HL 60: Focus Session: Coherent dynamics in semiconductor nanostructures and coupled devices

The further development of semiconductor nanophotonic devices such as high-speed lasers with bandwidths beyond 50 GHz requires a detailed understanding of the underlying nonlinear dynamical processes. Despite of severe conceptual and technological challenges in the study of associated ultra-fast phenomena, enormous progress has been achieved recently, e.g., coherent gain dynamics on a ps-timescale at room temperature. The study of ultrafast coherent processes is also vital for next generation quantum communication information systems. Here, dynamical and coherent aspects at the level of single emitters and photons are of crucial importance. This focus session will provide a platform for the presentation and discussion of state-of-the-art results, and will stimulate further research on ultra-fast and coherent nanophotonics. (Organizers: Stephan Reitzenstein and Eckehard Schöll, TU Berlin)

Time: Wednesday 15:00–18:30 Location: H16

Topical Talk HL 60.1 Wed 15:00 H16

Direct observation of coherent light matter interaction in room temperature semiconductor devices — •Gadi Eisenstein — EE Dept. Tedhnion, Haifa Israel

Direct observations of coherent light matter interactions requires that the electronic wave function dephases at a rate slower than the time of the measurement. In room temperature semiconductors, the dephasing time is 1-2 ps and therefore, experiments are traditionally performed at cryogenic temperatures so as to vastly increase the dephasing time.

An alternative approach is to shorten the observation time to well below the 1-2 ps dephasing time but this requires a special characterization capability. A very good approach is to use FROG or X-FROG systems in which the complete complex electric field of a pulse after propagating through a nonlinear medium can be determined with high precision.

We will describe such experiments in which X-FROG was used to demonstrate Rabi oscillations and self induced transparency in a room temperature electrically driven laser amplifier. The X-FROG system has a temporal resolution of about 1 fs and is highly sensitive. The experiments are accompanied by a comprehensive model based on solving the Maxwell - Schrodinger equations using an FDTD code. The simulations confirm all the experimental observations.

Topical Talk HL 60.2 Wed 15:30 H16

Impact of coherent processes on the dynamics of quantum-dot lasers and amplifiers — •Kathy Lüdge — Institut für Theoretische Physik, Technische Universität Berlin, Deutschland

The coherent interaction between material polarization and light mode is discussed with respect to its impact on the dynamics of quantum-dot (QD) laser and amplifiers. We use a semiclassical Maxwell-Bloch approach to predict the dynamics of these devices and give further insights into the the interplay between structure and device performance. An essential part of the model is the systematic consideration of all Coulomb scattering processes. The predictive power of the model makes the results interesting for experimentalists as well as for the community engaged in QD modeling. It is found that the QD laser dynamics is considerably affected by the coherent processes if the laser is operated in a self pulsating regime, e.g., if subjected to optical injection or feedback. Further we show that the coherent interaction of the quantum dot states and the reservoir states has a huge impact on the phase dynamics and the chirp of ultrashort input pulses in amplifiers, making it important for high speed data transmission. For high input pulse intensities we observe a pulse breakup at the output facet of the amplifier that is due to pronounced Rabi oscillations of the QD polarization.

Topical Talk HL 60.3 Wed 16:00 H16

Ultrafast coherent exciton dynamics in individual quantum dots - phonons, coherent coupling, and CQED — •Wolfgang Langbein — School of Physics and Astronomy, Cardiff University, The Parade, Cardiff CF24 3AA, United Kingdom

Excitons are the fundamental optical excitations of semiconductors, determining their optoelectronic properties important for present devices such as light emitting diodes and semiconductor lasers. The coherent dynamics of the excitonic excitation is dominated by coupling to phonons and photons. The three-dimensional confinement in quantum dots (QDs) creates a finite excitation volume, yielding a discrete excitonic spectrum and phonon-assisted transitions which are enhanced with decreasing volume. The zero-phonon transition dynamics can be dominated by radiative coupling at low temperatures [10.1103/PhysRevB.70.033301], and inserting the QDs into an optical cavity the quantum strong coupling regime of CQED can be reached [10.1038/NMAT2717]. Spatially separated excitons can be coupled via an optical cavity [arXiv1206.0592], or for weakly confined excitons via a two-dimensional continuum [10.1038/NPHOTON.2010.284]. I will present measurements on QD ensembles and individual QDs using nonlinear optical spectroscopy[10.1393/ncr/i2010-10054-1], including using heterodyne detected photon echo and two-dimensional spectroscopy using heterodyne spectral interferometry [10.1364/OL.31.001151].

Coffee break

Topical Talk HL 60.4 Wed 16:45 H16

Optical Properties of coupled InAs submonolayer depositions in GaAs — •Udo W. Pohl[1], Thomas Switaiski[2], Ulrike Woggon[2], Jan-Hindrik Schulze[1], Tim D. Germann[1], and André Strittmatter[1] — [1]Inst. f. Festkörperphysik, TU Berlin, Germany — [2]Inst. f. Optik und Atomare Physik, TU Berlin, Germany

Localized states formed in a stack of InAs submonolayer depositions separated by few monolayer thick GaAs spacer layers recently received much advertence for optoelectronic applications. A high areal density [1] and direct relaxation into localized quantum dot (QD) states not coupled to a wetting layer are interesting for, e.g., direct modulated high-speed lasers [2]. On the other hand, coupling of stacked submonolayer depositions to a Stranski-Krastanow (SK) QD layer provides a tuning ability for the carrier dynamics and the transition energies.

The talk outlines the structural and optical properties of InAs/GaAs submonolayer stacks and reports on the carrier dynamics of such stacks coupled to a layer of SK QDs beneath. In the coupled system, the radiative recombination rate is controlled by the separation to the SK QDs. The measured dynamics is well described by a numerically simulated population of states localized in the submonolayer stack coupled to those of the SK QDs, taking Fermi blocking into account.

[1] A. Lenz et al., Atomic structure of buried InAs sub-monolayer depositions in GaAs, Appl. Phys. Express 3, 105602 (2010).

[2] F. Hopfer et al., 20 Gb/s 85°C error-free operation of VCSELs based on submonolayer deposition of quantum dots, IEEE J. Sel. Top. Quantum Electron. 13, 1302 (2007).

Topical Talk HL 60.5 Wed 17:15 H16

Coherent optical control of quantum dot spins and spin-photon entanglement — •Sven Höfling[1,2], Kristiaan De Greve[2], Peter L. McMahon[2], David Press[2], Leo Yu[2], Jason S. Pelc[2], Chandra M. Natarajan[2], Na Young Kim[2], Thaddeus Ladd[2], Eisuke Abe[2], Sebastian Maier[1], Dirk Bisping[1], Christian Schneider[1], Martin Kamp[1], Robert H. Hadfield[3], Alfred Forchel[2], M. M. Fejer[1], and Yoshihisa Yamamoto[1] — [1]Technische Physik, Universität Würzburg, Germany — [2]Ginzton Laboratory, Stanford University, USA — [3]Heriot-Watt University, Edinburgh, UK

Quantum computer and long-distance quantum communication technologies require robust qubits that can be coherently controlled, interfaced and entangled. Single III-V semiconductor quantum-dots in microcavities are ultra-bright emitters of indistinguishable single photons, and single electron and hole spins confined in them can serve as embedded quantum memories. In this contribution, coherent control experiments of single electron and hole qubits in a Voigt magnetic field will be summarized. By employing spin echo techniques we obtain coherence times of both qubit carrier types in the microsecond-range. Within this time scale about 10^5 complete single qubit rotations can be coherently performed with ultrafast optical pulses. Utilizing the Λ-type system of a single quantum-dot containing a single electron spin and ultrafast non-linear frequency conversion, quantum-dot spin-photon entanglement is demonstrated and presented.

HL 60.6 Wed 17:45 H16

Quantum statistical simulation of quantum-dot laser dynamics — •Jurijs Grecenkovs, Christian Otto, Franz Schulze, Andreas Knorr, Eckehard Schöll, and Kathy Lüdge — Institute of Theoretical Physics, Technical University Berlin, Berlin, Germany

Quantum dot lasers are optical devices that exploit quantum properties of specific nanostructures. These nanostructures consist of layers of nanoscale small heterogeneous material inclusions (quantum dots) in a semiconductur and are formed through a self-organizing growth process on the surface of this semiconductur. This laser type exhibits highly nonlinear dynamical behaviour.
Previous efforts in quantum dot laser decription were based on semiclassical rate equations for light intensity and carrier densities inside an optical cavity and provided some insights about behavior of this laser. The focus of this work is to explore the unusual features of the laser that are connected exclusively to its quantum-mechanical properties. To achieve this goal a fully quantum-mechanical description of the laser is considered and a numerical analysis is performed.

HL 60.7 Wed 18:00 H16

Ultrafast dynamics of 0D/2D transitions in semiconductor DWELL structures — •Mirco Kolarczik, Nina Owschimikow, Yücel Kaptan, and Ulrike Woggon — Institut für Optik und Atomare Physik, Technische Universität Berlin, Straße des 17. Juni 135, D-10623 Berlin, Germany

We investigate 0D/2D coupling in semiconductor quantum dot (QD) in a well (DWELL) structures using heterodyne two-color pump-probe spectroscopy. In our two color pump-probe experiments we vary the pump energy from the QD ground state transition to values exceeding the quantum well (QW) band gap. Depending on the carrier population in the 2D and 3D continua created by an injection current, multiple excitation pathways are possible at a given pump laser energy. These dynamics are modelled in a fully electronic rate equation system. Including direct optical interband transitions between quantum dot and quantum well states yields excellent agreement of observed traces and the numerical model. These transitions may affect the well known intradot dynamics, especially for transition energies near the quantum well band edge, e.g. in cross gain and cross phase modulation.

To investigate coherent effects in the sub-picosecond time range, and thus obtain understanding of the complex interplay of energetically degenerate transitions, we extend the heterodyne setup to include pulse shape analysis.

HL 60.8 Wed 18:15 H16

Quantum optical approach towards quantum dot lasers with time-delayed optical self-feedback — Franz Schulze, Alexander Carmele, •Julia Kabuss, and Andreas Knorr — Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Germany

Semiconductor lasers under the influence of time-delayed self-feedback show a large variety of dynamics which includes even chaotic behavior. The Lang-Kobayashi-model[1] (L-K-model) is widely used to study such systems. In contrast to the classical description of the light field within the L-K-model, we present in our contribution a quantum optical treatment of the time-delayed self-feedback. Our theoretical approach is based on a semiconductor quantum-dot laser model [2], which we extend to dynamically take into account photon-photon correlations between the quantized cavity and external photon field. Incorporating the interaction between the different photon modes significantly alters the light-statistics of the cavity field and yields additional insights into the dynamics of quantum-dot lasers with time-delayed self-feedback.

[1] R. Lang and K. Kobayashi, IEEE J. Quantum Electron. **16**, 347 (1980)
[2] C. Gies *et al.*, Phys. Rev. A **75**, 013803 (2007)