QI 40: Quantum Control II (joint session QI/Q)

Time: Friday 11:00–13:00 Location: HS II

QI 40.1 Fri 11:00 HS II

Optimally Controlled NMR in Electrochemistry: Overcoming Challenges and Turning Them into Opportunities — •Armin J. Römer[1,2], Johannes F. Kochs[1,2], Michael Schatz[1], Matthias Streun[1], Simone S. Köcher[1,3], and Josef Granwehr[1,2] — [1]Forschungszentrum Jülich GmbH, Institute of Energy Technologies, Fundamental Electrochemistry (IET-1), Jülich, Germany — [2]RWTH Aachen University, Aachen, Germany — [3]Fritz Haber Institute of the Max Planck Society, Berlin, Germany

Quantum optimal control is a versatile, powerful method to tailor nuclear magnetic resonance (NMR) experiments. With the growing importance of NMR on electrochemical systems, we present how optimal control can be used to address experimental challenges in complex setups, such as *operando* electrolysis. Particularly, conductive cell components cause magnetic field distortions due to shielding and eddy current effects, leading to reduced resolution, non-quantitative results, and possible artifacts. In a complementary approach, we combine ensemble optimal control with finite element method (FEM) simulations. We show how NMR setups are accurately modeled in FEM and how this knowledge is used to improve NMR measurements on an *operando* electrolysis setup. Furthermore, we demonstrate how an NMR measurement can be turned surface selective by exploiting the characteristic near-surface magnetic field distortions. We demonstrate how quantum optimal control enables new experiments, which provide additional information and insights of unparalleled detail into complex systems.

QI 40.2 Fri 11:15 HS II

Comparison of Gate-set evaluation metrics for closed-loop optimal control on nitrogen-vacancy center ensembles in diamond — •Thomas Reisser[3,4], Philipp J. Vetter[1,2], Maximilian G. Hirsch[1,2,5], Tommaso Calarco[3,4,6], Felix Motzoi[3,4], Fedor Jelezko[1,2], and Matthias M. Müller[3] — [1]Institute for Quantum Optics, Ulm University, 89081 Germany — [2]Center for Integrated Quantum Science and Technology (IQST), 89081 Germany — [3]Institute for Quantum Control (PGI-8), Forschungszentrum Jülich GmbH, 52425 Germany — [4]Institute for Theoretical Physics, University of Cologne, 50937 Germany — [5]NVision Imaging Technologies GmbH, 89081 Germany — [6]Dipartimento di Fisica e Astronomia, Università di Bologna, 40127 Italy

Precise control of a quantum system is a prerequisite for quantum information, quantum computing, and quantum metrology. Quantum gates on ensembles of nitrogen vacancy centers usually suffer from decoherence, large amplitude errors, imperfect state preparation and therefore limited total operation fidelity. Large state preparation and measurement errors can cause the typically used quantum process tomography to fail. We investigate the applicability of quantum process tomography, linear inversion gate-set tomography, randomized linear gate-set tomography, and randomized benchmarking as measures for closed-loop quantum optimal control experiments. Closed-loop optimizations are performed and evaluated with all measures to find a gate-set with universally improved performance and demonstrate the relative trade-offs between the methods.

QI 40.3 Fri 11:30 HS II

Spin control of highly-strained silicon-vacancy centers in nanodiamonds — •Andreas Tangemann, Marco Klotz, and Alexander Kubanek — Institute for Quantum Optics, University Ulm, Germany

Spin qubits in solid state hosts are, due to their promise of scalability, candidates for the realization of quantum networks. The good spin properties of diamond paired with the optical properties of group-IV defects make them of special interest. We are using highly-strained silicon vacancy centers in nanodiamonds to mitigate phonon induced dephasing of the spin qubit at liquid Helium temperature, due to orbital ground state splittings exceeding 1THz. Here we show coherent control of the electron spin, access to a 13C nuclear spin via indirect control and nuclear spin single-shot readout, as well as coherent control over the optical dipole of the SiV centers. These techniques lay the foundation for future quantum network experiments with SiV centers at liquid Helium temperatures.

QI 40.4 Fri 11:45 HS II

Nuclear spin control with highly strained silicon-vacancy centers — •Marco Klotz, Andreas Tangemann, and Alexander Kubanek — nstitute for Quantum Optics, University Ulm, Germany

Spin qubits in solid state hosts are due to their promise of scalability candidates for the realization of quantum networks. The good spin properties of diamond paired with the optical properties of group-IV defects make them of special interest. We are using highly strained silicon vacancy centers to mitigate phonon induced electron spin dephasing at liquid Helium temperature. Here we show our current results on electron spin characterization. Furthermore, we use highly efficient electron spin driving to access, control and characterize coupled C13 nuclear spins. This paves the way for nuclear spin assisted quantum error correction and networking with group IV defects.

QI 40.5 Fri 12:00 HS II

Cryogenic microwave generator for quantum information processing with trapped ions — •Sebastian Halama[1], Peter Toth[2], Marco Bonkowski[1], and Christian Ospelkaus[1,3] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Welfengarten 1, 30167 Hannover, Germany — [2]Technische Universität Braunschweig, Institut für CMOS Design, Hans-Sommer-Str. 66, 38106 Braunschweig — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

Scaling up quantum computers to a higher number of qubits while maintaining control of all qubit states is still a major challenge. Surface-electrode ion traps are a promising platform for such a large-scale quantum computer. With the microwave near-field approach [1], qubit control realized by microwave conductors that are integrated into the ion trap naturally scale with the trap itself. However, the microwave signal generation currently takes place outside of the vacuum chamber in which the ion trap is located. Here we report on the design of a cryogenic three-channel microwave generator with amplitude modulation capabilities and its co-integrating with a surface-electrode ion trap on a common chip carrier. We present first measurements taken with the cryogenic microwave generator and discuss further steps of the experiment.

[1] Ospelkaus et. al, Phys. Rev. Lett. **101**, 090502 (2008)

QI 40.6 Fri 12:15 HS II

Optimizing Rydberg Ensemble Dynamics: Double Excitation Suppression — •Vidisha Aggarwal[1,2], Boxi Li[1], Eloisa Cuestas[1], Robert Zeier[1], Felix Motzoi[1,2], and Tommaso Calarco[1,2,3] — [1]Peter Grünberg Institute-Quantum Control (PGI-8), Forschungszentrum Jülich GmbH, 52425 Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, 50937 Koln, Germany — [3]Dipartimento di Fisica e Astronomia, Università di Bologna, 40127 Bologna, Italy

We propose an optimization strategy for Rydberg ensemble dynamics to suppress double excitations and enhance single-photon emission, crucial for quantum technologies like optical communication. Using a Rydberg 'superatom'-an ensemble of Rubidium-87 atoms in an optical cavity-we encode its internal state into an optical qubit [1]. While the Rydberg blockade ideally ensures single-photon emission, imperfections lead to double excitations, hindering controlled retrieval.

To address this, we use the Derivative Removal by Adiabatic Gate (DRAG) method, which introduces an auxiliary pulse to suppress unwanted transitions [2,3]. Though typically used with superconducting qubits, applying DRAG to neutral atoms demonstrates the versatility of quantum control techniques. This approach significantly improves the probability of obtaining just a single Rydberg excitation compared to the experimental pulse.

[1] V. Magro, A. Ourjoumtsev, et al. Nat. Photonics 17, 688*693 (2023). [2] F. Motzoi and F. K. Wilhelm, Phys. Rev. A 88, 062318 (2013). [3] B. Li, F. Motzoi et al., PRX Quantum 3, 030313 (2022).

QI 40.7 Fri 12:30 HS II

Motion-Insensitive Time-Optimal Control of Optical Qubits — •Léo Van Damme[1], Zhao Zhang[2], Amit Devra[1], Steffen J. Glaser[1], and Andrea Alberti[2] — [1]School of Natural Sciences, Technical University of Munich, Lichtenbergstrasse 4, D-85747 Garching, Germany — [2]Max-Planck-Institut für Quantenoptik, 85748

Garching, Germany

Ultranarrow optical transitions, widely used in modern atomic clocks, are gaining significant attention for quantum computing applications. However, optical qubits are highly susceptible to motion-induced decoherence and photon-recoil heating, which, if unaddressed, pose critical barriers to the realization of large-scale quantum circuits.

In this work, we demonstrate that these effects can be controlled by modulating the phase of the driving laser field over time, for general quantum gates and arbitrary initial atomic states.

We have developed a method that reduces the problem of infinite motional states to a set of constraints on a two-level system. This dramatic simplification, combined with optimal control techniques, reveals that optimal solutions not only substantially improve gate fidelity and speed but are also feasible for practical implementation.

QI 40.8 Fri 12:45 HS II

Accelerated creation of NOON states with ultracold atoms via counterdiabatic driving — •Simon Dengis[1], Sandro Wimberger[2,3], and Peter Schlagheck[1] — [1]CESAM Research Unit, University of Liege, 4000 Liege, Belgium — [2]Istituto Nazionale di Fisica Nucleare (INFN), Sezione Milano Bicocca, Gruppo collegato di Parma, Italy — [3]Dipartimento di Scienze Matematiche, Fisiche e Informatiche, Università di Parma, Parco Area delle Scienze 7/A, 43124 Parma, Italy

A quantum control protocol is proposed for the creation of NOON states with N ultracold bosonic atoms on two modes, corresponding to the coherent superposition $|N,0\rangle + |0,N\rangle$. This state can be prepared by using a third mode where all bosons are initially placed and which is symmetrically coupled to the two other modes. Tuning the energy of this third mode across the energy level of the other modes allows the adiabatic creation of the NOON state. While this process normally takes too much time to be of practical usefulness, due to the smallness of the involved spectral gap, it can be drastically boosted through counterdiabatic driving which allows for efficient gap engineering. We demonstrate that this process can be implemented in terms of static parameter adaptations that are experimentally feasible with ultracold quantum gases. Gain factors in the required protocol speed are obtained that increase exponentially with the number of involved atoms and thus counterbalance the exponentially slow collective tunneling process underlying this adiabatic transition. arXiv:2406.17545.