HL 34: Semiconductor Laser

Time: Wednesday 14:15–17:30 Location: EW 202

HL 34.1 Wed 14:15 EW 202

GaSb-based short cavity lasers using two-dimensional photonic crystal mirrors — •Adam Bauer, Mirjam Müller, Thomas Lehnhardt, Karl Rössner, Michael Hümmer, and Alfred Forchel — Technische Physik Universität Würzburg, Am Hubland, 97074 Würzburg

The realization of two-dimensional (2D) photonic crystals (PhCs) on the GaSb material system is presented using a Cl_2/Ar dry etch process. This allows the fabrication of PhCs covering air fill factors of $f = 20\% - 50\%$, lattice periods of $a = 400$-500 nm and aspect ratios of 5:1.

Quality and reflectivity of these structures are evaluated by incorporating the PhCs as high reflective rear mirrors in GaSb-based ridge waveguide lasers with cavity lengths between 100 μm and 1100 μm with cleaved front facets. The shortest devices show remarkable threshold currents well below 20 mA and efficiencies of 0.23 W/A, yielding a maximum output power of about 6 mW. These results prove the applicability of the developed fabrication technique to numerous further device concepts based on 2D PhCs on the GaSb material system.

A further example that illustrates the merit of being able to fabricate monolithically integrated 2D PhCs devices on GaSb is shown in terms of lasers with coupled cavities. These show single mode emission with side mode suppression ratios of 35 dB and discrete tuning behaviour over a wide driving current range.

To the best of the authors' knowledge, this is the first time 2D PhCs have successfully been integrated in optoelectronic devices on the GaSb material system.

HL 34.2 Wed 14:30 EW 202

Monolithic integration of pump lasers and high-power semiconductor disk lasers — •Wolfgang Diehl[1,2], Tony Albrecht[1], Peter Brick[1], Michael Furitsch[1], Stefan Illek[1], Stephan Lutgen[1], Ines Pietzonka[1], Johann Luft[1], and Wolfgang Stolz[2] — [1]Osram Opto Semiconductors, Regensburg, Germany — [2]Philipps Universität Marburg, Marburg, Germany

High output power combined with good beam quality and the possibility for wavelength engineering are the main reasons for the great interest in semiconductor disk lasers. One of the major disadvantages is the need for an external optical pump source that requires additional space and precise alignment. Therefore, integration of the pump laser and the disk laser is most desirable.

We demonstrate a novel design to integrate the pump laser monolithically with the semiconductor disk laser in a one-step epitaxy. By careful adjustment of the integrated pump laser and stacking sequence, it is possible to excite different mesa sizes, thus realizing power scalability. In particular, we show experimental results, demonstrating the power scalability and versatility of this design. Results are shown at 1000nm emission wavelength with high output power out of active regions with mesa diameters of 100μm to 400μm. We have demonstrated 1W out of a 100μm mesa and 2.5W out of a 200μm mesa in pulsed operation. Additionally, devices mounted on copper submounts have achieved more than 0.6W in cw operation using a 400μm structure.

In summary, we have pioneered an innovative approach for truly monolithic integration of a semiconductor disk laser with pump lasers.

HL 34.3 Wed 14:45 EW 202

Laser properties of (GaIn)Sb heterostructures - a microscopic evaluation — •Christina Bückers[1], Angela Thränhardt[1], Stephan W. Koch[1], Jörg Hader[2], Jerome V. Moloney[2], Marcel Rattunde[3], Nico Schulz[3], and Joachim Wagner[3] — [1]Fachbereich Physik und Wissenschaftliches Zentrum für Materialwissenschaften, Philipps-Universität Marburg, Renthof 5, 35032 Marburg, Germany — [2]Optical Sciences Center, University of Arizona, Tucson, Arizona 85721, USA — [3]Fraunhofer-Institut für Angewandte Festkörperphysik, Tullastraße 72, 79108 Freiburg, Germany

Semiconductor lasers emitting around 2 microns are of considerable interest in medical diagnostics, material processing or spectroscopic trace gas detection. GaSb-based (GaIn)Sb quantum well lasers are well suited for this wavelength range and promise excellent laser performance. On the basis of a microscopic many-particle theory, we predict optical gain spectra of such a (GaIn)Sb laser structure. The calculations show good agreement with the measurement, verifying that our model describes the material system with high precision. The obtained gain amplitude of the material system is remarkably large und we are enabled to attribute this feature mostly to band structure properties by a detailed comparison to simulations for an equivalent standard (GaIn)As structure.

HL 34.4 Wed 15:00 EW 202

Influence of low-absorption laser facets on catastrophic optical damage in AlGaInP lasers — •Marwan Bou Sanayeh[1], Peter Brick[1], Martin Reufer[1], Bernd Mayer[1], Martin Müller[1], Wolfgang Schmid[1], Mathias Ziegler[2], Jens W. Tomm[2], and Gerd Bacher[3] — [1]OSRAM Opto Semiconductors GmbH, Leibnizstrasse 4, 93055 Regensburg, Germany — [2]Max-Born-Institut, Max-Born-Strasse 2A, 12489 Berlin, Germany — [3]Universität Duisburg-Essen, Bismarckstrasse 81, 47057 Duisburg, Germany

AlGaInP lasers have emerged as the best candidates in the red spectral range for high-power applications like photodynamic therapy. However, catastrophic optical damage (COD) sets the ultimate limit for extracting high optical power out of the laser diodes. Over the past two decades, understanding and improving the COD effect has always been a challenge for scientists. In this work, complete characterization, detailed analysis, and performance improvement of AlGaInP lasers during COD are presented.

To study COD, microphotoluminescence mapping and focused ion beam analyses enabled the localization of the defects inside the resonator. Micro-Raman spectroscopy and real-time thermal imaging were used to study the physics behind COD, its related temperature dynamics, as well as associated defect and near-field patterns.

The knowledge of physics behind COD triggered a change in design of the near-facet region. We found that lasers with low-absorption facets design led to an increased COD level and an improvement in high-power laser performance.

HL 34.5 Wed 15:15 EW 202

Reliability of red 660 nm AlGaInP-VCSEL — •Marcus Eichfelder, Michael Wiesner, Robert Rossbach, Michael Jetter, and Peter Michler — Universität Stuttgart, Institut für Halbleiteroptik und Funktionelle Grenzflächen, Allmandring 3, D-70569 Stuttgart

Vertical cavity surface-emitting lasers (VCSEL) based on AlGaInP material system have attracted much interest as potential key components for low-cost optical data communication via plastic optical fibres (POF). Therefore, in this talk we discuss the degradation mechanisms of AlGaInP-based red VCSEL as there is only little known about this topic. Our oxide-confined VCSEL have a high optical output power, low threshold current and high-temperature stability. In aging studies the degradation behaviour of VCSEL was investigated. To determine the different aging processes we stressed the devices at high temperatures and at high currents. These measurements gave us a first hint on acceleration factors for life-time testing. These studies show a remarkable progress in reliability of latest VCSEL compared to older ones due to improvements of the VCSEL structure implemented during the last years. These optimized VCSEL were aged for more than 1000 hours and did not show any degradation.

As the degradation mechanisms are still under discussion, we try to exclude the degradation of the active region by time resolved experiments.

In the future the VCSEL cavity is used to serve as resonator for electrically pumped InP-quantum dots.

HL 34.6 Wed 15:30 EW 202

Temperature stable 920-nm quantum dot material for high power laser applications — •Emil Mihai Pavelescu and Johann Peter Reithmaier — Technische Physik, Institute of Nanostructure Technologies and Analytics, University of Kassel, Heinrich-Plett-Str. 40, D-34132 Kassel, Germany

Besides high output powers, a stable emission wavelength is the main prerequisite for using laser diodes to pump solid state lasers or fiber amplifiers, such as ytterbium at the 920 nm wavelength range. Using a less temperature sensitive gain material, such as InGaAs/GaAs quantum dots, 920-nm laser diodes with a higher acceptable tolerance of their operation temperature were realized.The laser structure was grown by solid source molecular-beam epitaxy and consists of 820 nm core waveguide composed of GaAs/Al0.57Ga0.43As short period superlattices and 1600 nm thick Al0.60Ga0.40As cladding layers. The InGaAs self-organized quantum dots were formed at 500 °C by an alternating submonolayer deposition of InAs and In0.16Ga0.84As, corresponding to a nominal indium content of 52 % and a thickness of 5.4 monolayers. At room temperature the lasers showed good properties with lasing wavelengths near 920 nm. The laser structure had a strong dependence of its lasing wavelength with cavity length, a finger print of QD lasers due to a broader gain as compared to QW lasers. Notably, the lasers revealed small coefficients (< 0.19 nm/K) of wavelength variation with temperature, whose values decreased with increasing cavity length down to a remarkably value of around 0.08 nm/K.

15 min. break

HL 34.7 Wed 16:00 EW 202

Tapered Quantum Cascade Lasers — •Julia Semmel[1], Lars Nähle[2], Wolfgang Kaiser[1], Sven Höfling[1], and Alfred Forchel[1] — [1]Technische Physik Universität Würzburg, Am Hubland, 97074 Würzburg — [2]Nanoplus GmbH, Oberer Kirschberg 4, 97218 Gerbrunn

Quantum Cascade Lasers (QCLs) are unipolar devices that have shown excellent performance in the mid-infrared wavelength range. For most applications, however, the beam divergence of the devices is a limiting factor, since it affects the coupling efficiency and resolution. In order to improve the horizontal far field characteristics, gain guided tapered sections have been introduced in 1996 [1]. They allow the fundamental mode to expand towards a broader output facet, which leads to a narrow far field.

In QCLs the gain guided approach can not be realized, since the laser structure displays an anisotropic electrical conductivity, which makes etching through the whole active region a necessity.

We report on index guided quantum cascade tapered lasers, which are based on a 2LO-Phonon-Resonace design [2]. The one-step dry-etching process provides etching depths of up to 12 μm with smooth, perpendicular edges. The output power of the tapered lasers at room temperature is as high as 300 mW and the FWHM angle of the horizontal far field scan is as small as 6.6 ° for a device with a 100 μm wide output facet.

References: [1] J. N. Walpole, Optical and Quantum Electronics, 28 (1996) 623; [2] Liu et al., Phot. Technol. Lett., 18 (2006) 1347

HL 34.8 Wed 16:15 EW 202

Coherence in Optics and Transport in Quantum Cascade Lasers — •Carsten Weber[1], Andreas Wacker[1], and Andreas Knorr[2] — [1]Mathematical Physics, Lund University, Box 118, 221 00 Lund, Sweden — [2]Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

Quantum cascade lasers have been extensively investigated as prototypes for terahertz and far-infrared intersubband systems in both the transport as well as the linear and nonlinear optical regime. Recent experiments have shown coherent signatures in the optical pump-probe signals, while it is known that in certain regimes, a fully coherent calculation (i.e. beyond Wannier-Stark hopping) is required for a sufficient description of the current. Here, we investigate within a microscopic density-matrix theory the regimes where a coherent description of the optical dynamics and transport properties is necessary. We find that, in general, a coherent description is necessary in order to fully account for the combination of nonlinear dynamical optical and transport properties of the system.

HL 34.9 Wed 16:30 EW 202

Wavelength stabilized high-brightness tapered quantum dot lasers — •Christian Zimmermann[1], Pia Weinmann[1], Wolfgang Kaiser[1], Johann-Peter Reithmaier[2], Martin Kamp[1], and Alfred Forchel[1] — [1]Technische Physik, Universität Würzburg, Am Hubland, D-97074 Würzburg — [2]INA, Universtität Kassel, Heinrich-Plett-Str. 40, D-34132 Kassel

In high-brightness semiconductor lasers, the use of quantum dots (QD) as active material has a number of advantages over the use of quantum wells (QW), e.g. lower threshold densities, reduced carrier diffusion and filamentation. Another beneficial property of QD lasers is their reduced temperature dependence of the emission wavelength. The decrease of the bandgap with increasing temperature is partially counterbalanced by a shift of the gain maximum caused by the increasing losses. This reduces the change of the emission wavelength $\Delta\lambda/\Delta T$ by a factor of two compared to quantum well devices.

We have investigated the performance of quantum dot based tapered lasers emitting at 920 nm. The devices have output power of more than 3W with a good beam quality. The extra losses of the taper have an impact on the operation point of the laser on the gain curve, leading to a dependence of $\Delta\lambda/\Delta T$ on the taper angle. A minimum value of 0.16 nm/K was measured for lasers with a 1^o taper. In addition, this effect was used to determine the taper losses for various taper angles. A further stabilization of the emission wavelength can be achieved by the incorporation of distributed Bragg reflectors (DBRs). These devices emit on a single wavelength with more than 1W output power.

HL 34.10 Wed 16:45 EW 202

Dynamic Response of Quantum-Dot Lasers – Influence of Nonlinear Electron-Electron Scattering — •Kathy Lüdge, Ermin Malić, Andreas Knorr, and Eckehard Schöll — Institut für Theoretische Physik, Sekr. EW7-1, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

We show that the dynamic response of electrically pumped quantum dot lasers can be quantitatively understood by including the strongly nonlinear character of electron-electron scattering processes. The numeric simulations presented here combine a microscopic approach used for calculating the non-radiative scattering rates with a rate equation model used for modeling the complex dynamic turn-on behavior. The quantum-dot laser is described by a 5-dimensional system, where the electrons and holes are first injected into a wetting layer before being captured into the quantum dot. The latter is considered as a two-level system for electrons and holes.

The calculated electron-electron scattering rates show a strongly nonlinear dependence on the electron and hole densities in the wetting layer which is found to be responsible for the strong damping of the relaxation oscillations of the laser. Furthermore we demonstrate the importance of the mixed (e-h) Auger capture processes that depend on both the electron and the hole density in the wetting layer. Finally we are able to explain experimental data over a wide range of different pump currents.

HL 34.11 Wed 17:00 EW 202

High Performance AlGaInAs Quantum Dot Lasers in the Visible Wavelength Region (λ =760 nm) — •Sven Gerhard, Thomas W. Schlereth, Wolfgang Kaiser, Sven Höfling, Alfred Forchel — Technische Physik Universität Hubland 97074 Würzburg

Since the commonly for quantum dot (QD) lasers employed GaInAs QDs do not allow for laser operation below ≈ 900 nm which is essential for a number of applications we incorporated the high bandgap material AlAs into GaInAs QDs forming $Al_xGa_{1-x-y}In_yAs$ QDs to reach short wavelengths. It was recently shown for 920 nm QD lasers that the insertion of Al into GaInAs QDs leads to lower threshold current densities J_{th} and increased material gain due to decreased QD sizes and increased QD densities [1]. We fabricated broad area (BA) lasers and distributed feedback (DFB) lasers based on $Al_xGa_{1-x-y}In_yAs$ QDs emitting in the wavelength region of ≈ 760 nm. The BA devices exhibit a high internal quantum efficiency η_i of 87 %, an absorption α_i of ≈ 6 cm^{-1}, a transparency current density J_{tr} of 132 Acm^{-2} and a modal gain coefficient Γg_0 of ≈ 37 cm^{-1}. The DFB laser diodes show typical threshold currents I_{th} of 32 mA and slope efficiencies of 0.3 W/A. Exhibiting a single emission line at 763.7 nm with a sidemode suppression ratio (SMSR) of at least 40 dB and single mode operation with output powers up to 25 mW per facet these DFB devices are suitable for oxygen gas detection.

References: [1] T.W. : Schlereth et al. Applied Physics Letters 90, 221113 (2007)

HL 34.12 Wed 17:15 EW 202

What can we learn from passive mode-locking of quantum dot (QD) based two-section semiconductor lasers? — •Stefan Breuer[1], Wolfgang Elsässer[1], Mark Hopkinson[2], and Michel Krakowski[3] — [1]Institute of Applied Physics, Darmstadt University of Technology, Schlossgartenstr. 7, D-64289 Darmstadt, Germany — [2]Electronic and Electrical Engineering, University of Sheffield, Mappin Street, Sheffield, S1 3JD, United Kingdom — [3]Alcatel Thales, III-V Lab, Route départementale 128, 91767 Palaiseau, France

The unique properties of QD based semiconductor laser sources in passively mode-locked operation have stimulated comprehensive studies of their picosecond pulsed emission. Towards a better understanding of the mode-locking process, two-section lasers based on dot-in-well (DWELL) layers as active media were closely investigated. Proper mode-locking at the cavity beat frequency was achieved by forward biasing the gain section and reverse biasing the absorber section, respectively. We have performed systematic measurements of the pulsed emission properties focusing on temporal characterisations using both a high-sensitivity intensity autocorrelation technique as well as an optical cross-correlation technique. The results, also from substantial radio-frequency domain investigations and spectral domain characterisations, will be presented. We will address the influence of gain current and reverse bias voltage especially on the evolution of the optical pulse duration, the repetition rate, the spectral width and the pulse-to-pulse timing jitter. This work has been performed within the scope of the European Union funded STREP project NANO UB-SOURCES.