HL 3: Focus Session: VECSEL

Vertical-external-cavity surface-emitting lasers (VECSELs) or optically pumped semiconductor disk laser perfectly combine the excellent beam quality of surface emitters and the high output power of edge-emitting diode-lasers. VECSELs are available in a broad spectral range. Their external-cavity design offers large versatility such as efficient intra-cavity frequency mixing, multi-color operation, frequency stabilization, or ultrafast operation, only to name a few. At the same time, typical advantages of semiconductor devices like solid-state on-chip fabrication, small packaging dimensions, and the spectral tunability are maintained. (Organizers: Sangam Chatterjee, University of Marburg and Michael Jetter, University of Stuttgart)

Time: Monday 9:30–12:45 Location: ER 164

Invited Talk HL 3.1 Mon 9:30 ER 164
Recent advances in ultrafast VECSELs and MIXSELs — •Thomas Südmeyer[1,2], Valentin J. Wittwer[2], Oliver D. Sieber[2], Mario Mangold[2], Martin Hoffmann[2], Yohan Barbarin[2], Matthias Christoph Golling[2], and Ursula Keller[2] — [1]ETH Zurich, Switzerland — [2]University of Neuchatel, Switzerland

Ultrafast VECSELs and MIXELS are promising cost-efficient, reliable, and compact ltrafast laser sources. Modelocked VECSELs can achieve low-noise operation and >1 W in sub-picosecond pulses have been reported. The highest average powers are obtained from MIXSELs, VECSELs with integrated saturable absorber. Recent developments in these devices are reported.

Topical Talk HL 3.2 Mon 10:00 ER 164
Intra-cavity frequency doubling in visible VECSELs towards high efficiency UV laser emission — •Thomas Schwarzbäck, Hermann Kahle, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen and Research Center SCoPE, Universität Stuttgart, Allmandring 3, 70569 Stuttgart, Germany

Since the pioneering work of Kuznetsov et al. in 1997, vertical external cavity surface-emitting lasers (VECSELs) have excited growing interest in science. These kinds of lasers combine some advantages, which none of the remaining semiconductor laser sources can offer. High continuous-wave (cw) output power and near-diffraction-limited beam quality with a TEM_{00} Gaussian beam profile are somewhat unique. Furthermore the possibility of bandgap engineering make VECSELs predestinated for lots of applications in various fields such as medicine, life sciences, display or projection applications and in research. Besides these compelling arguments, the VECSEL offers an additional feature resulting from the external cavity. Using optical elements in the external resonator like frequency selecting filters allow for spectral tuning and with non-linear crystals efficient intra-cavity frequency doubling can be provided. The fundamental laser emission is provided by a red emitting VECSEL fabricated via metal-organic vapour-phase epitaxy. Using a compact v-shaped cavity, it is possible to generate UV laser emission at a wavelength of 330 nm with output powers in the 100 mW regime with a tuning range of several nanometers.

Topical Talk HL 3.3 Mon 10:30 ER 164
GaSb-based VECSELs for the $2-3\,\mu$m wavelength range — •Marcel Rattunde, Sebastian Kaspar, Tino Töpper, Christian Manz, Klaus Köhler, and Joachim Wagner — Fraunhofer Institut für Angewandte Festkörperphysik (IAF), Tullastr. 72, 79108 Freiburg, Germany

In recent years, vertical external cavity surface emitting lasers (VECSELs) have attracted increasing interest due to their capability of delivering simultaneously high output power and excellent beam quality, together with their suitability for the realization of tunable and single-frequency laser emission. Recently, the realization of high-performance VECSELs based on the (AlGaIn)(AsSb) material system with emission wavelengths around 2 μm and above has been reported. Such high-brightness laser sources are of interest for a range of applications such as long range sensing, medical therapy and diagnostics as well as seeding and pumping of solid state or fiber lasers. In this report we will present recent advances achieved using our GaSb-based VECSEL technology. In a high-power configuration, up to 10 W output power in CW-operation were demonstrated at 2.0 μm. With intracavity filters, tunable single-frequency laser modules were realized with a tuning range of 70-120 nm (depending on the cavity details). The emission linewidth (measured with a heterodyne beat note setup) was below 100 kHz (100 μs sampling time) at an output power above 1 W in CW operation. These results highlight the versatility of this concept for high-power, tunable and narrow-linewidth lasers in the $2-3\,\mu$m wavelength range.

Coffee Break (15 min)

Invited Talk HL 3.4 Mon 11:15 ER 164
Novel wavelength VECSELs via intracavity Raman conversion and InP quantum dots — •Jennifer E. Hastie, Peter J. Schlosser, Daniele C. Parrotta, Alan J. Kemp, and Martin D. Dawson — Institute of Photonics, University of Strathclyde, 106 Rottenrow, Glasgow G4 0NW, UK

In this talk we will present our recent work demonstrating intracavity Raman conversion of VECSELs, a nonlinear means to red-shift the emission wavelength of these high brightness semiconductor lasers. Practically, this involves the development of low-loss CW crystalline Raman lasers pumped by the VECSEL intracavity field, with tuning of the Raman laser achieved via tuning of the VECSEL oscillation wavelength. We reported a KGW Raman laser emitting around 1150nm, and more recently a diamond Raman laser with broad tuning around 1230nm, both pumped within the high finesse cavity of an InGaAs-based VECSEL. Multi-Watt Raman laser output power has been achieved with efficiency >14% w.r.t. diode pump power absorbed by the VECSEL. As well as addressing gaps in spectral coverage, Raman conversion is potentially an attractive alternative to the use of highly strained gain structures or less robust materials required for direct emission at longer wavelengths, without significant cost to power and efficiency.

The extension of VECSEL spectral coverage via novel semiconductor materials and gain structure design remains an important focus of our research, in parallel to our work on nonlinear conversion, and during the talk we will also briefly review our work on directly visible VECSELs utilising AlGaInP quantum wells and InP quantum dots.

Topical Talk HL 3.5 Mon 11:45 ER 164
Quantum-dot VECSEL — •Tim David Germann — Institut für Festkörperphysik EW 5-2, Technische Universität Berlin, Deutschland

Optical pumped vertical external-cavity surface-emitting lasers (VECSEL) based on multiple quantum well active regions have demonstrated multi-watt cw-operation and gaussian beam profiles enabling a bunch of new applications [1]. By introducing quantum-dot (QD) based active regions inside VECSEL new functionalities for such devices are enabled. A broader feasible wavelength range, higher temperature stability, and decreased threshold power densities are demonstrated. In order to achieve sufficient gain for high-power QD-based VECSEL stacking of many QD layers is required. For epitaxial growth processes the challenge is to maintain pseudomorphic growth and constant QD properties throughout the gain section while each QD layer induces a laterally inhomogeneous strain field. Thus QD overgrowth parameters are crucial to recover a smooth growth surface.

Here two conceptually different (In,Ga)As-based approaches for novel VECSEL gain media are demonstrated. Either the Stranski-Krastanow growth mode for QD fabrication or cycled sub-monolayer deposition of InAs embedded into GaAs is used aiming at a spectrally broad gain range or at high modal gain respectively. VECSELs for wavelengths ranging from 950 nm to 1210 nm are fabricated by stacking up to 30 active layers. Up to 1.4 W continuous wave output power and ultra low threshold of only 2.4 kW/cm^2 are achieved.

[1] A. C. Tropper and S. Hoogland, *Extended cavity surface-emitting semiconductor lasers*, Progress in Quantum Electronics **30**, 1 (2006).

Topical Talk HL 3.6 Mon 12:15 ER 164

Vertical-external-cavity surface-emitting lasers for high-power applications — •Alexej Chernikov[1], Jens Hermann[1], Bernadette Kunert[1], Wolfgang Stolz[1], Tsuei-Lian Wang[2], Joe M. Yarborough[2], Joerg Hader[2], Jerome V. Moloney[2], Martin Koch[1], Sangam Chatterjee[1], and Stephan W. Koch[1] — [1]Faculty of Physics and Materials Sciences Center, Philipps-Universität Marburg, Germany — [2]College of Optical Sciences, The University of Arizona, Tucson, USA

Developed in the late 90s, vertical-external-cavity surface-emitting lasers combine the high output power of the edge-emitting diode lasers with the excellent beam quality of the surface-emitters. In addition, the external-cavity design offers additional advantages, faciliating frequency mixing applications as well as the operation of the device in a pulsed regime. Here, the high-power potential of the vertical-external-cavity surface-emitting lasers is discussed. Different cooling concepts are studied and the limits of the power-scaling are investigated by spacially resolved temperature measurements.