8

Ultra-stable open micro-cavity platform for closed cycle cryostats — •Michael Förg[1,2], Jonathan Noé[1,2], Manuel Nutz[1,2], Theodor W. Hänsch[1,3], and Thomas Hümmer[1,2,3] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität Munich, Germany — [2]Qlibri GmbH, Munich, Germany — [3]Max-Planck-Institut für Quantenoptik, Garching, Germany

High-finesse, open-access, mechanical tunable, optical micro-cavities offer a compelling system to enhance light matter interaction in numerous systems, e.g. for quantum repeaters, single-photon sources, quantum computation and spectroscopy of nanoscale solid-state systems. Combining a scannable microscopic fiber-based mirror and a macroscopic planar mirror creates a versatile experimental platform. A large variety of solid-state quantum systems can be brought onto the planar mirror, analyzed, addressed individually, and (strongly) coupled to the cavity. We present a fully 3D-scannable, yet highly stable micro-cavity setup, which features a stability on the sub-pm scale under ambient conditions and unprecedented stability inside closed-cycle cryostats. An optimized mechanical geometry, custom built stiff micro-positioning, vibration isolation and fast active locking enables quantum optics experiments even in the strongly vibrating environment of closed-cycle cryostats.