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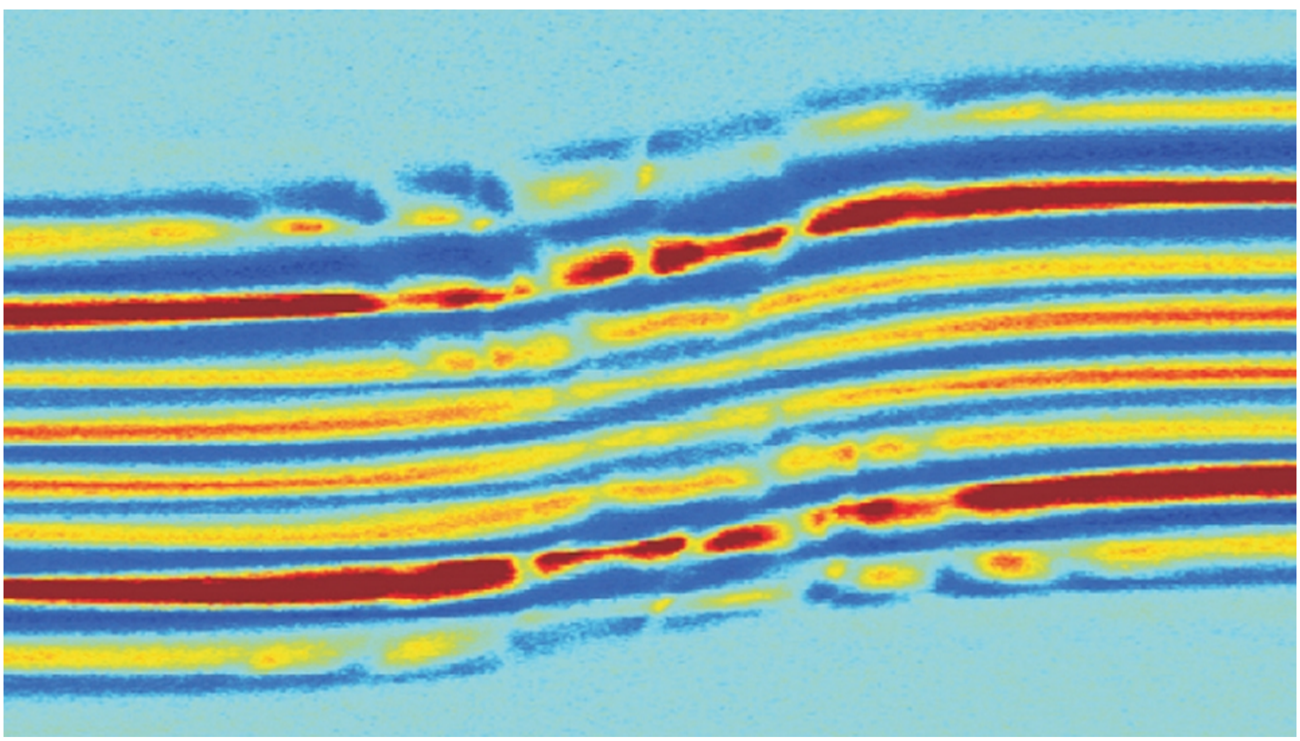
Abstracts



Supersymmetric photonics

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In recent years, the ever-increasing demand for high-capacity transmission systems has driven remarkable advances in technologies that encode information on an optical signal. Mode-division multiplexing makes use of individual modes supported by an optical waveguide as mutually orthogonal channels. The key requirement in this approach is the capability to selectively populate and extract specific modes. Optical supersymmetry (SUSY) has recently been proposed as a particularly elegant way to resolve this design challenge in a manner that is inherently scalable, and at the same time maintains compatibility with existing multiplexing strategies. Supersymmetric partners of multimode waveguides are characterized by the fact that they share all of their effective indices with the original waveguide. The crucial exception is the fundamental mode, which is absent from the spectrum of the partner waveguide. Here, we demonstrate experimentally how this global phase-matching property can be exploited for efficient mode conversion. Multimode structures and their superpartners are experimentally realized in coupled networks of femtosecond laser-written waveguides, and the corresponding light dynamics are directly observed by means of fluorescence microscopy. We show that SUSY transformations can readily facilitate the removal of the fundamental mode from multimode optical structures. In turn, hierarchical sequences of such SUSY partners naturally implement the conversion between modes of adjacent order. Our experiments illustrate just one of the many possibilities of how SUSY may serve as a building block for integrated mode-division multiplexing arrangements. Supersymmetric notions may enrich and expand integrated quantum photonics by versatile optical components and desirable, yet previously unattainable, functionalities.

Bell-Nonlocality in Phase Space with Click-Counting Detectors

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Since the dawn of quantum theory in the early 20th century, its understanding gave rise to many technological uses, like semiconductors and lasers. A rather new field of use is quantum computing and communication. These use special properties of certain quantum systems, which could not be described in classical theories. The goal of this work is to study such nonclassicalities and to analyze the existence of these for a given quantum optical example. The techniques used in this considered experimental scheme, click-counting and unbalanced homodyning, will also be briefly examined.

Squeezing distillation for quantum atmospheric channels.

Karsten Weiher
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I will introduce a quantum communication protocol, which aims to distill a squeezed state out of a noisy signal. The protocol does contain atmospheric loss models presented in PRL 108, 220501 (2012). For distillation, a tap beam splitter is applied on the beam and the tap beam serves as a control measurement.

The influence of spin-obit coupling on the quantum defects of excitons

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The understanding of the surrounding matter was always part of scientific research. First assumptions about the atomic structure of the world were made by Demokrit and Leukipp 2400 years ago. Since the twentieth century huge progress was made by using quantum mechanical methods to describe the properties of matter. In this thesis we will concentrate on excitons, which are a fundamental excitation of a semiconductor and can be described analogous to the hydrogen atom. More specifically we will look at so called quantum defects, which were first introduced by Rydberg to characterize atoms with highly excited electrons but can be applied in a similar way to excitons. This excitonic quantum defects describe the deviation of the energy eigenvalues from those of the Wannier equation, which are caused by the non-parabolic properties of the band structure of a solid. The latter are influenced by a fundamental interaction of the angular momentum and the spin of a particle, called spin-orbit coupling. Our main focus in this presentation is to show how the quantum defects change under variation of the spin-orbit coupling in which we will show that for high spin-orbit energies the non-parabolic terms vanish and the energy eigenvalues of the exciton form a hydrogen-like series.

Artificial Two Levels System in Semi-Quantum Approximation

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Our consideration is quite general and can be applied to different types of qubit-resonator systems, including semiconductor qubits, for concreteness we concentrate on a transmon-type qubit in cavity [1,2,3]. Such systems were studied for different perspectives, recently including such elaborated phenomena as the Landau-Zener-Stückelberg-Majorana interference [4]. Specifically, the transmon qubit is coupled to the transmission-line resonator; this system is considered to be probed via the resonator. Here we explicitly take into account the nonzero effective temperature impact on both resonator and qubit. First, we obtain simplified but transparent analytical expressions for the transmission coefficient in the semi-classical approximation, which ignores the qubit-resonator correlations. Such semiclassical approach is useful, but its validity should be checked. For this reason, we further develop our calculations, by taking into account the qubit-resonator correlates.

[1] S.N. Shevchenko, G. Oelsner, Ya.S. Greenberg, P. Macha, D.S. Karpov, M. Grajcar, U. Hubner, A.N. Omelyanchouk, E. Il'ichev, Phys. Rev. B 89, 184504 (2014).

[2] D.S. Karpov, G. Oelsner, S.N. Shevchenko, Ya.S. Greenberg, E. Ilichev, Low Temp. Phys. 42, 189 (2016)

[3] R. Bianchetti, S. Filipp, M. Baur, J. M. Fink, M. G� oppl, P. J. Leek, L. Steen, A. Blais, and A. Wallra, Phys. Rev. A 80, 043840 (2009).

[4] M. Gong, Y. Zhou, D. Lan, Y. Fan, J. Pan, H. Yu, J. Chen, G. Sun, Y. Yu, S. Han, et al., Applied Phys. Lett. 108, 112602 (2016).

Snap-through transition of graphene membranes for memcapacitor applications using elastic theory

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Using computational and theoretical approaches, we investigate the snap-through transition of buckled graphene membranes. Our main interest is related to the possibility of using the buckled membrane as a plate of capacitor with memory (memcapacitor). For this purpose, we performed elasticity-theory calculations of the up-to-down and down-to-up snap-through transitions for the membranes of several sizes. We have obtained expressions for the threshold switching forces needed for both up-to-down and down-to-up transitions. Our elastics results are in general agreement with molecular-dynamics simulations. We believe that our approach may be useful for the description of other systems, including nanomechanical and biological ones, which experience the snap-through transitions.

Experimental demonstration of high dimensional synthetic lattices in planar photonic structures

Lukas Maczewsky
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We introduce a general method to map multi-dimensional lattices to planar photonic structures, and demonstrate experimentally a sharp transition from zero to strong localization in up to five-dimensional synthetic lattices.

Local symmetries and discrete continuity in Schrödinger arrays

Nora Schmitt
University of Rostock - Experimental Solid-State Optics

We study the effect of local symmetries on the dynamics of light propagation in waveguide arrays governed by a Schrödinger equation. In contrast to the idealized scenario of perfect global symmetries, instances of local symmetries abound in nature. Likewise, they can readily be incorporated into synthetic structures, where they enable new ways to tailor global material properties. The effect of local symmetries on the system's dynamics and eigenstates may be described by a nonlocal discrete continuity formalism that is a generalization of the well-known Bloch and parity theorem. We fabricated representative examples of locally symmetric, globally symmetric and non-symmetric configurations in femtosecond laser-written photonic arrays, and probed the corresponding system dynamics via coherent excitations. Whereas the locally and globally symmetric systems satisfy the nonlocal continuity equation, our observations highlight the difference to the non-symmetric case, characterized by the absence of locally symmetric domains.

Realisation of a photonic C-Not gate using exclusively straight waveguides.

René Pollmann

Uni Rostock, Experimental Solid-State Optics

Integrated photonics is a promising platform for a wide variety of optical applications since it provides the means to implement complex functionalities on a compact footprint. Crucially, optical devices realized within the bulk of a monolithic chip offer an unprecedented degree of stability and robustness with respect to external perturbations, rendering them an ideal platform for quantum optics. In this vein, curvature-induced bending losses are the key factors limiting both performance and achievable degree of integration. We aim to address this challenge by introducing a novel coupler design that reduces the need for curved waveguide trajectories while minimizing the overall device length to increase the yield of multiphoton experiments. Using the femtosecond laser inscription technique, we fabricated a prototype CNOT gate, characterized its transition matrix in the coincidence basis and compared these results to a classical, non-coincident input state.

Frequency up-conversion of squeezed quantum states of light

Milan Gödecke

University of Rostock, Institute of Physics, Experimental Quantum Optics

Frequency conversion of quantum states can be the link between otherwise incompatible quantum systems. An example could be a quantum state source that operates at a given optical frequency, and a single quantum emitter that requires a different, defined optical frequency to interact with. Frequency conversion of the prepared quantum states allows to use both of the already existing devices in one experiment. Furthermore, the conversion to the visible spectrum often grants higher detection efficiencies. In this work frequency conversion is demonstrated for photons prepared in a squeezed state. Squeezed light offers a possibility of improving the accuracy of ultra-sensitive measurements beyond the quantum noise limit. In our lab we generate squeezed light at a wavelength of 1064nm with up to 5dB of measurable squeezing. Frequency up-conversion is particularly useful here, because the direct generation of squeezed light in the visible spectrum is not feasible due to phase matching limitations. In sum-frequency generation the squeezed field at 1064nm is mixed with a strong coherent pump field at the same wavelength to generate a squeezed field at 532nm. To achieve higher conversion efficiencies, the nonlinear crystal utilized for the SFG is placed in an optical cavity locked on resonance for the input fields.

Giant Dipole States of Rydberg Excitons in Cu2O

Thomas Stielow
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An exotic species of Rydberg states of atoms in crossed electric and magnetic fields are so-called giant-dipole states. These states are characterized by a directed electron-ionic core separation in the range of several micrometers, leading to huge permanent electric dipole moments of several hundred thousand Debye. So far, these states stay out of reach for observation. Recently, the possible formation of giant dipole states by Rydberg excitons in Cu${}_2$O has been proposed. We discuss different possible excitation paths leading to giant dipole excitons based on the latest descriptions of excitonic giant dipole states.

Interatomic Coulombic Decay & Auger Decay in Environment

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Albert-Ludwigs-Universität Freiburg, Physikalisches Institut

Interatomic Coulombic decay is a double ionization process similar to the Auger decay: An inner-shell ionized atom relaxes by filling the vacancy with an electron of a higher energy level. The emitted photon that carries the energy difference is then absorbed by a second atom and ionizes it. The process typically occurs in weakly bound atomic van-der-Waals clusters and is highly relevant in a biological context since the emitted electron in the secondary process typically exhibits energies which have been shown to be harmful to the DNA. Using macroscopic quantum electrodynamics, we have derived a general expression to describe the interatomic Coulombic decay rate. Two different approaches, namely time-dependent and time-independent perturbation theory yield contradicting predictions for this decay rate. We present different results concerning the decay rate in the presence of different environments. As the investigation of the related Auger process competes with interatomic Coulombic decay we investigate it in a similar manner. Finally, we give an outlook for the application of our theory to a nano droplet experiment where the decay rate in the presence of the environment can be predicted.

Implementation of 'Artificial Quantum Life' in Integrated Photonic Circuits

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University of Rostock, Experimental-Solid-State Optics

In biology, the phenotype of an organism describes the entirety of its observable characteristics. As such, it arises from the interplay of the information encoded in its underlying genotype with the multitude of influences presented by its environment. With this inspiration in mind, we introduce a protocol that allows photonic quantum states to act as artificial "living units" which undergo successive reproductive steps represented by a sequence of logical quantum gates. In order to demonstrate the capabilities of our paradigm and to verify its functionality, we employ femtosecond laser-written photonic circuits to simulate and observe the "evolution" of a given phenotype along stochastic quantum walks.

Improving continuous variable quantum teleportation in atmospheric channels

Kevin Hofmann
Universität Rostock

We study the Braunstein-Kimble continuous-variable quantum-state teleportation protocol under the influence of atmospheric losses. In this context, we develop different strategies to optimize the teleportation fidelity being the figure of merit of such protocols. In particular, we derive an expression for the teleportation fidelity for coherent states affected by fluctuating losses in atmospheric channels. We show that postselection protocols and adaptive methods, which correlate the fluctuating losses in the system, lead to an improved teleportation performance. Our teleportation strategies are tested for the loss characteristics of an existing experimental free-space channel demonstrating their feasibility and advantages under realistic conditions.

Generation of cluster states using laser-written integrated quantum circuits

Eric Meyer
University of Rostock

Highly entangled quantum states, such as cluster states, play a fundamental role in the field of quantum computing and quantum communication especially in the context of the so-called one-way or measurement based quantum computing. The one-way quantum computer differs from the common unitary model quantum computer in that sense that a sequence of single qubit measurements are performed on a cluster or graph state. Due to the comparable simplicity of single qubit measurements, any difficulties of performing large phase stabile quantum circuits are moved to generate large resource states. By using femtosecond laser-written waveguides in Gorilla Glass we aim to fabricate integrated quantum networks which generate four-qubit cluster states encoded into the polarization of four photons.

Optical resonator for separation of quantum sidebands and carrier frequencies of Kerr-squeezed mode-locked fs-pulses

Kai Barnscheidt
University of Rostock Experimental Quantum Optics

Due to high intensities propagating over long distances within the core of the fiber pulses of a few hundred femtoseconds in optical fibers are mainly influenced by the nonlinear Kerr-effect resulting in a Kerr-squeezed state. Noise from Brillouin scattering is avoided by the short pulse duration yet the pulses are to long encounter significant Raman scattering. Nevertheless, these quantum states are difficult to analyze as the high optical power and the changing pulse shape impede schemes with a normal local oscillator. Hence only schemes using either counter or co propagating pulses have been implemented measuring squeezing. A impedance matched optical resonator simultaneously resonant for all frequency modes of the pulses (exactly matching the free spectral range to the laser repetition rate) transmits all optical power in the carrier frequencies while all sidebands outside the line width are reflected. Homodyne measurements on the reflected sidebands can be implemented using the transmitted light as a local oscillator. Both intrinsic stability and active stabilization are key for such an experimental setup and have to be archived and maintained.