HL 70: Semiconductor Lasers I

Time: Thursday 9:30–13:00 Location: H13

HL 70.1 Thu 9:30 H13

Few quantum emitters – small cavities: exact treatment of the electron-photon coupling in mesoscopic quantum devices — •Michael Gegg, Andreas Knorr, and Marten Richter — Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Germany

Open many body quantum systems consisting of N quantum emitters (QEs), e.g. dye molecules or quantum dots, coupled to a lossy cavity/optical mode have been subject to extensive research for decades. These systems can be described by N two- (multi-) level systems interacting with bosonic cavity modes including dissipation and pumping in the Lindblad formalism. This provides access to a manifold of interesting applications, such as lasers, parametric amplifiers for normal cavities and spasers or surface plasmon generators for metallic systems.

We develop an exact and numerically scalable solution to the N multi-level system Lindblad equation [1], which provides a dramatic speedup compared to conventional solutions. Especially in the few ($N \sim 1 - 100$) emitter case the solution is a major advance compared to existing techniques, while retaining the full quantum correlations and entanglement properties. Some applications of the developed method will be shown.

[1] M. Richter, M. Gegg, T.S. Theuerholz, A. Knorr, Phys. Rev. B 91: 035306 (2015)

HL 70.2 Thu 9:45 H13

Collective enhancements in many-emitter phonon lasing. — •Leon Droenner, Nicolas Naumann, Julia Kabuss, and Alexander Carmele — Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

The confinement of a single acoustic phonon mode and the acoustic analogue of lasing has been experimentally demonstrated on several platforms [1]. However, to achieve threshold-less lasing and high output intensities the strong coupling regime is necessary but still difficult to engineer. To circumvent this ingredient, we propose an N-emitter phonon laser based on a detuned excitation set-up, where either cooling or vibrational amplification can be realized [2]. We show that by detuning the optical excitation to the anti-Stokes resonance of the N-emitter ensemble, that collective enhancements become important. These enhancements are similiar to the super- and subradiance effects in optics but differ in effective density-density shifts. We pinpoint feasible excitation and coupling regimes and show that these collective shifts lead to a strongly enhanced quantum yield. Thereby, we show that the N-emitter setup is a promising route to realize highly efficient phonon lasing.

[1] K. Vahala, M. Herrmann, S. Knünz, V. Batteiger, G. Saathoff, T. W. Hänsch, Th. Udem, Nature Physics 5, 682 - 686 (2009).
[2] Nicolas L. Naumann, Leon Droenner, Alexander Carmele, Andreas Knorr, Weng W. Chow, Julia Kabuss, arXiv:1509.06910 (2015).

HL 70.3 Thu 10:00 H13

High-β Quantum Dot Micropillar Lasers under Optical Injection — •Elisabeth Schlottmann[1], Steffen Holzinger[1], Sören Kreinberg[1], Christian Schneider[2], Martin Kamp[2], Sven Höfling[2], Janik Wolters[1], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Germany — [2]Technische Physik, Julius-Maximilians-Universität Würzburg, Germany

Injection locking of standard semiconductor lasers, where the slave adapts to the master laser's frequency is well known and is widely applied e.g. for laser stabilization. Here we go beyond the classical injection locking by exploring the quantum limit of injection locking by using a microscopic quantum dot laser as a slave. This device with a high quality factor of Q $\sim$ 70000 and a low mode volume exhibits high spontaneous emission enhancement due to the Purcell effect, enabling stable lasing at intra-cavity photon numbers as low as a few tens. In these devices, small structural asymmetries lead to bimodal emission and gain competition above threshold, resulting in different intensities for the two orthogonal polarization modes.

Under optical injection we achieve frequency locking, surprisingly accompanied by simultaneous strong emission at the slave's solitary frequency. When the master laser and the stronger mode of the microscopic laser have the same polarization, the stronger mode is "partial injection locked" in a wide range of master-slave detuning. Simultaneously, the orthogonal polarized weak mode suffers a pronounced suppression of emission via gain coupling.

HL 70.4 Thu 10:15 H13

On the threshold behavior of high-β quantum dot micropillar lasers — •Sören Kreinberg[1], Weng W Chow[2], Christian Schneider[3], Frank Jahnke[4], Sven Höfling[3], Janik Wolters[1], Martin Kamp[3], Christopher Gies[4], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Germany — [2]Sandia National Laboratories, Albuquerque, NM, USA — [3]Technische Physik, Julius-Maximilians-Universität Würzburg, Germany — [4]Institut für Theoretische Physik, Universität Bremen, Germany

We present a comprehensive study on the transition between spontaneous emission and stimulated emission of quantum dot microcavities in the regime of cavity quantum electrodynamics (cQED). The structures are based on high-quality, high-β semiconductor GaAs/AlAs micropillar cavities containing a single layer of optically pumped InGaAs quantum dots (QD) as active medium. A widely used criterion for lasing is a characteristic non-linearity in the in the input-output curve which gradually vanishes with increasing β values in micro- and nanolasers. To provide a conclusive lasing criterion, we show that QD micropillar cavities with almost identical intensity and spectral properties can be easily categorized into lasing and non-lasing classes by analysis of the equal-time second-order photon autocorrelation by means of a Hanbury-Brown and Twiss setup and the excitation-dependent impulse response of the system using time resolved spectroscopy. For a comprehensive picture, we compare our results to a microscopic theory to clearly identify lasing criteria in high-β microcavities.

HL 70.5 Thu 10:30 H13

Effects of single-quantum-dot lasing in the presence of strong coupling — Fabian Gericke[1], Leon Messner[1], Steffen Holzinger[1], Caspar Hopfmann[1], Tobias Heindel[1], Janik Wolters[1], Matthias Florian[2], Frank Jahnke[2], Christian Schneider[3], Martin Kamp[3], Sven Höfling[3], •Christopher Gies[2], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin — [2]Institut für Theoretische Physik, Universität Bremen — [3]Technische Physik, Universität Würzburg, Germany

Nanolasers with only few self-assembled semiconductor quantum dots (QDs) as active medium push solid-state emitter cavity-QED into new operational regimes, where the definition of 'lasing' needs to be closely reexamined. We present insight and results from a theory/experiment collaboration to explore the possibility of lasing in a system that exhibits strong coupling between a single emitter and a high-Q cavity mode. The coupling of higher multi-exciton states of detuned QD emitters is considered as a cavity feeding mechanism in a microscopic theory that treats the light-matter interaction of the few-emitter system non-pertubatively. We demonstrate that strong coupling and lasing can coexist in the experiment, and that the onset of stimulated emission already causes a transition to a single peak in the emission spectrum before strong coupling is lost due to increasing excitation-induced dephasing.

HL 70.6 Thu 10:45 H13

Two color excitation of a single-QD Laser in the strong coupling regime — •Fabian Gericke[1], Martin von Helversen[1], Maximilian Sommer[1], Tobias Heindel[1], Christian Schneider[2], Frank Jahnke[3], Sven Höfling[2], Janik Wolters[1], Martin Kamp[2], Christopher Gies[3], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany — [2]Technische Physik, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany — [3]Institut für Theoretische Physik, Universität Bremen, 28334 Bremen, Germany

Single semiconductor quantum dots embedded in microcavities offer the unique opportunity to study different regimes of cavity quantum electrodynamics. The light-matter interaction, especially in the coherent coupling regime, is of particular interest for a variety of applications in quantum information processing and novel effects such as single photon nonlinearities.

In this work, we present comprehensive study on quantum dot (QD) microcavity lasers operating at the intersection of weak and strong light matter interaction. By combined resonant and non-resonant excitation, we distinguish between the gain contribution given by a single resonant QD and small number of nonresonant QDs, where the latter are weakly coupled to the lasing mode via e.g. phonon-induced cavity feeding. This enables us to proof the onset of laser oscillations with a single quantum dot as gain medium. The presented results significantly advance the understanding of single quantum dot lasers and stimulate further experiental as well as theoretical investigations.

30 min. Coffee Break

HL 70.7 Thu 11:30 H13

SESAMs for mode locking of red-emitting VECSELs — •Roman Bek[1], Quynh Duong-Ederer[1], Hermann Kahle[1], Thomas Schwarzbäck[1], Michael Jetter[1], Maria A. Cataluna[2], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Research Centers SCoPE and IQST, University of Stuttgart, Allmandring 3, 70569 Stuttgart, Germany — [2]School of Engineering, Physics and Mathematics, University of Dundee, Dundee DD1 4HN, United Kingdom

Passively mode-locked vertical external-cavity surface-emitting lasers (VECSELs) emitting in the infrared spectral range have first been realized in 2000. These compact pulsed laser sources have excellent properties such as high output power, short pulse duration and a near diffraction-limited beam profile. In the visible spectrum, VECSELs have been mode-locked by semiconductor saturable absorber mirrors (SESAMs) since 2013 with emission wavelengths between 650 nm and 675 nm.

We present and compare different SESAM designs for mode locking of AlGaInP VECSELs. Our samples are fabricated by metal-organic vapor-phase epitaxy and include Bragg mirrors consisting of AlGaAs/AlAs on GaAs substrates. The active regions contain either GaInP quantum wells or InP quantum dots embedded in AlGaInP barrier layers. Some of the absorber structures are coated with a fused silica layer to improve the mode locking performance. We use v-shaped cavity configurations with the outcoupling mirror used as folding mirror to strongly focus onto the absorber.

HL 70.8 Thu 11:45 H13

Optimization of the cavity design for passively mode-locked VECSELs in the red spectral range — •Quynh Duong-Ederer[1], Roman Bek[1], Hermann Kahle[1], Thomas Schwarzbäck[2], Michael Jetter[1], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Research Center SCoPE and IQST, Universität Stuttgart, Allmandring 3, 70569 Stuttgart — [2]TRUMPF Lasersystems for Semiconductor Manufacturing GmbH, Johann-Maus-Straße 2, 71245 Ditzingen

Since the first demonstration of a passively mode-locked VECSEL in 2002, this type of semiconductor laser has become a fundamental element in present research. Pulsed lasers directly emitting in the red spectral range are promising candidates for many applications ranging from spectroscopy to biomedical fields. We successfully demonstrated a SESAM mode-locked VECSEL emitting at around 660 nm with a pulse duration of 2 ps and a repetition rate of 850 MHz. However, due to the cavity design the maximum peak power was limited.
We present in this contribution major improvements to overcome this circumstance. First the plane diamond heat spreader is replaced by a wedged one with a wedged angle of 2° and an anti-reflection coating for the target wavelength. Furthermore, the gain chip mount is modified to match the wedged heat spreader for an enhanced heat dissipation from the chip. This enables us to increase the optical pump power without a thermal roll-over of the device resulting in higher peak power and a stable performance of our mode-locked laser.

HL 70.9 Thu 12:00 H13

Investigations on pump-power dependences of a self-mode-locked VECSEL — •Max Vaupel, Mahmoud Gaafar, Fan Zhang, Christoph Möller, Wolfgang Stolz, Arash Rahimi-Iman, and Martin Koch — Faculty of Physics and Materials Sciences Center, Philipps-Universität Marburg, 35032 Marburg, Germany

Recently, self-mode-locked vertical-external-cavity surface-emitting lasers (SML-VECSEL) were presented as promising saturable-absorber-free pulsed lasers, although, up to now, the responsible effect is not fully understood. In this work, experimental studies have been performed in order to gain insight into the pump-power-dependent mode-locking behaviour of such a laser device and to foster the assumption of Kerr-lensing being significantly involved, by using a Z-cavity and a linear cavity configuration, respectively. The results show, that generating losses for the continuous-wave resonator mode with a well-placed hardaperture in the cavity leads to mode-locking and therefore pulsed operation for these resonator geometries. ABCD-matrix calculations for the intra-cavity beam radius as a function of a negative or positive Kerr lens inside the VECSEL-chip are in accordance with the obtained results.

HL 70.10 Thu 12:15 H13

Hybrid VCSEL and DFB Organic Microlasers — •Tim Wagner, Markas Sudzius, Andreas Mischok, Hartmut Fröb, and Karl Leo — Institut für Angewandte Photophysik, Technische Universität Dresden, George-Bähr-Str. 1, 01069 Dresden

Two of the numerous resonator architectures are the vertical-cavity surface-emitting laser (VCSEL), in which the laser mode is vertically confined between two highly reflective DBR mirrors, and the distributed-feedback laser (DFB), incorporating a horizontal waveguide with a periodic diffraction grating. We prepare these microlasers using an identical set of materials with Alq_3:DCM as the active medium. Although based on entirely different geometries and mechanisms, the two resonators exhibit similar lasing thresholds.

In this work, we design a continuously tunable hybrid device combining both resonators in a composite system, in which second-order Bragg diffraction serves as a coupling mechanism between vertical and lateral modes. Coherent interaction of the different resonances is observed and described by a coupled oscillator model. The analysis of mode dispersions and lasing characteristics leads to the identification of the different mechanisms on optical feedback and losses. Based on the results obtained, novel structures are designed to balance the performances of the vertical and lateral resonator inside the hybrid device.

HL 70.11 Thu 12:30 H13

Design considerations of oxide-confined red emitting electrically pumped VECSEL — •Zhihua Huang, Michael Zimmer, Roman Bek, Hermann Kahle, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen and Research Centers SCoPE and IQST, University of Stuttgart, Allmandring 3, 70569 Stuttgart, Germany

Electrically pumped vertical external cavity surface-emitting laser (EP-VECSEL) is an attractive laser source for compact, low-cost, high-brightness applications. However, achieving high output power with fundamental mode operation is still a challenging work. Here, we present a detailed numerical analysis of EP-VECSEL structure at a wavelength of 665 nm with the focus on the current confinement and thermal management of AlGaInP based devices. We apply an electro-thermal model to treat effective conductivity and current distribution in multiple quantum wells (MQW) and distributed Bragg reflectors (DBRs). By analyzing the diameters and positions of oxide-aperture, different material composition, doping and thickness of current spreading layer (CSL), an improved structure with homogeneous current distribution and a trade-off between optical loss and device resistance is obtained. This configuration contains one oxide-aperture placed at the bottom and a 10 μm thick Al0.10GaInP CSL with medium n-doped concentration. For this optimized structure, simulation results indicate that the emission area in active region with a near Gaussian current distribution can be increased up to about 60 μm. This work provides a significant guideline for the design and optimization of EP-VECSEL.

HL 70.12 Thu 12:45 H13

Semiconductor quantum membrane external-cavity surface-emitting laser — •Hermann Kahle[1], Cherry M. N. Mateo[2], Roman Bek[1], Uwe Brauch[2], Michael Jetter[1], Thomas Graf[2], and Peter Michler[1] — [1]Universität Stuttgart, Institut für Halbleiteroptik und Funktionelle Grenzflächen IHFG and research centers IQST and SCoPE, Allmandring 3 — [2]Universität Stuttgart, Institut für Strahlwerkzeuge IFSW and research center SCoPE, Pfaffenwaldring 43

Due to their simplicity and the efficient optical pumping, vertical external-cavity surface-emitting lasers (VECSELs) are becoming more and more important systems. Furthermore, the good beam quality as well as the open resonator which enables the use of intra-cavity (ic) frequency selective/multiplying elements make them laser systems with an unique palette of benefits. The use of semiconductors as gain material allows bandgap engineering and provides a broad gain. However, most VECSEL systems suffer from the bad thermal conductivity of the substrate and the DBR. A wet-chemically released active region of a VECSEL, sandwiched between anti-reflection coated diamond ic heatspreaders leads to an improved thermal behavior. The absence of the DBR allows us to use regular laser mirrors in the resonator and therefore completely exploit the gain provided by the active region. We present first characterisation measurements of the optically pumped semiconductor quantum membrane external-cavity surface-emitting laser (OPS-MECSEL or QML).