Q 12: Quantum Optics II

Time: Monday 14:00–16:00 Location: K 0.016

Q 12.1 Mon 14:00 K 0.016

A free-electron laser oscillator in the quantum regime — •Peter Kling[1,2], Enno Giese[3,1], Roland Sauerbrey[2], and Wolfgang P. Schleich[1] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology IQ$^{\mathrm{ST}}$, Universität Ulm, D-89069 Ulm — [2]Helmholtz-Zentrum Dresden-Rossendorf e.V., D-01314 Dresden — [3]University of Ottawa, Ottawa, Ontario K1N 6N5, Canada

Decreasing the wavelength of a free-electron laser (FEL) increases the quantum mechanical recoil an electron experiences, when it scatters with the light fields, and ultimately leads to the emergence of quantum effects. If the recoil dominantes the dynamics, we speak of the quantum regime of the FEL [1]. In this limit, the electron populates only two resonant momentum levels [2,3].

We present here the theory of a low-gain FEL oscillator in the quantum regime and derive properties such as the gain and the steady-state photon statistics. Moreover, we compare this device with (i) the micromaser and (ii) the classical FEL.

[1] R. Bonifacio, N. Piovella, and G. R. M. Robb, Fortschr. Phys. **57**, 1041 (2009).
[2] P. Kling *et al.*, New J. Phys. **17**, 123019 (2015).
[3] P. Kling *et al.*, Appl. Phys. B **123**, 9 (2017).

Q 12.2 Mon 14:15 K 0.016

Time-Resolved Photon Statistics Measurements at Lasing Threshold with Homodyne Detection — •Carolin Lüders, Johannes Thewes, and Marc Assmann — Experimentelle Physik 2, Technische Universität Dortmund, 44221 Dortmund, Germany

For laser science and application, understanding the temporal dynamics of the lasing transition is crucial. An indicator for characterizing the light state during this process is the second-order correlation function $g^{(2)}(\tau = 0, t)$, which distinguishes between Poissonian or thermal photon statistics. However, recording it over longer timescales while maintaining a high time resolution is needed for a detailed analysis. By employing homodyne detection, where a pulsed Local Oscillator field provides temporal selectivity, we observed $g^{(2)}$ of a diode laser with microsecond time resolution. Thus, we were able to investigate its switching between coherent and thermal mode on various time scales. While our findings provide insight in the dynamics of the lasing transition, our method may also be applied to investigate light from samples such as polariton microcavities or to test the fidelity of memories for optical quantum information.

Q 12.3 Mon 14:30 K 0.016

Quantum-limited Coherent Combination of Optical Signals — •Sourav Chatterjee[1,2,3], Christian R. Müller[1,2], Florian Sedlmeir[1,2], Christoph Marquardt[1,2,3], and Gerd Leuchs[1,2,3] — [1]MPI for the Science of Light, Erlangen, Germany — [2]Department of Physics, FAU, Erlangen, Germany — [3]School in Advanced Optical Technologies, Erlangen, Germany

Extremely powerful lasers are needed for various applications in science and industry. State-of-the-art technology only offers quantum-noise-limited lasers in the power range of a few watts. Thermal mode instabilities (TMI) cause high quality fibre laser beams to become unstable above a certain threshold power [1]. This limits the precision of quantum-limited metrology as well as the efficiency of coherent parametric processes.

Coherent combination enables the scaling of fibre laser power beyond the TMI threshold. In this technique, multiple weaker quantum-noise-limited beams, split from a seed laser, are individually amplified with identical fibre amplifiers operating below TMI threshold and then recombined by a series of beam-splitters to generate a high power beam [2]. However, the quality of the output beam depends crucially on the interference after the beam-splitter series. In our experiment, we demonstrate interferometric locking schemes utilizing quantum-limited phase measurements along with fast feedback electronics to investigate fundamental boundaries and quantum limits of coherent combination.

[1] T. Eidam et al., Opt. Express 19 (2011).
[2] H. Tünnermann et al., Opt. Express 19 (2011).

Q 12.4 Mon 14:45 K 0.016

quantum backscatter communication — •Roberto Di Candia — Freie Universitat, Berlin, Germany

Quantum illumination is a revolutionary photonic quantum sensing technology that improves the hypothesis testing performance in noisy and lossy environments. On the other hand, backscatter communication is a long-standing paradigm making use of amplitude and phase modulation together with radar technology to allow data transmission between devices. In this talk, we show how quantum illumination enhances the performance of backscatter communication protocols. We study a narrowband system, in which the symbol duration is long enough that the photodetector receiver is able to receive a sufficiently large number of photons before making any decision. We rigorously derive the signal-to-noise ratio gain in the error probability exponent for the cases of Gaussian and non-Gaussian states as input. We also characterize the quantum radar cross-section of a simple flat dipole antenna and propose a simple model of Rician fading in the quantum setting. These results extend the usefulness of quantum illumination performance beyond the quantum radar, which is supposed to be long-range and, therefore, challenging to build.

Q 12.5 Mon 15:00 K 0.016

Optimization of photovoltaic upconversion by tailoring the photonic density of states — •Fabian Spallek, Andreas Buchleitner, and Thomas Wellens — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg

Upconversion materials, which convert two low-energy photons into one photon with higher energy, combined with photonic structures, open promising possibilities to improve the efficiency of silicon solar cells by utilizing the full range rather than only a fraction of the solar spectrum [1]. Quantum yield and the luminescence enhancement, which quantify the overall efficiency of the embedded upconverter material, are determined by the interplay of energy transfer processes, local irradiance and local density of (photonic) states - all of which can be influenced by photonic dielectric nanostructures. We derive the local density of states from macroscopic QED, for arbitrary finite multi-layered dielectric structures. This allows us to optimize the structure, such as to enhance desired, or to suppress unwanted spontaneous emission processes from distinct excited energy levels of the upconverter material. In combination with previous results on the optimization of the local irradiance in multi-layered structures [2], we compare our predictions for the achievable luminescence and upconversion quantum yield to thus far experimentally implemented [1] Bragg structures.

[1] C. L. M. Hofmann et al., Opt. Express 24, 14895 (2016)
[2] F. Spallek et al., J. Phys. B: At. Mol. Opt. Phys. 50, 214005 (2017)

Q 12.6 Mon 15:15 K 0.016

The 1 m prototype for the 'Any Light particle Search' experiment — •Kanioar Karan, Dennis Schmelzer, Li-Wei Wei, and Benno Willke — Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), Callinstraße 38, 30167 Hannover

Extensions of the Standard Model of particle physics predict a variety of new particles, among them so-called WISPs, or very Weakly Interacting Sub-eV Particles. The most famous WISP candidate is the axion.

The ALPS collaboration is setting up a light shining through a wall experiment (LSW) for production and detection of WISPs. This experiment is based on the simple idea that a high power laser field that traveled through a static magnetic field can partly oscillate into an axion filed. The axion field then cross an opaque wall to a second static magnetic field and re-oscillate into an electromagnetic field. On both sides of the wall optical cavities are used to increase the laser field for the WISPs production and the likelihood for the re-oscillation of the WISPs into electromagnetic fields.

A key challenge in the experiment is to achieve a spatial overlap of 95% of the two optical cavities. Therefore, the parallelism of the cavity mirrors has to be $\leq 5\mu$rad. With the 1m prototype table-top experiment the ALPS collaboration will show with a breadboard concept how to achieve a parallelism of 5μrad and the required spatial overlap of 95%. We will report on the status of this 1m-prototype experiment.

Q 12.7 Mon 15:30 K 0.016

Experimental setup for quantum logic inspired cooling and detection of single (anti-)protons — •Teresa Meiners[1], Johannes Mielke[1], Malte Niemann[1], Juan M. Cornejo[1], Anna-Greta Paschke[1,2], Matthias Borchert[1], Jonathan Morgner[1], Amado Bautista-Salvador[2,1], Stefan Ulmer[3], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Physikalisch Technische Bundesanstalt, Braunschweig — [3]Ulmer Fundamental Symmetries Laboratory, RIKEN

The goal of the QLEDS (Quantum Logic Enabled Test of Discrete Symmetries) experiment is to develop quantum logic inspired techniques for the comparison of the magnetic moments of the proton and the antiproton to test CPT invariance. Therefore, the spin state of the proton in a Penning trap has to be determined. Following a proposal by Heinzen and Wineland [1], sympathetic cooling, state preparation and spin state readout could be done using a co-trapped atomic ion. These ideas could be implemented within the BASE collaboration [2] to obtain significantly lower temperatures and faster cycle times.

Here, we report on the current status of the project. We present the experimental apparatus that consists of several stacked cylindrical Penning traps. This configuration allows for (sympathetic) cooling, transport, and motional coupling of two Be$^+$ ions.

[1] Heinzen and Wineland, PRA **42**, 2977 (1990)

[2] C. Smorra *et al.*, Eur. Phys. J. Special Topics **224**, 3055-3108 (2015)

Q 12.8 Mon 15:45 K 0.016

Spectral properties of ultrabroadband squeezed pulses of quantum light — •Thiago Lucena de M. Guedes, Matthias Kizmann, Guido Burkard, and Andrey S. Moskalenko — University of Konstanz, Konstanz, Germany

In recent years, a series of works [1,2,3] provided a deeper understanding on how to sample and squeeze the vacuum fluctuations of the electric field at a femtosecond time scale. Following the respective works, the squeezing operator for an ultrabroadband (continuous) multimode squeezed vacuum state generated in a thin nonlinear crystal was derived. The squeezing is found to depend on the shape and duration of the pump pulse that enters one of the ports of the generating crystal. The photon number density distribution in frequency for such squeezed states can be calculated perturbatively and shows to a good accuracy an exponential decaying behavior for most of the pump field shapes. We compare the corresponding spectra with the spectrum of the Unruh-Davies radiation [4,5], which would be seen by a detector at rest in a highly-accelerated non-inertial reference frame. We analyze the temporal behavior of the normal-ordered variance of the electric-field operator. On the subcyle time scale there are pronounced differences to the conventional harmonic dependence of the variance of a single-mode squeezed state on the phase delay.

[1] C. Riek et al., Science 350, 420 (2015). [2] A.S. Moskalenko et al., Phys. Rev. Lett. 115, 263601 (2015). [3] C. Riek et al., Nature 541, 376 (2017). [4] W. G. Unruh, Phys. Rev. D 14, 870 (1976). [5] P. C. W. Davies, J. Phys. A 8, 609 (1975).