FM 83: Poster: Enabling Technologies Sources of Quantum States of Light

Time: Thursday 16:30–18:30 Location: Tents

FM 83.1 Thu 16:30 Tents

Bi-colour photon pair source for light-matter interactions with nitrogen-vacancy centres in diamond — •Julian Gurs, Erik Hesselmeier, Timo Steidl, Charles Babin, Matthias Niethammer, Thomas Kornher, Roland Nagy, Naoya Morioka, Ilja Gerhardt, Roman Kolesov, Jörg Wrachtrup, and Florian Kaiser — 3rd Physics Institute, University of Stuttgart and IQST, Germany

The nitrogen-vacancy centre (NV) in diamond is a promising platform for quantum information distribution. To unleash the full potential, an efficient interface between the NV's natural emission and telecom-wavelength photons is required. To date, wavelength down-converters from 637 nm to 1550 nm suffer from too high photonic noise [1]. Here, we show an alternative solution. We develop a polarisation entangled photon pair source in which one photon is at a telecom wavelength (1560 nm), and the other is generated at 637 nm to match the resonant absorption line of the NV centre. By absorbing the latter photon in the NV centre [2], we intend to entangle the NV centres electron and nuclear spins with a telecom photon. Regarding the photon pair source, we will show our measures to minimise optical loss, while still maintaining a breadboard transportable setup geometry for applications in the field. We will also evaluate the performance of the above mentioned entangled photon storage protocol.

[1] A. Dréau et al., Phys. Rev. Appl. 9, 064031 (2018) [2] S. Yang et al., Nature Photon. 10, 507 (2016)

FM 83.2 Thu 16:30 Tents

Injection locking and synchronization in Josephson circuits — •Lukas Danner, Ciprian Padurariu, Björn Kubala, and Joachim Ankerhold — Institute for Complex Quantum Systems and IQST, Ulm University, 89069 Ulm, Germany

Motivated by recent progress in realizing sources of quantum states of microwave light using Josephson circuits, we explore reducing the emission linewidth to potentially enable measurements of microwave quantum entanglement [1]. We employ the phenomena of injection locking and synchronization that stabilize the phase of emitted radiation against electrical noises [2].

We study injection locking of a single Josephson cavity and show that the low frequency environment plays an essential role in frequency pulling and locking. We model a realistic circuit that includes the resistive part of the impedance and calculate the radiation spectrum finding good agreement with recent experiments.

We further study the synchronization of two (nearly) degenerate Josephson cavities. At low driving amplitudes we find a competition between squeezing and entanglement production. The steady state Wigner density indicates squeezing along an axis that can be rotated by tuning the ratio of the cavity loss rates. Building on these results, we argue the emergence of non-linear response and synchronization as the driving power is increased.

[1] M. Westig et al., Phys. Rev. Lett. 119, 137001 (2017).
[2] M.C. Cassidy et al., Science 355, 939 (2017).

FM 83.3 Thu 16:30 Tents

Towards demultiplexed photons from GaAs quantum dots for multi-photon interference experiments — •Julian Münzberg[1], Maximilian Prilmüller[1], Siamon Covre Da Silva[2], Daniel Huber[2], Markus Reindl[2], Armando Rastelli[2], Gregor Weihs[1], and Robert Keil[1] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria — [2]Institute of Semiconductor and Solid State Physics, Johannes Kepler University, 4040 Linz, Austria

Bright sources of multiple indistinguishable photons are pivotal in experiments on boson sampling [1] and many-particle interference [2]. Demultiplexed photons collected from a quantum dot (QD) are a viable implementation of such a bright multi-photon source [1, 3-5]. In this work, we aim to use droplet-etched GaAs QDs [6] for single-photon generation. Preliminary characterization of the QDs yielded promising results and a setup for two-photon resonant excitation and collection is under construction. We plan to actively route consecutively emitted photons with freespace electro-optical modulators for polarisation rotation in conjunction with polarising beam splitters. These spatially separated photons will be eventually used for a multi-photon interference experiment in femtosecond laser written glass waveguides.

[1] Wang et al. Nat. Photonics 11, 361 (2017). [2] Giordani et al. Nat. Photonics 12, 173 (2018). [3] Lenzini et al. Laser Photonics Rev. 11, 1600297 (2017). [4] Hummel et al. arXiv:1903.08785 (2019). [5] Antón et al. arXiv:1905.00936 (2019). [6] Huber et al. PRL 121, 033902 (2018).

FM 83.4 Thu 16:30 Tents

Strongly Correlated Photon Transport in a Waveguide with Weakly Coupled Emitters — Adarsh Prasad[1], Jakob Hinney[1], Klemens Hammerer[2], Sahand Mahmoodian[2], Samuel Rind[1], •Max Schemmer[3], Philipp Schneeweiss[1,3], Anders Sørensen[4], Jürgen Volz[1,3], and Arno Rauschenbeutel[1,3] — [1]TU Wien, Atominstitut, Stadionallee 2, 1020 Vienna, Austria — [2]Institute for Theoretical Physics, Institute for Gravitational Physics (Albert Einstein Institute), Leibniz University Hannover, Appelstraße 2, 30167 Hannover, Germany — [3]Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin, Germany — [4]Center for Hybrid Quantum Networks (Hy-Q), Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, DK-2100 Copenhagen, Denmark

We experimentally show correlated photon transport through an optical waveguide that contains an ensemble of weakly coupled quantum emitters. We observe that the photon statistics of the transmitted light can be continuously changed from anti-bunched light to bunched light by solely changing the number of emitters. This effect arises due to an interplay of the nonlinear optical response of the emitters, linear optical losses, and interference between the transmitted and the forward-scattered two-photon states. We use laser-cooled atoms confined in a nanofiber-based optical dipole trap and analyze the transmission through the fiber with single-photon counters. The recorded second-order time-correlation function, $g_2(t)$, is in agreement with its theoretical prediction and reaches values as low as $g_2(0) \approx 0.5$.

FM 83.5 Thu 16:30 Tents

Tuning the Emission of Quantum Dots for Coupling to a Rb-Memory — Liang Zhai[1], •Giang N. Nguyen[1,2], Matthias C. Löbl[1], Jan-Philipp Jahn[1], Julian Ritzmann[2], Andreas D. Wieck[2], Armando Rastelli[3], Arne Ludwig[2], and Richard J. Warburton[1] — [1]University of Basel, 4056 Basel, Switzerland — [2]Ruhr-Universität Bochum, 44780 Bochum, Germany — [3]Johannes Kepler University Linz, 4040 Linz, Austria

Combining a solid-state quantum dot (QD) with an atomic memory is a promising hybrid-system for application in quantum communication [1]. Coupling the QD to a quantum memory, such as a Rb-memory, can circumvent the short coherence time of QDs. For coupling both systems, the photons emitted by the QD have to match the atomic ensemble in bandwidth and frequency [2, 3].
We use droplet-etched GaAs QDs embedded in AlGaAs as a source of coherent single photons and present two different methods to match the Rb-frequency of 794 nm: Applying mechanical strain to the material [4] and applying an electric field to the QD which is embedded in a diode structure [5, 6].

[1] N. Sangouard *et al.*, Phys. Rev. A **76**, 050301 (2007).
[2] J.-P. Jahn *et al.*, Phys. Rev. B **92**, 245439 (2015).
[3] L. Beguin*et al.*, Phys. Rev. B **97**, 205304 (2018).
[4] D. Huber *et al.*, Phys. Rev. Lett. **121**, 033902 (2018).
[5] L. Bouet *et al.*, Appl. Phys. Lett. **105**, 082111 (2014).
[6] F. Langer *et al.*, Phys. Lett. **105**, 081111 (2014).

FM 83.6 Thu 16:30 Tents

Reduction of spectral diffusion by applying a sequence of optical control pulses — •Laura Orphal[1], Joseph H. D. Munns[1], and Tim Schröder[1,2] — [1]Department of Physics, Humboldt-Universität zu Berlin, Berlin, Germany — [2]Ferdinand-Braun-Institut, Berlin, Germany

Lifetime limited emission linewidths are a fundamental requirement for the generation of coherent photons, which are crucial for efficient entanglement of stationary qubits in quantum information systems.

However, for the negatively charged nitrogen-vacancy centre (NV) in diamond, natural linewidths (∼13 MHz) are challenging to achieve. In addition to homogeneous broadening, in particular, spectral diffu-

sion, i.e., the change of optical transition frequency over time, caused by fluctuations of the electrostatic environment, leads to an inhomogeneous broadening of the zero-phonon emission line (ZPL).

While work is done on optimizing material properties, active control schemes are an interesting alternative to suppress spectral diffusion. Recently the approach of pulsed coherent control was proposed [1]. A sequence of optical π-pulses is expected to modify the average rate of phase accumulated between the emitter states, affecting the emission spectrum. In this way the ZPL can be stabilized at a chosen frequency given by the carrier frequency of the pulses.

Here, we present our work towards experimentally implementing the protocol for reducing spectral diffusion of the ZPL of NV defect centres by applying a sequence of optical control pulses.

[1] H. F. Fotso et al., Phys. Rev. Lett. 116, 033603 (2016)

FM 83.7 Thu 16:30 Tents

Exceptional points in optical anisotropic thin films — •Sebastian Henn[1], Evgeny Krüger[1], Chris Sturm[1], Armin Dadgar[2], Matthias Wieneke[2], Marius Grundmann[1], and Rüdiger Schmidt-Grund[1,3] — [1]Universität Leipzig, Felix-Bloch-Institut für Festkörperphysik, Linnéstr. 5, Leipzig — [2]Otto-von-Guericke-Universität Magdeburg, Institut für Physik, Universitätsplatz 2, Magdeburg — [3]now at: Technische Universität Ilmenau, Institut für Physik, Weimarerstr. 25, Ilmenau

We investigate exceptional points (EP) in optically anisotropic transparent thin films both experimentally and theoretically. Such points represent degeneracies in k-space and were already observed in absorptive biaxial crystals [1] and microcavities [2,3]. At the EP the eigenspace of the optical eigenmodes becomes one-dimensional, yielding degeneracy in the complex energy and polarization state. This is reflected by a complex square root topology of the eigenmode energies [1]. Promising systems for the realization of EP are optically anisotropic thin films, providing symmetry breaking and dissipation through losses at the interfaces. We demonstrate the presence of EP in GaN as well as ZnO thin films using spectroscopic ellipsometry and polarization resolved reflection measurements and present rigorous Maxwell-based calculations. We discuss ways to control the occurrence and direction of the EP by altering the design of the system.

[1] W. Voigt *et al.*, Ann. Phys 314, 367 (1902)
[2] S. Richter *et al.*, Phys. Rev. A 95, 023836 (2017)
[3] J. Wiersig, Phys. Rev. Lett. 112, 203901 (2014)

FM 83.8 Thu 16:30 Tents

Measurement-induced effects in two-mode systems. — •Matvei Riabinin, Polina Sharapova, Tim J. Bartley, and Torsten Meier — Paderborn University, Warburger Strasse 100, D-33098 Paderborn, Germany

In optics, nonlinear effects can lead to various transformations of light. Parametric down-conversion (PDC) and four-wave mixing (FWM) are nonlinear effects that can generate entangled photons, quadrature squeezing, and other nonclassical effects. The generation of these effects typically requires strong light intensities. Another way of creating such non-linear transformations in quantum optics is creating so-called measurement-induced nonlinearities, where nonlinear effects can be acquired by applying detection. The detection provides a photon subtraction and might result in various nonlinear transformations. The advantage of using detection compared to PDC is that fewer incident photons are required to generate nonclassical effects. However, acquired effects have a probabilistic nature. In our work, we model a two-mode interferometer where we input different states such as a coherent state and single photon state and apply detection to each channel. We analyze the aquired nonclassical properties such as entanglement and two-mode squeezing at the output. With certain combinations of system parameters, the detection leads to two-mode squeezing which is absent without detection. It is also possible to generate quantum states similar to two-mode cat states with high fidelity. These results will be used for a theoretical description of quantum photonic chips with superconducting detectors embedded into an integrated platform.

FM 83.9 Thu 16:30 Tents

A fiber-coupled single photon source based on a single molecule — •Guilherme Stein[1], Vladislav Bushmakin[1], Yijun Wang[1], Andreas Schell[2], and Ilja Gerhardt[1] — [1]3. Institute of Physics, University of Stuttgart and Institute for Quantum Science and Technology, IQST, Pfaffenwaldring 57, D-70569 Stuttgart — [2]CEITEC, Brno University of Technology, 621 00 Brno, Czech Republic

The generation of non-classical light and single photons is a key element for many quantum communication and information schemes. Organic dye molecules under cryogenic conditions allow for the implementation of narrow-band and very bright sources [1]. The integration of single molecules into dielectric structures allows for the construction of fully integrated devices. Here we present our approach to experimentally implement a fully fiber-coupled single photon source based on a single molecule. The source utilizes a high numerical-aperture fiber, and is operated under cryogenic conditions. The source emits more than 45 000 photons per second, while the spectral width of the molecule is identified as 25 MHz. The implicit Raman background of the fiber leads to some unwanted effects. We compare the free-space excitation, where the single photon emission is solely collected through the fiber and the fiber-based excitation, in which the light to excite the molecule is supplied through the fiber.

[1] - Siyushev et al., Nature, 2014, 509, 66-70

FM 83.10 Thu 16:30 Tents

Growth and Characterization of Quantum Dot Molecules — •Nikolai Bart[1], Ismail Bölükbasi[1], Christian Dangel[2], Jonathan Finley[2], Kai Müller[2], Arne Ludwig[1], and Andreas D. Wieck[1] — [1]Ruhr-Universität Bochum, Lehrstuhl für Angewandte Festkörperphysik, Universitätsstraße 150, 44801 Bochum — [2]Technische Universität München, Walter Schottky Institut, Am Coulombwall 4, 85748 Garching bei München

Quantum repeaters and storage devices are crucial requirements for efficient quantum communication. One possible materials system for these are, along color centers and trapped ions, semiconductor quantum dots (QDs). We examine the molecular-beam-epitaxy-growth and optoelectronic properties of two coupled layers of InAs QDs on GaAs, acting as QD molecules. We show that coupling of the two layers can be achieved by adjusting emission wavelengths of direct and indirect exciton recombinations via size modification and electrical tuning.

FM 83.11 Thu 16:30 Tents

Towards monolithic diamond cavities for highly efficient photon extraction — •Lea Balzert, Philipp Fuchs, Thomas Jung, and Christoph Becher — Universität des Saarlandes, Fakultät NT - FR Physik, Campus E2.6, 66123 Saarbrücken

Color centers in diamond, e.g. the nitrogen (NV), silicon (SiV) or recently the tin (SnV) vacancy center, are promising candidates for the implementation of qubits due to the combination of long spin coherence times and optical control and read out of the spin states. Efficient collection of the emitted photons is mandatory for almost all applications, enabling e.g. enhanced signal-to-noise ratios in quantum sensing or efficient spin-photon interfaces for quantum communication. The latter further profits from fluorescence enhancement by an optical cavity allowing for cavity-assisted spin-photon transfer.

We here investigate optical cavities based on thin (< 10 μm) single crystal diamond membranes, fabricated from commercially available, high purity diamond material via reactive ion etching. The devices consist of a solid immersion lens (SIL), which is milled in the front facet of the membrane and works as spherical mirror. The unstructured back facet forms a planar mirror, enabling the whole device to work as a monolithic cavity. With appropriate coatings on both sides , we can tailor the device properties towards an efficient extraction of the emitted photons from a color center placed inside the cavity.

FM 83.12 Thu 16:30 Tents

Optical and morphological characterizations of lanthanide complexes — •Miriam Gerstel[1], Ingo Köhne[2], Artur Lik[2], Rudolf Pietschnig[2], Johann Peter Reithmaier[1], and Mohamed Benyoucef[1] — [1]Institute of Nanostructure Technologies and Analytics (INA) — [2]Institute of Chemistry, CINSaT, University of Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany

Reliable single-photon sources based on semiconductor or molecular systems are of great interest since they are key elements in promising quantum technology applications. However, complex methods of quantum information processing require a large number of indistinguishable photons. Lanthanide complexes are regarded as attractive luminescent materials due to characteristic narrow emission bands, wide emission spectrum and long lifetime. To enhance the absorbance and thus the emission intensity of transitions, utilizing ligands to sensitize the lanthanide emissions is a suitable choice.

For characterization of synthesized lanthanide molecules, the complexes are dissolved in proper solvent and spin-coated on a substrate. To achieve a low density molecule distribution, the influence of prepa-

ration and modification of the substrates, choice of solvent, and concentration of the solution is examined. Morphology and homogeneity of the molecules are discussed. Optical properties of lanthanide complexes are determined by photoluminescence spectroscopy, which reveal emission spectra at visible wavelength region.

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FM 83.13 Thu 16:30 Tents

Spatial-temporal correlations of the light of an ion crystal — •Stefan Richter[1], Sebastian Wolf[2], Andre Weber[3], Yury Prokazov[4], Evgeny Turbin[4], Joachim von Zanthier[1], and Ferdinand Schmidt-Kaler[2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, Staudtstraße 1, 91058 Erlangen — [2]QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz, 55128 Mainz, German — [3]LIN, Leibniz Institute for Neurobiology, Brenneckestraße 6, 39118 Magdeburg — [4]Photonscore GmbH, Brenneckestraße 6, 39118 Magdeburg

We measured first [1] and second order correlation functions of the light spontaneously emitted from a trapped, cold two-ion crystal for various detector positions in the temporal regime. Strikingly, the $g^{(2)}(\vec{x},\tau)$ signal shows bunching or antibunching for different observer positions [2]. Position sensitive Micro Channel Plate detectors developed for applications in fluorescence lifetime microscopy combining a high spatial resolution with temporal resolution. By using two detectors in correlation mode, it is possible to implement intensity interferometry with the light of a two-ion crystals. The spatial modulation of $g^{(2)}(\vec{x}_1,\vec{x}_2,\tau)$ was predicted in [3] and can now be measured by recording the corresponding two photon events for any time difference ΔT and corresponding positions $\vec{x}_1$ and $\vec{x}_2$. After the event stream is recorded, the correlations for arbitrary geometries can be reconstructed. [1] S. Wolf et al., Phys. Rev. Lett. 116, 183002 (2016) [2] S. Wolf et al., in preparation [3] C. Skornia et al., Phys. Rev. A 64, 063801 (2001)

FM 83.14 Thu 16:30 Tents

Spatio-Temporal Higher Order Photon Correlations of a Few-Atom System — •Lukas Götzendörfer[1], Simon Mährlein[1,2], Kevin Günthner[3,1], Jörg Evers[4], and Joachim von Zanthier[1,2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen, Germany — [3]Max Planck Institute for the Science of Light (MPL), 91058 Erlangen, Germany — [4]Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, 69117 Heidelberg, Germany

We study a particular model of independent single photon emitters and resulting multi-photon interferences in space and time: Investigating the time evolution of two-level atoms spontaneously emitting photons gives rise to a time-dependent electric field amplitude in the far field. Utilizing field intensity correlations we are then able to observe the collective emission properties of the atomic system manifesting themselves in modified spontaneous decay rates. The correlations are studied for a system of three atoms, where two of them are very close to each other such that they interact via dipole-dipole interaction. Although the residual atom is separated by a large distance and hence does not interact with the other two atoms it can be used to alter the systems* emission properties. This model system can be interpreted as a generalized free-space Hong-Ou-Mandel setup where the probability of measuring three photons not only depends on space but also on time.