HL 36: Focussed Session: Frontiers in Laser Diode Physics I

Since the first demonstration in 1962, laser diodes experienced tremendous developments. Today, laser diodes find widespread use as small, cheap, robust and reliable sources of coherent light. They are available in a very wide wavelength range with extreme output powers, short pulse width, small energy consumption, special beam properties, or extremely small sizes. Nevertheless,design, fabrication, and analysis of laser diodes to achieve novel or improved properties compose very active, interdisciplinary fields spanning over semiconductor physics, electrical engineering, and materials science. This focus session brings together leaders from industry, internationally renowned expert scientists, and young and active researchers in the field.

Organizers: Tim Wernicke(TU Berlin), and André Strittmatter (OvGU Magdeburg)

Time: Thursday 9:30–13:00 Location: EW 202

Invited Talk HL 36.1 Thu 9:30 EW 202

Semiconductor laser diodes: applications, trends and their technological challenges — •Werner Bergbauer, Andre Somers, Teresa Wurm, Matthias Peter, Christoph Eichler, Sven Gerhard, Georg Bruederl, Soenke Tautz, Bernhard Stojetz, Andreas Loeffler, Martin Mueller, Harald Koenig, and Uwe Strauss — OSRAM Opto Semiconductors GmbH, Leibnizstr. 4, 93055 Regensburg, Germany

The variety of applications using semiconductor lasers is strongly increasing. Especially the tremendous performance increase over the past years is enabling new designs. For example, nitride based laser diodes are used for augmented reality and business projection as well as for phosphor based automotive headlamps. Thus both, efficient low power single mode as well as high power multi-mode lasers, have to be addressed in development and production. In parallel, applications like gesture recognition and autonomous driving powered by infrared lasers based on the arsenide material system will strongly increase. Next to the performance, reliability and finally the cost reduction of the devices are key factors for success. During the presentation we will discuss the current status, actual technological challenges and future perspectives for laser diodes.

Invited Talk HL 36.2 Thu 10:00 EW 202

Recent progress on VCSELs for the near- to mid-infrared spectral region — •Markus Amann — Walter Schottky Institut, TU München, 85748 Garching, Am Coulombwall 4

Previously, near-infrared Vertical-Cavity Surface-Emitting Lasers (VCSELs) have emerged as versatile single-mode, wavelength-tunable and high-speed laser diodes for numerous applications in communications and sensing. This is because of their intrinsic advantages against edge-emitting lasers such as sub-milliamp threshold currents, high slope efficiencies, low beam divergence and corresponding simple fiber-coupling. Extending the lasing regime further into the mid-infrared, however, is challenged by strong increase ($\propto \lambda^2$) of free-carrier absorption, enhanced Auger recombination, and low thermal conductivity of the underlying quaternary and quinternary alloys.

Recently, the operation wavelengths of VCSELs were significantly increased further into the near- and even mid-infrared by the introduction of the Buried-Tunnel-Junction (BTJ) technology and the application of new materials and quantum well designs. We present InP-based BTJ-VCSELs that operate at wavelengths up to 2.6μm by using type-II heterostructure active regions. With active regions based on the AlGaInAsSb material system, optimized type-I and type-II heterostructures yield emission wavelengths in the entire 3-4μm wavelength range. All devices operate in continuous-wave at room temperature, show an excellent single-mode emission with SMSR of 30dB and a continuous electro-thermal wavelength tunability up to about 20nm.

HL 36.3 Thu 10:30 EW 202

Self-mode locking of VECSELs in the red spectral range — •Marius Grossmann[1], Roman Bek[1], Hermann Kahle[1], Arash Rahimi-Iman[2], Martin Koch[2], Michael Jetter[1], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart — [2]Department of Physics and Materials Sciences Center, Philipps-Universität Marburg, Renthof 5, 35032 Marburg

Since the first demonstration of a mode-locked vertical external-cavity surface-emitting laser (VECSEL) using a saturable absorber (SA) in 2000, these lasers have shown diffraction limited beam quality as well as high output powers across multiple emission wavelengths. In 2011, a new technique termed self-mode locking (SML) emerged in the infrared spectral range by abandoning the SA and thereby creating a cavity with outstanding simplicity, which allows emission with pulse lengths down to the sub-picosecond regime.

We recently showed the self-mode locked operation of a red-emitting VECSEL with the gain structure based on the AlGaInP material system. The linear cavity formed by the AlAs/AlGaAs distributed Bragg reflector and a curved outcoupling mirror delivers up to 35 mW of average output power at a repetition rate of 3.5 GHz. Additional measurements are presented with focus on laser pulse properties visible in the radio frequency power spectrum as well as the intensity autocorrelation of the noise-like pulse.

HL 36.4 Thu 10:45 EW 202

Characteristics of InAsSb/GaAs submonolayer lasers — •David Quandt[1], Dejan Arsenijević[1], Dieter Bimberg[1], and André Strittmatter[2] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, D-10623 Berlin, Germany — [2]Otto-von-Guericke Universität Magdeburg, Universitätsplatz 2, D-39106 Magdeburg, Germany

The addition of Sb to the growth of InAs/GaAs submonolayer stacks results in a stronger charge carrier localization and a broader photoluminescence emission spectrum. Thereby an additional degree of freedom for the tailoring of the emission properties is gained. The static and dynamic characteristics of ridge-waveguide laser diodes containing submonolayer stacks with and without Sb have been investigated in detail. While the static characteristics show a slight degradation upon the addition of Sb, broader gain spectra and increased large signal modulation speeds could be realized.

HL 36.5 Thu 11:00 EW 202

Time dependent correlation dynamics and stochastical bifurcations in high-β quantum-dot mircopillar lasers — •Christoph Redlich, Benjamin Lingnau, and Kathy Lüdge — Institut für theoretische Physik, TU Berlin

We theoretically investigate semiconductor quantum-dot (QD) micropillar lasers with respect to the dynamics of their photon statistics and correlation functions. Semiconductor micropillar lasers show a two mode polarization degeneracy and high spontaneous emission noise (β-factor). This combination yields a strong mode interaction via the common gain medium and consequently, these lasers can show frequent mode switching and super-thermal emission characteristics.

During dynamic relaxation processes that occur far from thermodynamic equilibrium e.g. after optical perturbations or turn-ons, the second order correlation function $g^{(2)}(0)$ can yield valuable information about the laser behavior.

We describe the emission dynamics of the laser with a simple semiclassical model that contains a Langevin noise source for spontaneous emission. Using the ergodicity of the system, time-dependent intensity correlation functions can be evaluated by means of the variations from an ensemble of noise realizations. In contrast to fully quantum mechanical evaluation of $g^{(2)}$, we do not need a fully quantized approach to calculate these correlations. Particularly interesting are cases of relaxation oscillations or mode switching where we find strong oscillations in $g^{(2)}(0)$.

15 min. break.

Invited Talk HL 36.6 Thu 11:30 EW 202

Simplicity VCSELs — •James A. Lott[1], Nasibeh Haghighi[1], Gunter Larisch[1], Ricardo Rosales[1], and Martin Zorn[2] — [1]Technische Universtität Berlin, Berlin, Germany — [2]JENOPTIK Diode Labs GmbH, Berlin, Germany

We experimentally and theoretically investigate the optical, electrical, and thermal physics of vertical-cavity surface-emitting lasers (VCSELs) grown on gallium-arsenide substrates with epitaxial structures based on simplicity-in-design principles. We aim to minimize the complexity of our VCSEL epitaxial designs while simultaneously improving our VCSEL performance and reliability for specific resurgent, mainstream, and new VCSEL applications in sensing, communication, heating, and illumination. Our reduced epitaxial design complexity is expected to greatly reduce the cost to produce massive quantities of VCSELs on ever larger diameter starting wafers, and we believe similar Simplicity principles may be applied to the processed VCSEL device geometries to further reduce commercial VCSEL production costs. We demonstrate 980 nm Simplicity VCSELs with a wide range of emitting aperture diameters with record performance that exceeds the performance or our previous more complex VCSEL designs in common figures-of-merit including optical output power, efficiency and small-signal modulation bandwidth

HL 36.7 Thu 12:00 EW 202

High bandwidth versus high optical output power in 980 nm VCSELs — •Nasibeh Haghighi[1], Gunter Larisch[1], Ricardo Rosales[1], Martin Zorn[2], and James A. Lott[1] — [1]Technische Universtität Berlin, Berlin, Germany — [2]JENOPTIK Diode Labs GmbH, Berlin, Germany

Vertical-cavity surface-emitting lasers (VCSELs) are a key optical source for modern and future high bit rate optical interconnects in data centers, supercomputers, and silicon photonic integrated circuits, and for data communications across multimode optical fiber and across free (terrestrial) space. We study the trade-offs in VCSEL design between high bandwidth and high optical output power. At room temperature with our small (about 4 micrometers and smaller) oxide-aperture diameter VCSELs we achieve record small-signal modulation bandwidths exceeding 34 gigahertz with single-mode optical output powers exceeding 4 milliwatts. In contrast with our large (about 10 micrometers and larger) oxide-aperture diameter VCSELs we achieve bandwidths exceeding 20 gigahertz with multiple-mode optical output powers up to about 30 milliwatts. We compare our VCSEL designs for use in example near-term practical applications including arrays for free-space data communications and as illumination and sensing sources for smart mobile telephones.

HL 36.8 Thu 12:15 EW 202

Optimization upon AlGaInP-based membrane lasers — •Thomas Klumpp, Roman Bek, Hermann Kahle, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart

Vertical external-cavity surface-emitting lasers (VECSELs), also known as optically pumped semiconductor disc lasers (OPSDLs), are becoming more and more popular due to their simplicity and excellent emission properties. Improvements regarding the output power can be obtained by optimized semiconductor gain structures, but also by advanced methods for heat extraction from the active region. Especially for AlGaInP-based VECSELs emitting in the red spectral range, one of the main limitations is the low charge carrier confinement in combination with heat incorporated into the active region by optical pumping. The thermal management can be particularly improved by a membrane laser concept, the membrane external-cavity surface-emitting laser (MECSEL). Furthermore, with the active region sandwiched between two transparent intracavity heat spreaders, growth of a distributed Bragg reflector is avoided. We present our current work on the progress of AlGaInP-based MECSELs aiming on high output power and wavelength versatility.

HL 36.9 Thu 12:30 EW 202

Stability of Two-State Quantum-Dot Lasers with Optical Feedback — Lucas Kluge, •Stefan Meinecke, and Kathy Lüdge — Institut für Theoretische Physik, 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 with optical self-feedback. 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.

In our previous work [1], we demonstrated that two-state lasing, although increasing the dynamical degrees of freedom, stabilizes the response of a QD laser to optical injection. We now report, that in the case of time-delayed feedback, a similar mechanism also increases the dynamical stability of a two-state laser. Regions of complex dynamics, which are predicted for single-color QD lasers, are greatly reduced, if lasing from the excited state is possible.

This behavior makes two-state QD lasers suitable for applications where a high tolerance for unwanted back-reflections is crucial for stable operation.

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

HL 36.10 Thu 12:45 EW 202

Towards mode locking of a semiconductor membrane laser — •Ana Ćutuk, Roman Bek, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart

Optically pumped semiconductor disk lasers (SDLs) provide several advantageous properties like near-diffraction-limited beam profile and the flexibility to add optical components inside the cavity. However, due to the incorporated heat in the active region by the pump laser, the output power of SDLs is limited by the thermal management. A new concept, the membrane external-cavity surface-emitting laser (MECSEL), first presented in 2016, uses an active region sandwiched between heat spreaders for optimized heat dissipation. Furthermore, it enables new material combinations for new laser wavelengths, which are not possible with the Bragg reflector in the conventional disk laser. Especially attractive is the combination of this new laser device with semiconductor saturable absorbers for ultrafast pulse generation.

In this contribution, we investigate the characteristics of an AlGaInP-based MECSEL emitting in the red spectral range. Current research focuses on time and frequency domain measurements with and without an absorbing semiconductor intracavity component and evaluates the possibility of mode-locked operation.