HL 18: Semiconductor Lasers II

Time: Monday 14:45–17:30 Location: POT 06

HL 18.1 Mon 14:45 POT 06

Pump-power-driven mode switching in quantum-dot microlasers — •Heinrich A.M. Leymann[1,2], Daniel Vorberg[2], Thomas Lettau[1], Caspar Hopfmann[3], Christian Schneider[4], Martin Kamp[4], Sven Höfling[4], Roland Ketzmerick[2,5], Jan Wiersig[1], Stephan Reitzenstein[3], and André Eckardt[2] — [1]OvG Universität Magdeburg — [2]MPI PKS Dresden — [3]Technische Universität Berlin — [4]Universität Würzburg — [5]Technische Universität Dresden

We investigate the switching of the steady-state lasing mode of a high-β quantum-dot microlaser, occurring in bimodal lasers when varying the pump power. Comparing experiment to theory, we identify the underlying mechanism to be based on the competition between the effective gain on the one hand and the inter-mode kinetics on the other. We show that, while the largest effective gain determines the laser mode for weak pumping (just above the lasing threshold), it is the inter-mode kinetics that selects the laser mode in the limit of strong pumping. We point out that the latter mechanism is akin to (non-equilibrium) condensation of massive bosons. This similarity allows us to describe the mode switching by generalizing the theory of Bose selection and to obtain an analytical criterion for the mode selection. Within this framework, we find that the excitation-power-dependent switching from one laser mode to the other occurs via an intermediate phase, where both modes are lasing. Finally, we employ exact numerical simulations to investigate the origin of the experimentally observed super-thermal intensity fluctuations of the non-lasing mode.

HL 18.2 Mon 15:00 POT 06

First order coherence of semiconductor nanowire lasers — •Franz Langrieger, Michael Kaniber, Thomas Stettner, Philipp Zimmermann, Gregor Koblmüller, and Jonathan J. Finley — Walter Schottky Institut and Physik Department, Technische Universität München, Garching b. München, Germany

We experimentally probe the temporal coherence of the emission from individual GaAs-AlGaAs core-shell nanowire lasers dispersed onto Al_2O_3 substrates. Excitation power dependent photoluminescence spectroscopy shows continuous wave lasing from individual nanowires with threshold power densities of 11.3 ± 0.8 kW/cm2 and lasing persists from cryogenic temperatures up to T=140K. By measuring the first order coherence using a Michelson interferometer we obtain coherence times τ_c of a few ps. Our results are compared with spectral linewidth measurements of the lasing mode. The mechanism that lead to a limitation of the coherence times in nanowire lasers will be discussed.

HL 18.3 Mon 15:15 POT 06

Controlling the influence of background emitters on lasing in quantum dot micropillars — •Fabian Gericke[1], Mawussey Segnon[3], Martin von Helversen[1], Tobias Heindel[1], Christian Schneider[2], Frank Jahnke[3], Sven Höfling[2], Anna Musial[2], Xavier Porte[2], Martin Kamp[2], Christopher Gies[3], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Germany — [2]Technische Physik, Universität Würzburg, Germany — [3]Institut für Theoretische Physik, Universität Bremen, Germany

In case of microlasers with a low number of quantum dots (QDs) acting as gain material, it is important to consider the relative gain contribution from individual QDs. In particular, in the single QD lasing regime one has to distinguish between the gain contribution of a single QD in resonance with the cavity mode and that of additional off-resonant emitters. In this regime, we control and study the relative gain contribution of the resonant QD and a small ensemble of non-resonant QDs by using a two-color excitation scheme. The experiments are supported by a theoretical description in which we describe the system using a microscopic semiconductor model. This enables us to discriminate a truly single QD laser from a device where lasing threshold is enabled by additional background emitters. We show that a single QD in the spontaneous emission regime contributes with up to 70% to the laser output. Interestingly, increasing the number of contributing off-resonant emitters changes the effective beta-factor and lowers the laser threshold.

HL 18.4 Mon 15:30 POT 06

Gain compression induced polarization mode competition in quantum-dot micropillar lasers: Effects of coherent feedback on multi-mode rate equations — •Benjamin Kurt Miller, Christoph Redlich, Lina Jaurigue, Benjamin Lingnau, and Kathy Lüdge — Institut f. Theo. Physik, Sekr. EW 7-1, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

Quantum-dot (QD) high-Q micropillar lasers are promising optoelectronic devices for data communication. The effects of feedback on QD lasers has profound consequences on stability and behavior, as seen in our previous work on single-mode QD micropillar lasers [1]. We investigated bimodal systems without feedback [2] and our preliminary results found that introducing feedback would induce novel dynamics. We present a bifurcation analysis of two-mode light emission from QD semiconductor micropillar VCSEL lasers subjected to optical feedback. Our model includes multi-mode rate equations with phenomenological gain compression parameters; a deterministic spontaneous emission parameter; and delayed, optical feedback. In this presentation, we consider the effects of tuning feedback phase, time delay, and intensity on the stability and output of a QD micropillar VCSEL. Our results offer optimization data for future experimental implementation.

References: [1]C. Otto, B. Globisch, K. Lüdge, E. Schöll and T. Erneux, Int. J. Bifurcation Chaos **22**, 1250246 (2012). [2]C. Redlich, B. Lingnau, S. Holzinger, E. Schlottmann, S. Kreinberg, C. Schneider, M. Kamp, S. Höfling, J. Wolters, S. Reitzenstein, and K. Lüdge, New J. Phys. **18**, 063011 (2016).

HL 18.5 Mon 15:45 POT 06

Non-markovian delay in the formation of coherence in a pulsed quantum-dot crytal laser — •Mawussey Segnon[1], Galan Moody[2], Frank Jahnke[1], Marty Stevens[2] und Christopher Gies[1] — [1]Institute for Theoretical Physics, University of Bremen, P.O. Box 330 440, 28334 Bremen, Germany — [2]Departement of Physics, University of Colorado and National Institute of Standards and Technology, Boulder, Colorado 80309-04440 USA

Photonic crystal (PC) cavities represent one way of tailoring the electromagnetic environment of an emitter and constitute an important structure for studying quantum electrodynamic phenomena. Within this work, we present results for time-resolved photon-correlation spectroscopy and its interpretation in terms of theory of InAsP/InP quantum dots (QDs) coupled to L3 cavity of a PC structure. The theoretical model, having its basis on a microscopic Hamiltonian of the QD and the quantum mechanical light field, allows us to access the output intensity and the second-order correlation function $g^{(2)}(t, \tau = 0)$. When using pulsed excitation, the time evolution of the photon number crosses different regimes of thermal and coherent light, together making up the emitted pulse. We find systematic shifts between the time-resolved intensity pulse maximum and the coherence maximum revealed in $g^{(2)}(t, \tau = 0)$. It is demonstrated that this stems from non-Markovian effects in the correlation dynamics. Our findings point out the possibility of using such devices as thermal light sources with unconventionally large output power.

Coffee Break

HL 18.6 Mon 16:30 POT 06

Stability in Optically Injected Two-State Quantum Dot Lasers — •Stefan Meinecke, Benjamin Lingnau, André Röhm, and Kathy Lüdge — Technische Universtität Berlin, Berlin, Germany

Semiconductor lasers based upon self-assembled quantum-dots (QDs) are promising sources for applications in optical networks used e.g. for data transmission via optical fibers. Recently, their ability to show simultaneous two-state lasing became the focus of diverse investigations.

We theoretically study a two-state quantum-dot laser subjected to optical injection into the ground state from a master laser. Our modeling approach is based on microscopically based rate-equations and goes beyond the constant alpha-factor approximation by including carrier dependent frequency shifts obtained from a full Bloch-equation approach.

Our results nicely reproduce recent experimental results on optical bistability. Furthermore, we show an increase of the dynamical stability of the two-state QD laser if compared to a single-color QD laser.

We find that the chaotic dynamics, predicted for single-color QD lasers under strong and detuned injection, completely vanish, if excited state lasing is possible [1]. This phenomenon is surprising, as an increase in the dynamical complexity, i.e. the degrees of freedom, leads to a stabilization of the device.

[1] S. Meinecke, B. Lingnau, A. Röhm, K. Lüdge, Ann. d. Physik (2017)

HL 18.7 Mon 16:45 POT 06

Towards self-mode locking of VECSELs in the red spectral range — •Marius Grossmann[1], Roman Bek[1], Max Vaupel[2], Hermann Kahle[1], Thomas Schwarzbäck[1], Arash Rahimi-Iman[2], Michael Jetter[1], Martin Koch[2], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen and Research Centers SCoPE and IQ^{ST}, Universität Stuttgart, Allmandring 3, 70569 Stuttgart, Germany — [2]Department of Physics and Materials Sciences Center, Philipps-Universität Marburg, Renthof 5, 35032 Marburg, Germany

The introduction of mode-locked vertical external-cavity surface-emitting lasers (VECSELs) in 2000 was followed by tremendous progress in laser performance, especially for mode locking within the IR spectral range. Such devices facilitate a compact realization of ultrafast and -short pulse generation and are certainly desirable over a wide wavelength range. The recently demonstrated self-mode locking technique simplifies these devices even more, bypassing the intrinsic non-saturable losses of semiconductor saturable absorber mirrors.

We present the characterization of pulsed VECSELs with repetition rates in the GHz regime with focus on self-mode locking in the red spectral range. Our semiconductor structures are fabricated by metal-organic vapor-phase epitaxy. The active regions consist of quantum wells or dots based on the AlGaInP material system. Current research includes the investigation of hard and soft aperture modulation initiating the pulsed operation as well as the effect of the gain chip characteristics on the mode locking behavior.

HL 18.8 Mon 17:00 POT 06

Optical losses in intra-cavity heat spreaders for GaSb based VECSELs — •Chiara Lindner, Steffen Adler, Peter Holl, Andreas Bächle, Elke Diwo-Emmer, Rolf Aidam, and Marcel Rattunde — Fraunhofer-Institut für Angewandte Festkörperphysik IAF, Tullastr. 72, D-79108 Freiburg, Germany

Semiconductor disk lasers, also known as vertical-external-cavity surface-emitting lasers (VECSEL), exhibit the wavelength versatility of semiconductor lasers in combination with the capability of a nearly diffraction-limited high-power output. In order to achieve this, an efficient heat extraction from the active medium is needed. For GaSb (and also InP) based VECSEL, heat extraction through the distributed Bragg reflector is inefficient and thus has to be realized with an intra-cavity heat spreader. Due to their transparency at emission and pump wavelength and high thermal conductivity, silicon carbide (SiC) and diamond are most often applied.

Using a diamond heat spreader, a GaSb based VECSEL with up to 20 W output power at room temperature at 2 μm emission wavelength has been reported recently. However, the quality of the optical grade diamond still differs significantly from sample to sample.

In this presentation, we report on the results of a new experimental setup designed to determine the optical intra-cavity losses and the homogeneity of heat spreaders. We will compare different SiC and diamond based samples and discuss their influence on power scaling of VECSEL with an intra-cavity heat spreader.

HL 18.9 Mon 17:15 POT 06

Measuring the Photon Number Distribution of a Bimodal Quantum Dot Microlaser — •Elisabeth Schlottmann[1], Martin von Helversen[1], Marco Schmidt[1,2], Felix Krüger[1], Heinrich A.M. Leymann[3], Thomas Lettau[4], Alexander Foerster[4], Mikayel Khanbekyan[4], Christian Schneider[5], Sven Höfling[5], Martin Kamp[5], Jörn Beyer[2], Jan Wiersig[4], and Stephan Reitzenstein[1] — [1]Technische Universität Berlin — [2]Physikalisch Technische Bundesanstalt — [3]MPIPKS Dresden — [4]Universität Magdeburg — [5]Universität Würzburg

Microlasers operating in the regime of cavity quantum electrodynamics (cQED) exhibit enhanced coupling of spontaneous emission into the cavity mode. This leads to a smooth transition from thermal to coherent emission at threshold which makes it difficult to prove lasing solely by the input-output behavior. Against this background, measuring the second order auto-correlation function $g^{(2)}(\tau)$ has become a valuable tool to identify laser action. Beyond that, $g^{(2)}(\tau)$ is also indicative for superradiance, mode-switching or thermal emission.

Here, we apply for the first time a photon number resolving transition edge sensor (TES) to directly access the photon number distribution of quantum dot microlasers. Our combined experimental and theoretical study demonstrates that TES detectors can be used to differentiate between mode-switching and thermal emission of bimodal microlasers. Both show a $g^{(2)}(0) \approx 2$, but in the case of switching, a linear combination of a thermal and a coherent distribution appears in the photon number distribution.