# HL 48: Semiconductor Lasers

Time: Thursday 9:30–12:45 Location: H13

HL 48.1 Thu 9:30 H13

**Dynamic Properties of Quantum Dot Semiconductor Optical Amplifiers** — •Niels Majer, Miriam Wegert, Kathy Lüdge, and Eckehard Schöll — Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

We investigate the dynamic properties of quantum dot semiconductor optical amplifiers (QD-SOAs) on the basis of Bloch equations for the coupled interband polarization and carrier dynamics of the QDs along with a travelling wave type field equation for the electric field within the device. The model includes microscopically calculated Coulomb scattering rates in the dynamic equations for the carrier populations of the quantum dots.

Pump-probe simulations using ultrashort input pulses (∼150 fs) give insight into the (ultra-) fast gain recovery dynamics of QD-SOAs, whereas the propagation dynamics of ultrashort input pulses reveals coherent effects such as pulse breakup.

HL 48.2 Thu 9:45 H13

**Quantum Dot Based Electro Absorption Waveguide Modulator** — •Mirko Stubenrauch, Christian Meuer, Gerrit Fiol, and Dieter Bimberg — Institut für Festkörperphysik, Technische Universität Berlin, EW 5-2, Hardenbergstr. 36, 10623 Berlin, Germany

InAs quantum dot (QD) based electro absorption ridge waveguide modulators (EAM) having different length and layer number are fabricated and tested. The operation wavelength of the devices is around 1.3 $\mu$m and the fast change of electro absorption is induced by the Quantum Confined Stark Effect (QCSE). Transmission spectra simulations based on kp-calculations including charge carrier Coulomb interaction predict a QCS shift of 20 nm and an extinction ratio of maximum 35 dB at 10 V reverse bias. These results are compared to experimentally achieved values for maximum absorption edge shift of 15 nm at an applied field of 240 kV/cm, corresponding to 9 V reverse voltage. Transmission power measurements show the highest extinction ratio of 18 dB reached so far for QD devices at a wavelength of 1315 nm. First dynamic scattering parameter measurements using a completely calibrated network analyzer show a maximum 3dB bandwidth of 17 GHz at a wavelength of 1310 nm with an applied reverse bias of 1.5 V. These are promising results for monolithic integration with single mode emitting lasers, e.g. distributed feedback lasers.

HL 48.3 Thu 10:00 H13

**Effects of 1st order Coulomb Interaction on the Turn-on Dynamics of Quantum Dot Lasers** — •Benjamin Lingnau[1], Kathy Lüdge[1], Eckehard Schöll[1], and Weng Chow[2] — [1]Institut f. Theo. Physik, Sekr. EW 7-1, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Sandia National Laboratories, Albuquerque, New Mexico 87185-1086, USA

We investigate the influence of many-body and nonequilibrium effects on the turn-on dynamics of a quantum dot laser. The interplay of bandgap renormalization, population hole-burning and inhomogeneous broadening is crucial for understanding the dynamics of the turn-on process and gives rise to modifications in relaxation oscillation behaviour. The theory used in the simulations is based on a semiclassical approach, where the laser field and active medium are described by the Maxwell-semiconductor-Bloch equations. Many-body Coulomb effects are described in the screened Hartree-Fock approximation. Carrier-carrier and carrier-phonon collisions are treated within the effective relaxation rate approximation. Inhomogeneous broadenening of the quantum-dot distribution is taken into account. Many-body effects were found to have a large effect on the turn-on dynamics of the laser device and especially on the relaxation oscillations after turn-on. We observe a noticeable increase in oscillation frequency and a stronger damping due to the bandgap renormalization. Furthermore, when changing the width of the inhomogeneously broadened quantum dot distribution, increasing frequencies and more pronounced oscillations for smaller broadening widths are observed.

HL 48.4 Thu 10:15 H13

**Charaterization of red VCSELs via S-Parameter Analysis** — •Hendrik Niederbracht[1], Marcus Eichfelder[1], Wolfgang Vogel[2], Michael Wiesner[1], Sandra Klinger[2], Robert Rossbach[1], Michael Jetter[1], Manfred Berroth[2], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, 70550 Stuttgart, Germany — [2]Institut für Elektrische und Optische Nachrichtentechnik, 70550 Stuttgart, Germany

The future optical data transmission via Polymer Optical Fibre needs devices which are able to achieve high modulation frequencies. The ideal candidates for this task are vertical-cavity surface-emitting laser (VCSEL) due to their splendid properties. In this presentation we show small signal modulation measurements examined by the method of scattering (S)–parameter analysis to characterize 660 nm AlGaInP–based VCSELs. Based on $S_{11}$ measurements and an equivalent circuit model for the VCSEL geometry, device values are revealed. First steps of optimization are shown, allowing a higher modulation frequency, mainly by reducing parasitic pad capacitance. The area surrounding the mesa was reduced and the spatial distance between p– and n–contacts was increased by a thick layer of high dielectric material. The intrinsic response is evaluated through the simulated low pass and the measurement of the $|S_{21}|$–parameter. The difference between single and multiple apertures for current confinement reducing intrinsic capacitance is also part of the presentation.

HL 48.5 Thu 10:30 H13

**40 GHz hybrid mode-locking in a monolithic quantum dot laser** — •Dejan Arsenijevic, Gerrit Fiol, and Dieter Bimberg — Institut für Festkörperphysik, Technische Universität Berlin, EW 5-2, Hardenbergstr. 36, 10623 Berlin, Germany

The quantum dot mode-locked lasers presented here are processed into ridge waveguide structure from material grown by molecular beam epitaxy and contain 15 stacks of InGaAs/GaAs quantum dots emitting at 1.3 $\mu$m. To enhance temperature stability the material is p-doped. The lasers having an overall length of 1 mm are separated into two sections (900 $\mu$m gain, 100 $\mu$m absorber). For hybrid mode-locking in addition to the DC-biasing of these two sections a RF signal was applied to the absorber. The emitted optical pulses for varying frequency and power of the RF source as well as different heat sink temperatures are analyzed by auto-correlation and electrical spectra measurements. The pulse width ranges from below 2 ps to about 8 ps. Although no change in pulse width is found by switching the operation mode from passive to hybrid mode-locking a decrease in optical timing jitter is observed. The maximum locking range for one operating point is 30 MHz and in addition can be linked to the widths of the pulses. The dependence of the locking range on the RF power is found to be linear. Interestingly the region of hybrid mode locking is asymmetric compared to the passive mode-locked frequency.

HL 48.6 Thu 10:45 H13

**Monolithic electro-optically modulated vertical cavity surface emitting laser** — •Jan-Hindrik Schulze[1], Tim D. Germann[1], Alex Mutig[1], Alexey M. Nadtochy[1], James A. Lott[2], Sergey A. Blokhin[1], Vitaly A. Shchukin[2], Nikolay N. Ledentsov[2], Udo W. Pohl[1], and Dieter Bimberg[1] — [1]Inst. für Festkörperphysik, EW 5-2, Hardenbergstr. 36, TU-Berlin, 10623 Berlin — [2]VI-Systems GmbH, Hardenbergstr. 7, 10623 Berlin

The steadily growing data traffic requires high speed and low-cost laser diodes. Conventional current modulated vertical cavity surface emitting lasers (VCSEL) are limited in their bit rate due to a quadratic increase in the current density with the bit rate. Monolithically integrated electro-optic modulator (EOM) VCSEL promise to overcome this problem. In this work we demonstrate a GaAs-based 850 nm EOM-VCSEL. The VCSEL is driven continuously while the pulsed light output is generated by reflectivity modulation of the top DBR through an embedded EOM section. A very low modulation voltage ($<$ 2 V) is needed to reach -3 dB extinction ratio enabling the use of such EOM-VCSELs with low power consumption CMOS drivers. Excellent output stability at a significant extinction ratio is demonstrated up to 85°C. A similar extinction ratio was revealed in large-signal modulation experiments at frequencies presently up to 3 GHz. Thus the first high bit rate data transmission by an EOM-VCSEL is demonstrated.

**15 Min. Coffee Break**

HL 48.7 Thu 11:15 H13

**Two-section DBR lasers based on surface defined gratings for**

**high-speed applications** — •Sohaib Afzal[1], Florian Schnabel[1], Wenzel Scholz[1], Johann Peter Reithmaier[1], Gadi Eisenstein[2], Amir Capua[2], Evgeny Shumakher[2], Petri Melanen[3], and Ville Vilokkinen[3] — [1]Technische Physik, Institute of Nanostructure Technologies and Analytics (INA), Universität Kassel, 34132, Kassel, Germany — [2]Technion, Electrical Engineering Department. Technion City Haifa 32000, Israel — [3]Modulight Inc. FIN-33720, Tampere, Finland

To realize low-cost high-performance lasers for high-speed optical transmission a new surface-defined grating etching process was developed based on a four gas ICP-RIE etching process, which allow high aspect ratios of > 1:15. The gratings are lithogaphically defined on the sample surface by e-beam lithography, but could be easily adapted by low-cost large volume nanoimprint lithography. The gratings are formed lateral to the ridge in 1st and 2nd order with a trench width of about 120 nm and an etch depth of about 2 um. With this surface defined patterning techique two-section DBR lasers were fabricated on a 1.3 um InP laser material, which exhibit low cw threshold currents down to 8 mA by pumping the grating section at 50 mA (total device length = 900 um). The influence of the grating period and operation temperature on the threshold current and emission wavelength will be discussed. First small signal measurement results show a -3dB bandwidth of 10 GHz with an extrapolated max. bandwidth of about 40 GHz.

HL 48.8 Thu 11:30 H13

**Time-resolved studies of a rolled-up semiconductor laser** — •Christian Strelow[1], Michael Sauer[1], Sebastian Fehringer[2], Tobias Korn[2], Christian Schüller[2], Andrea Stemmann[1], Christian Heyn[1], Detlef Heitmann[1], and Tobias Kipp[1,3] — [1]Institut für Angewandte Physik und Zentrum für Mikrostrukturforschung, Universität Hamburg — [2]Institut für Experimentelle und Angewandte Physik, Universität Regensburg — [3]Institut für Physikalische Chemie, Universität Hamburg

We report on lasing in microtube bottle resonators that are fabricated by the self-rolling mechanism of thin strained semiconductor bilayers. The optical modes are confined by total internal reflection inside the thin walls of the AlGaAs/InAlGaAs microtubes with typically 42 nm wall thickness and about 2.4 $\mu$m radius. Constructive interference after a round trip leads to the formation of ring modes. In axial direction a special modulation of the wall thickness, similar to a ridge waveguide, confines the modes on a length of about 1.4 $\mu$m. A GaAs quantum well as optical gain material is excited nearly resonantly by sub-picosecond laser pulses. Time-resolved studies on this novel kind of semiconductor laser reveal particularly fast turn-on times and short pulse emission above the threshold, as well as single-mode lasing. We observe a strong redshift of the laser mode during the pulse emission which is compared to the time evolution of the charge-carrier density calculated by rate equations.

HL 48.9 Thu 11:45 H13

**InGaN-based greenish seperate confinement heterostructures** — •Jakob Ebeling, Timo Aschenbrenner, Christian Tessarek, Stefan Figge, and Detlef Hommel — Institut für Festkörperphysik, Universität Bremen

For opto-electronic applications green laser diodes (LDs) are of great interest. The fabrication of such GaN-based light emitting diodes (LEDs) and LDs however faced different problems ranging from the lack of adequate homoepitaxial substrates to the miscibility gap of InGaN. Recently [1,2] there have been reports of laser diodes based on InGaN quantum wells (QWs) in the green spectral region. In this work the influence of InGaN quantum dots (QDs) on the opto-electronic properties of LDs is discussed in detail. All samples were grown by metal-organic vapour-phase epitaxy on free-standing GaN substrates from Lumilog and the number of QD stacks or QWs was varied. The samples were processed as ridge and deep ridge waveguide structures with different ridge widths and measured by high-resolution X-ray diffraction and electroluminescence, and light-current (L-I) and current-voltage (I-V) characteristics were recorded. A comparison of all different growths and process designs in respect of opto-electronic properties is presented.

[1] D. Queren et al., Appl. Phys. Lett. 94, 081119 (2009).
[2] T. Miyoshi et al., Appl. Phys. Express 2, 062201 (2009).

HL 48.10 Thu 12:00 H13

**Exceeding 1 W output power of a red AlGaInP-VECSEL emitting at 665 nm** — •Thomas Schwarzbäck, Marcus Eichfelder, Wolfgang-Michael Schulz, Robert Rossbach, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart, Allmandring 3, 70569 Stuttgart, Germany

Vertical external cavity surface-emitting lasers (VECSELs) have emerged recently as an important category of power-scalable semiconductor lasers in a wide range of applications in biophotonics, television or projectors and spectroscopy. With usage of external cavities and optical pumping, VECSELs achieve high continuous-wave output power and near-diffraction-limited beam quality with a $TEM_{00}$ Gaussian beam profile.

We present a VECSEL system based on a multi-quantum-well structure with 20 compressively-strained GaInP quantum wells (QWs) for an operation wavelength of around 665 nm. Five QW packages are placed in $(Al_{0.55}Ga_{0.45})_{0.51}In_{0.49}P$ cladding layers in a resonant periodic gain design. Each package consists of four QWs embedded in $(Al_{0.33}Ga_{0.67})_{0.51}In_{0.49}P$ barriers, respectively. The $3\lambda$ cavity is fabricated on an $Al_{0.50}Ga_{0.50}As$/AlAs distributed Bragg reflector. By bonding an intra-cavity diamond heatspreader on the chip, continuous-wave operation exceeding 1 W output power is achieved.

We show key parameters like power transfer characteristics, beam profile and spectra of the laser. The measurement of the beam propagation factor is also presented.

HL 48.11 Thu 12:15 H13

**Tuning the emission wavelength of interband cascade lasers in the 3-4$\mu m$ spectral range** — •Matthias Dallner[1], Adam Bauer[1], Fabian Langer[1], Marcin Motyka[2], Grzegorz Sek[2], Krzysztof Ryczko[2], Jan Misiewicz[2], Martin Kamp[1], Sven Höfling[1], Lukas Worschech[1], and Alfred Forchel[1] — [1]Technische Physik, University of Würzburg, Röntgen Research Center for Complex Material Systems, Am Hubland, 97074 Würzburg, Germany — [2]Institute of Physics, Wrocław University of Technology, Wybrzeze Wyspiańskiego 27, 50-370 Wrocław, Poland

Interband cascade lasers (ICLs) are a unique type of semiconductor lasers, which is very promising to cover the mid-infrared wavelength range from 3-4$\mu m$. In contrast to conventional diode lasers, in ICLs only electrons are injected, although the laser operation is driven by interband transitions. The special broken gap alignment within the active quantum wells (QWs), combined with electronic band gap engineering, allows to achieve the needed population inversion. In addition, ICLs can make use of various active cascades to provide higher gain.

In this work we fabricated and investigated ICLs and reference QWs with regards to the dependence of active QW thickness on emission wavelength. Room temperature operation has been achieved and a emission range between 2.97 to 4.16$\mu m$ could be covered. An average tuning rate of 0.55$\mu m$ per monolayer was obtained from photoluminescence and electrically driven ICL device data. This was confirmed by theoretical band structure calculations. Furthermore, a temperature dependent tuning behavior of 1.88$nm/K$ was found.

HL 48.12 Thu 12:30 H13

**Efficient modeling of non-equilibrium quantum transport in 3D nanostructures** — •Peter Greck, Christoph Schindler, and Peter Vogl — Technische Universität München, Germany

We present non-equilibrium Green's function (NEGF) alculations based on an extension of the standard Büttiker Probe model [1]. Büttiker Probes provide a phenomenological method to model incoherent scattering very efficiently. However, any effects of discrete energy coupling (e.g. by optical phonons) are not captured due to the simple structure of the model. Therefore, devices relying on resonant phonon effects such as THz quantum cascade lasers (QCLs) call for more sophisticated models for the scattering self energies. While the self-consistent Born approximation provides the required accuracy, it is extremely costly in terms of computational resources, especially for 3D nanostructures. We have extended the standard Büttiker Probe model in a way that accurately accounts for optical phonon scattering without losing the computational efficiency and simplicity of the Büttiker Probe model. The method allows one to control the scattering mechanisms individually. This renders realistic quantum transport calculations of 3D nanostructures feasible. We present detailed calculations of mid-infrared quantum cascade structures and compare the results with experimental data as well as with full NEGF results [2].
[1] M. Büttiker, Phys. Rev. Lett. 57, 1761 (1986) [2] T. Kubis, C. Yeh, P. Vogl, A. Benz, G. Fasching, and C. Deutsch, Phys. Rev. B 79, 195323 (2009)