ESLW 2024

European Semiconductor Laser Workshop

University of Kassel, September 20-21

Welcome to the University of Kassel and the European Semiconductor Laser Workshop 2024

We like to welcome you in Kassel, which was founded in the 10th century, and for a long time the capital of the state of Hesse-Kassel. Nowadays the city is the largest city in north of Hesse and famous of its multi-cultural life (about 40% has a migration background) with many museums, the UNESCO world heritage "BergparkWilhelmshöhe", living place and place of activity of Grimm's brothers, world-wide largest and most important contemporary arts exhibition "documenta". The city is also an industrial and innovative city with well-known big and mid-size companies such as Volkswagen, Mercedes Benz, Bombardier, Wintershall, SMA etc.

The European Semiconductor Laser Workshop has already a long history and started in 1978 (see www.eslw.eu) and is the 47th in a row. The last workshops were in Glasgow (2023), Neuchatel (2022), Paris (2021) and Eindhoven (2020) traditionally in the same country and nearby location of the European Conference on Optical Communication (ECOC), which takes place this year in Frankfort (south of Hesse).

The workshop takes place in the new lecture hall building at the main campus of the University of Kassel. We are delighted to gain two distinguished keynote and four invited speakers to address a historic view as well as several actual topics.

We wish you an inspiring and scientifically fruitful workshop and we hope that you will also enjoy the conference dinner at the HerkulesTerassen at the top of the world heritage site "mountain park Wilhelmshöhe".

We are also very grateful to the sponsors of the workshop and to all people contributing to the workshop organization.

Johann Peter Reithmaier
Frederic Grillot
Mariangela Gioannini
Wolfgang Elsaesser
Paul Crump
Scott Watson
Stephen Sweeney
Gadi Eisenstein

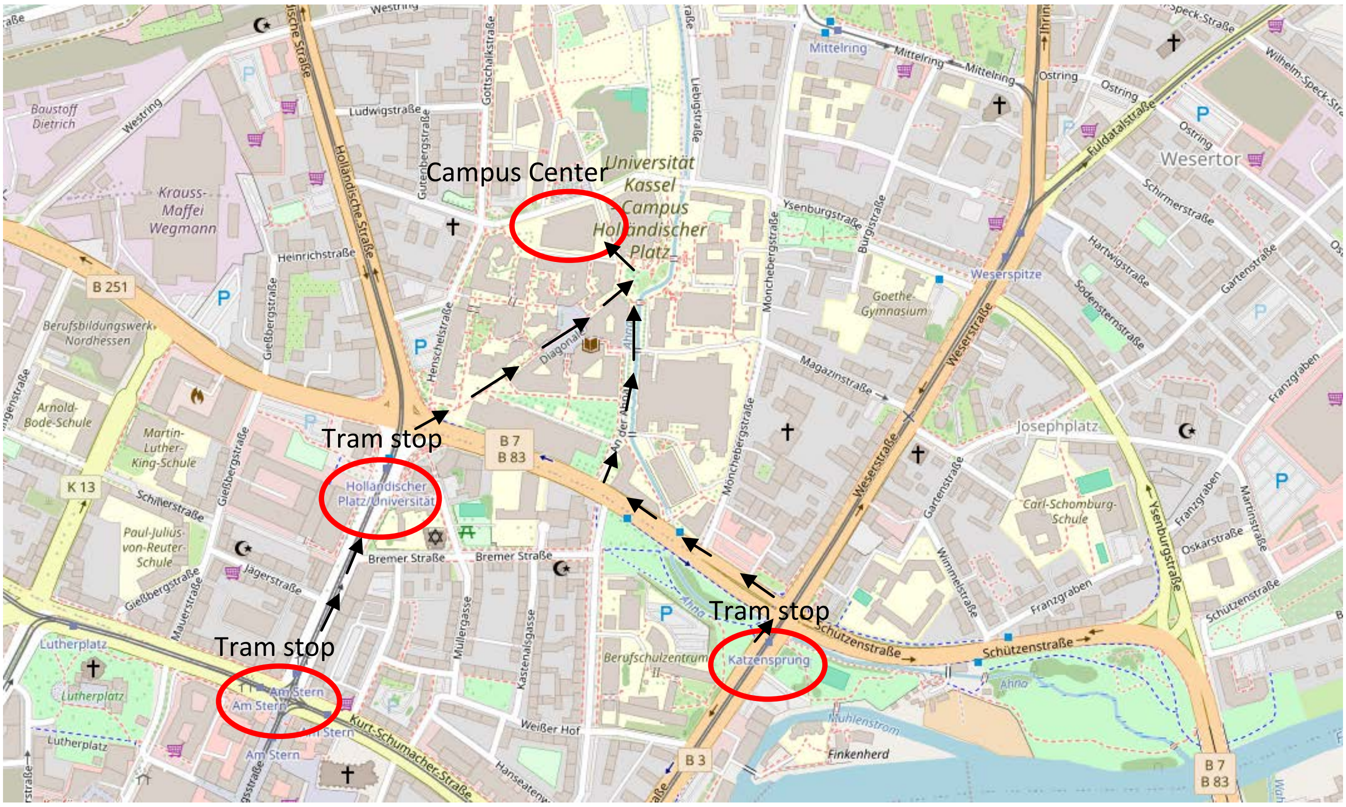
Organizational Information

Venue

University of Kassel Campus Center,

Moritzstraße 18, 34127 Kassel, Germany.

Getting to the Workshop Venue



- By Tram

Tram stops:

- "Holländischer Platz - University" Tram lines 1, 5; Regional-Tram RT1, RT4.
- "Katzensprung" Tram lines 3, 6 and 7.
- Tram line 3, 4 or 7 to stop "Am Stern", change there to Tram line 1 or 5 or walk the short distance to Holländischer Platz.

- By Bus

Bus Station:

- "Holländischer Platz - University" Bus 52 direction: Sandershausen, or Bus 100 direction: Calden Flughafen.

- NVV transportation app for quick and easy access to Transportation information in Kassel

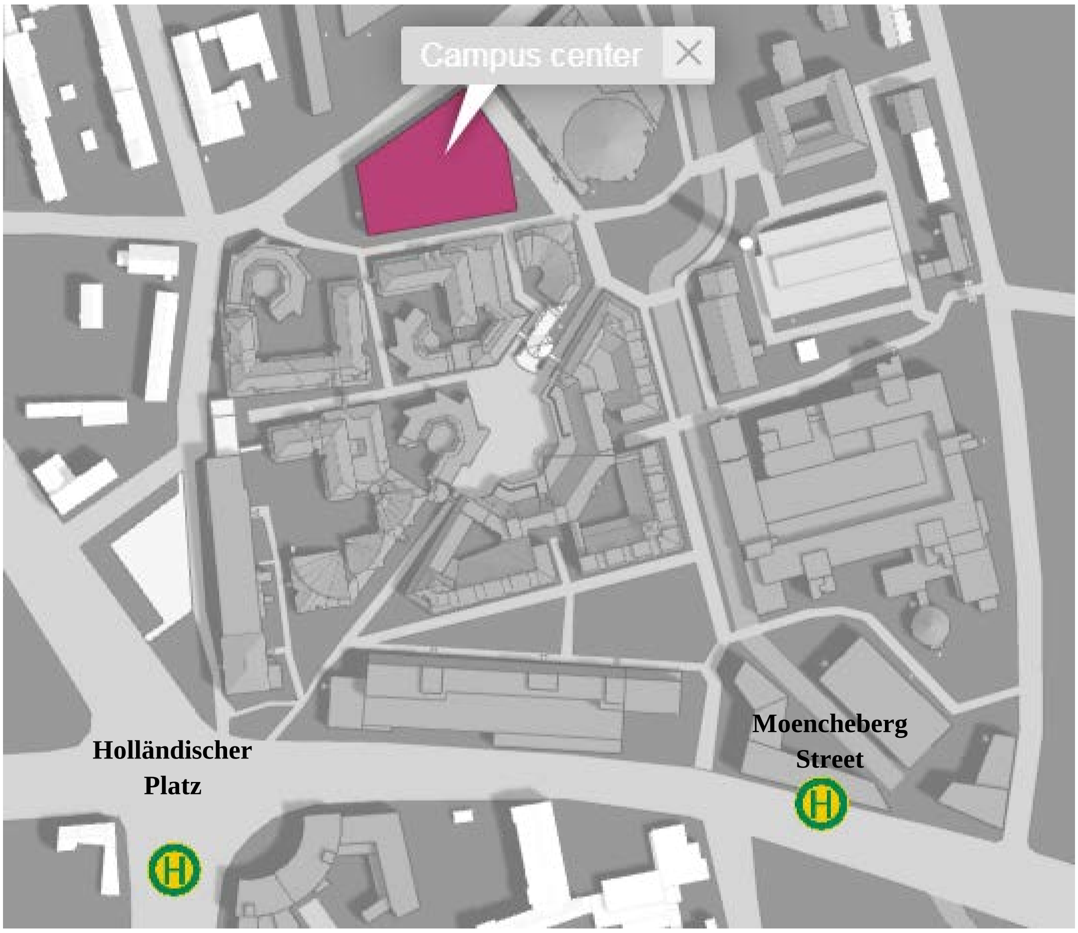
www.nvv.de

- To download NVV app:

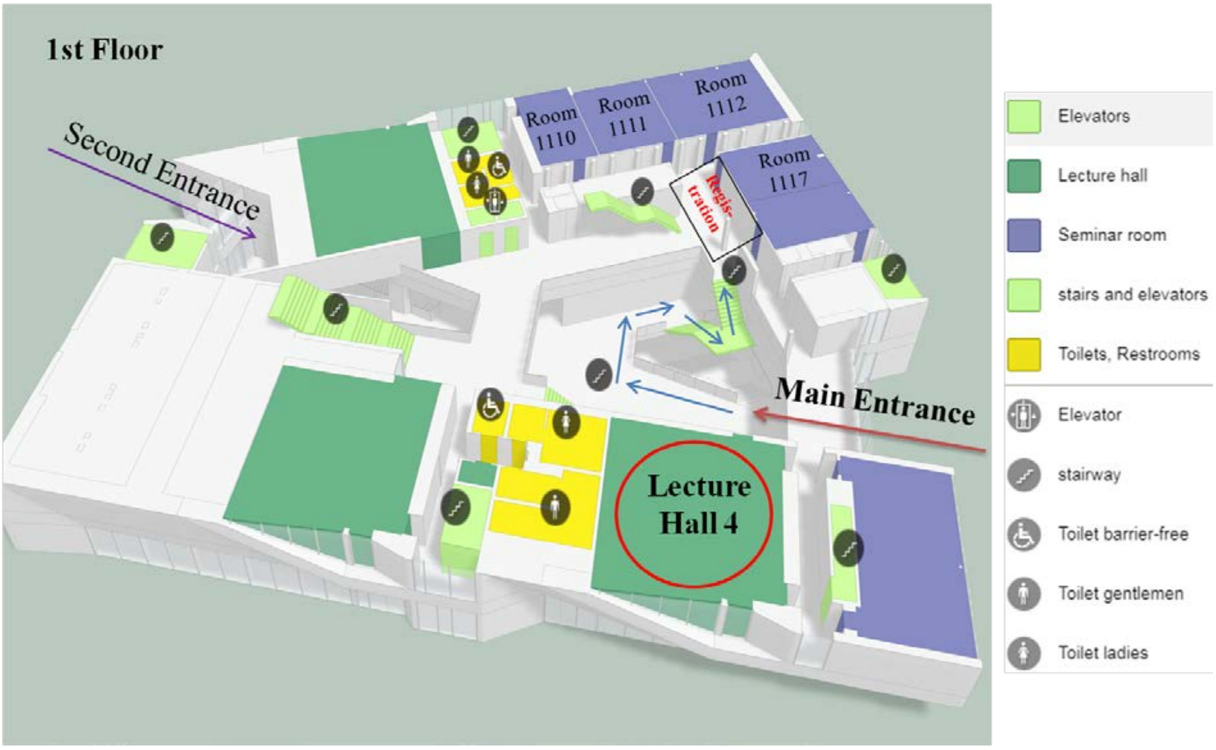
Google Play Store

Apple App Store

Campus Map



Campus Center Building Map



The European Semiconductor Laser Workshop will take place at the **1st floor** of Campus Center building; the following rooms are assigned for:

- Lecture Hall 4: Workshop oral presentations

- Room 1110: Come together area

- Room 1111: Poster session

- Room 1112: Coffee breaks and lunch area

- Room 1117: Cloak room where you can store your coats and luggage (we take no liability for it)

Oral Presentations

Please bring your presentation on a USB device and copy it in advance during the breaks to the workshop laptop before your session.

WiFi

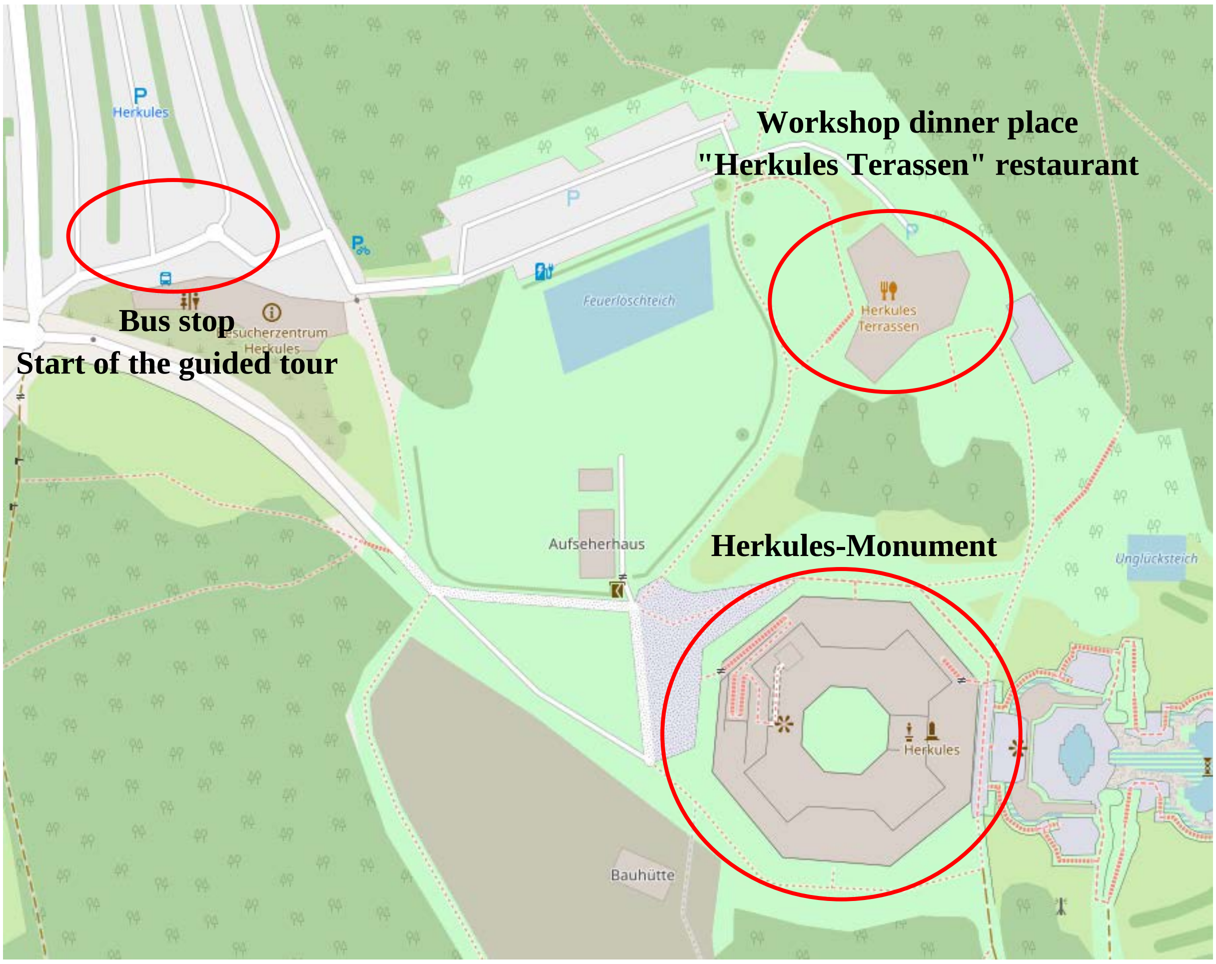
Wifi network is available, login information will be provided on site.

Coffee break and lunch

During the official program breaks, catering will be provided for all participants and will take place in Room 1112.

Getting to Workshop Tour and Dinner

The workshop guided tour will take place around **Herkules-Monument** followed by dinner at **Herkules Terassen** restaurant (Schloßpark 26, 34131 Kassel). A bus is provided to take attendees from the Campus Center to the venue directly after the conference on Friday at 18:00. A bus is also provided to take attendees from dinner place back to the city at 22:30. If you want to leave dinner before 22:30, you can order Taxi.



Lab Visit at INA

If you wish to visit the laboratories at the Institute of Nanostructure technology and Analytics (INA) of University of Kassel, please register your name at the registration desk.

Leaving Kassel to Frankfurt

To get to Kassel main train station (Kassel Wilhelmshöhe Bahnhof), you can use NVV transportation website or app. You can check train schedules from German train website

www.bahn.de

47th European Semiconductor Laser Workshop 2024 in Kassel

Program

20.09. (Friday)		
9:30	Registration starts	
9:30	Come together (beverages)	
Session I chaired by J.P. Reithmaier		
10:20	Welcome Note and Remarks	Workshop chair
10:30	**Keynote talk:** Breakthroughs in the applications of III-V laser sources: past & future	**Günther Tränkle** *Ferdinand Braun Institut, Berlin, Germany*
11:30	**CT:** 364 W high pulse power laser with multiple epitaxially stacked active regions for LiDAR applications	**Nor Ammouri**; Heike Christopher; Jörg Fricke; Andre Maaßdorf; Sonja Nozinic; Armin Liero; Hans Wenzel; Andrea Knigge, *Ferdinand Braun Institut, Berlin, Germany*
11:50	**CT:** Large optical cavity 1550nm Laser with 4.9 W optical output power from a 100 µm wide single emitter	**Niklas Kanold**; Martin Möhrle; Falco Ehrensack; Martin Schell *Fraunhofer Heinrich-Hertz-Institut HHI, Germany*
12:10	**CT:** Monolithic wavelength-stabilized high-power semiconductor laser	**Alberto Maina**; Fulvio Gaziano; Alessandro Di Maggio; Valentina Massetti; Fabio Pozzi; Ezio Riva; Claudio Coriasso *LUMIBIRD PHOTONICS ITALY, Italy*
12:30	**CT:** Scaling towards 80% conversion efficiency at 25°C in GaAs-based Broad Area Lasers	**Paul Crump**; A. Boni; M Elattar; S.K. Khamari; I.P. Marko; S. J. Sweeney; S. Arslan; B. King; M.J. Miah; D. Martin; A. Knigge, P. Della Casa; G. Tränkle *Ferdinand Braun Institut, Berlin, Germany*
12:50	Lunch break	
Session II chaired by Stephen Sweeney		
13:50	**Invited talk:** Dynamic Optical Injection of Mode-Locked Quantum-Dot Lasers for High-Speed Optical Sampling	**Maria Ana Cataluna** *Heriot Watt University, Edinburgh, UK*
14:30	**CT:** 5.2 µm GaSb-based interband cascade laser with hybrid superlattice plasmon-enhanced claddings	**Borislav Petrović**; Andreas Bader; Josephine Nauschütz; Takuma Sato; Stefan Birner; Robert Weih; Fabian Hartmann; Sven Höfling *Julius-Maximilians-Universität Würzburg, Nanoplus Advanced Photonics, Gerbrunn, nextnano , München, Germany*
14:50	**CT:** New versatile and compact laser source for short pulse trains at 900 nm for 2ph-FLIM	Sylvain Boust; Maxime Meghnagi; Guillaume Daccord; Francois Duport; Eva Izquierdo; Jean-Pierre Legoec; Michel Garcia; Olivier Parillaud; Dimitri Boiko; **Michel Krakowski** *III-V Lab, France; CSEM, Switzerland*
15:10	**CT:** How to build a monolithically mode-locked 200 pJ laser enabling two photon excitation time-resolved fluorescence imaging at 8 Megapixels per second?	**Dimitri Boiko**; Severin Oeschger; Nicolas Torcheboeuf; Sylvain Boust; François Duport; Michel Garcia; Nadja Böhm; Zachary Baltzer; Alessandro Esposito; Alessandro Tontini; Leonardo Gasparini; Patrick Flückiger; Andreas Rauschmayr; Philipp Andre; Michel Krakowski *CSEM, Switzerland; III-V Lab, France; VivaScope, Germany; Caliber I.D., USA; Brunel University London, UK, FBK Italy*
15:30	**CT:** Spectral Control in Quantum Walk Frequency Combs from Quantum Cascade Lasers	**Diego Piciocchi**; Ina Heckelmann; Alexander Dikopoltsev; Mathieu Bertrand; Mattias Beck; Giacomo Scalari; Jérôme Faist *ETH Zürich, Switzerland*
15:50	Coffee break	

Session III chaired by Wolfgang Elsaesser		
16:10	**Invited talk:** Modeling VCSEL modes: from the beginnings to new geometries and future applications.	**Pierluigi Debernardi** *Consiglio Nazionale delle Ricerche (NCR), IEIIT, Torino, Italy*
16:50	**CT:** VCSELS for chip scale Rubidium based atomic clocks	**Inbal R. Marciano**; Visorian Mikhaelashvili; Amnon Willinger; Lior Gal; Meir Orenstein; Gadi Eisenstein *Technion, Haifa*
17:10	**CT:** Relative Intensity Noise and Four Wave Mixing in elliptical oxide aperture multi-mode VCSELs	Marco Novarese; Cristina Rimoldi; Lorenzo Columbo; Sebastian Romero-Garcia; Christian Raabe; **Mariangela Gioannini** Politecnico di Torino, Italy; Cisco Optical Nuremberg, Germany
17:30	**CT:** Dynamical behaviour from short to long feedback delay regime in mid-infrared ICL	**Thomas Poletti**; Hyunah Kim; Heming Huang; Daniel A. Diaz Thomas; Maëva Fagot; Alexei N. Baranov; Laurent Cerutti; Frédéric Grillot *LTCI Télécom Paris; Institut d'Electronique et des Systèmes, Montpellier, France; Center of High Technology Materials, Albuquerque, USA*
17:50	End of 1st workshop day	
18:00	Travelling to dinner place	
18:30	Short guided tour around “Herkules”	
19:30	Dinner at “Herkules Terassen”	

21.09. (Saturday)		
08:00	Registration starts	
Session IV chaired by Frederic Grillot		
09:00	**Keynote talk:** Heterogeneous Integration for Silicon Photonics: Techniques and Perspectives	**Jonathan Klamkin** *University of California S. Barbara (UCSB), CA, USA*
10:00	**CT:** InP-based QD-laser for O-band telecom applications	**Vinayakrishna Joshi**; Vitalii Sichkovskyi; Florian Schnabel; Johann Peter Reithmaier *Institute of Nanostructure Technologies and Analytics, CINSaT, University of Kassel, Germany*
10:20	**CT:** InAs Quantum Dot O-band Laser for ultra-high Temperature Operation	Pawan Mishra; **Lydia Jarvis**; Chris Hodges; Abigail Enderson; Fwoziah Albeladi; Sara-Jayne Gillgrass; Richard Forrest; Craig P. Allford; Huiwen Deng; Mingchu Tang; Huiyun Liu; Samuel Shutts; Peter M. Smowton *School of Physics and Astronomy, Cardiff University, UK; Physics Department, University of Jeddah, Saudi Arabia; University College London, UK*
10:40	**CT:** Growth optimization of InP-based InAs quantum dots for high-performance 1.55 µm laser applications	**Vikram Khatri**; Vitalii Sichkovskyi; Johann Peter Reithmaier *Institute of Nanostructure Technologies and Analytics, CINSaT, University of Kassel, Germany*
11:00	Coffee break	
Session V chaired by Mariangela Gioannini		
11:20	**Invited talk:** Very high-power SOAs laser modulator for access networks	**Ngoc-Linh Tran** *Almae Technoligies, Marcoussis, France*
12:00	**CT:** Gallium nitride lasers for optical communications and quantum applications	**Scott Watson**; Finlay Walton; Shuqiao Cai; Daehyun Kim; Sean Mulholland; Stephen P. Najda; Piotr Perlin; Tadek Suski; Lucja Marona; Mike Leszczynski; Szymon Stanczyk; Thomas Slight; Patrick Gill; Anthony Kelly *University of Glasgow, UK; National Physical Laboratory, UK; TopGaN Ltd, Poland; Unipress*

		Institute of High Pressure Physics, Poland; Sivers Photonics Ltd, UK
12:20	**CT:** Effect of direct modulation on the spatial and temporal coherence of a semiconductor laser with optical feedback	**María Duque Gijón**; Jordi Tiana Alsina; Cristina Masoller Universitat Politècnica de Catalunya, Spain; Universidad de Barcelona, Spain
12:40	**CT:** Performance improvement of 1.55 µm AlInGaAs on InP through introduction of electron blocking layers	**Grzegorz Sobczak**; Steven Kleijn; Peter Thijs *SMART Photonics, Eindhoven, The Netherlands*
13:00	Lunch break	
Poster Session chaired by Johann Peter Reithmaier		
14:00	Short poster presentations (2 min each), poster list see below	
14:20	Poster session + beverages	
Session VI chaired by Paul Crump		
15:20	**Invited talk:** Topological stabilized VCSEL array	**Sebastian Klembt** *University of Würzburg, Germany*
16:00	**CT:** Room-Temperature Continuous-Wave Operation of a Semiconductor Nanolaser with Extreme Dielectric Confinement	**Yi Yu**; Meng Xiong; Yury Berdnikov; Simon Klinck Borregaard; Adrian Holm Dubré; Rasmus Ellebæk Christiansen; Elizaveta Semenova; Kresten Yvind; Jesper Mørk *Department of Electrical and Photonics Engineering, Technical University of Denmark,; NanoPhoton - Center for Nanophotonics,; Department of Civil and Mechanical Engineering, Technical University of Denmark, Lyngby, Denmark*
16:20	**CT:** Time-dependent simulation of photonic crystal surface emitting lasers	**Eduard Kuhn**; Mindaugas Radziunas; Hans Wenzel; Ben King; Paul Crump Weierstrass Institute, Berlin, Germany; Ferdinand-Braun-Institut (FBH) Berlin, Germany
16:40	Awards & Workshop closing	Sponsors & J.P. Reithmaier
17:00	End of Workshop	

Possibility to visit Institute of Nanostructure Technologies and Analytics	
17:10	Travelling by tram to Heinrich-Plett-Str. (Uni Campus AVZ)
17:50	Lab visit of INA
18:50	Travelling back to downtown area or train station

Poster list:		
(1)	**P:** Design of DBR BRW lasers for parametric fluorescence	**Thomas Tenzler**; Hans Wenzel *Ferdinand-Braun-Institut GmbH, Germany*
(2)	**P:** Design of high-power photonic crystal surface emitting lasers with an all-semiconductor photonic crystal	**Ben King**; Hans Wenzel; Eduard Kuhn; Mindaugas Radziunas; Paul Crump *Ferdinand-Braun-Institut Berlin, Germany; Weierstrass Institute, Berlin, Germany*
(3)	**P:** Numerical study of the phase dynamics of mutually coupled lasers in a photonic integrated circuit for quantum random number generation	**Berta Martínez-Pàmias**; Miquel Rudé; Cristina Masoller Quside Technologies S.L., Castelldefels; Universitat Politècnica de Catalunya, Dptm de Física, Terrassa (Barcelona), Spain
(4)	**P:** Automated Assembly and Alignment of NIR and MIR External Cavity Diode Laser Systems	Denis Erfle; Christian Assmann; Sebastian Schmidtmann; **Martin Honsberg**; Joachim Sacher Sacher Lasertechnik GmbH, Germany; Sensor Photonics GmbH, Marburg, Germany

Abstracts

Breakthroughs in the Applications of III-V Laser Sources: Past and Future

Günther Tränkle

Ferdinand Braun Institut, Berlin, Germany

High Pulse Power Laser with Multiple Epitaxially Stacked Active Regions for LiDAR Applications

Nor Ammouri*, Heike Christopher, Jörg Fricke, Andre Maaßdorf, Sonja Nozinic, Armin Liero, Hans Wenzel, and Andrea Knigge

Ferdinand-Braun-Institut (FBH),Berlin,Germany

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Diode lasers generating short optical pulses in the nanosecond range with high optical pulse power are highly desirable for various applications. Compact, reliable, and energy-efficient lasers are particularly required for LiDAR systems. Efficient operation of such systems requires laser sources with high pulse power and lower pulse current amplitudes than are currently available. To this end, multiple lasers can be epitaxially stacked in series and separated by tunnel junctions within a common vertical waveguide, enabling wavelength stabilization through implementation of an internal surface Bragg grating. This approach reduces the required current at the expense of higher voltage while maintaining high pulse power. Here we present the design and experimental results of wavelength-stabilized distributed Bragg reflector broad-area lasers featuring 3 and 5 epitaxially stacked active regions, and 2 and 4 tunnel junctions, respectively. The gain-switched lasers are integrated into electronic drivers capable of generating pulse currents with a length of 10 ns, a repetition frequency of 10 kHz, and a peak current of up to 400 A. The lasers with cavity lengths of 2 mm and 4 mm and a stripe width of 200 µm are compared in terms of pulse power, optical spectrum and beam characteristics. We show, that a high pulse power of 364 W at a current of only 167 A within a narrow spectral bandwidth of 0.2 nm can be achieved. The wavelength peak around 905 nm at 25°C shifts with temperature by only 66pm/K. Far-field measurements demonstrate successful operation in the 2^{th} and 4^{th} order vertical modes.

Large Optical Cavity 1550nm Laser with 4.9W Optical Output Power from a 100µm Wide Single Emitter

Niklas Kanold*, Martin Möhrle, Falco Ehrensack, and Martin Schell

Fraunhofer Heinrich-Hertz-Institut HHI, Berlin, Germany

*email: niklas.kanold@hhi.fraunhofer.de

High power laser diodes nowadays play a crucial role in a lot of industrial, medical and defence applications. In this work we show 1550 nm large optical cavity broad area lasers reaching 4.9 W output power for a current of 15 A. The single emitters have a width of 100 µm and a length of 3 mm. The peak wall plug efficiency of the laser amounts to more than 40 %. Such values could be achieved with precise control of the doping levels in the MOVPE grown layers in order to find an optimum balance between low series resistance and a low optical loss. With the presented structure, a series resistance as low as 22 mOhm has been achieved while the internal loss could be limited to an acceptable level of 3.2 cm^{-1}. The active region of the devices is based on an InGaAsP multi-quantum-well structure. Thanks to the large optical cavity structure, the devices feature also a narrow optical far-field of 25° x 15° (fast axis / slow axis). By integration of an additional 1st order DBR-Grating, a stabilization of the laser emission wavelength across the full current operation range is achieved.

Monolithic Wavelength-Stabilized High-Power Semiconductor Laser

Alberto Maina, Fulvio Gaziano, Alessandro Di Maggio, Valentina Massetti, Fabio Pozzi, Ezio Felice Riva, and Claudio Coriasso*

LUMIBIRD PHOTONICS ITALY, Italy

*email: c.coriasso@lumibird.com

This work reports on a high-power semiconductor laser emitting around 976nm whose emission wavelength is defined and stabilized by a monolithically integrated DBR section in an identical layer epitaxy (ILE) structure. The first-order grating allows for a DBR section as short as 0.5mm with a total chip length of 5mm. Three different grating pitches were defined over the wafer, resulting in diode lasers emitting at three wavelengths spaced by 5nm. Due to the transparency-induced effect in the passive DBR section, its insertion loss is almost negligible and the overall LIV characteristics are very similar to those of a reference Fabry-Perot laser. An emission optical power of 8W at 12A CW, 85°C has been consistently achieved for the three wavelengths. The wavelength drift over injected current and temperature is 0.040nm/A and 0.077nm/K respectively, while the spectral width is always less than 0.6nm for all the operating conditions analyzed (0÷16A, 25÷85°C). Experimental results show significant advantages over other wavelength-stabilization technologies, such as Volume Bragg Gratings or DFB lasers. In the former case, this device is more compact and efficient while in the second case, it shows a significantly reduced wavelength drift over current, due to the grating outside the active cavity. Furthermore, a degree of polarization greater than 96% allows for an effective polarization combination of different laser beams. This device can be used as a compact wavelength-stabilized high-power laser source over a wide current and temperature range, particularly suited to high-brightness multi-emitter development using both spectral and polarization combination schemes.

Friday, 12:30-12:50**, Session I**

Scaling Towards 80% Conversion Efficiency at 25°C in GaAs-based Broad Area Lasers

Paul Crump[1*], Anisuzzaman Boni[2], Mohamed Elattar[1], Shailesh Khamari[3], Igor Marko[4], Stephen J. Sweeney[4], Seval Arslan[1], Ben King[1], M. Jarez Miah[5], Dominic Martin[1], Andrea Knigge[1], Pietro Della Casa[1], and Günther Tränkle[1]

[1]*Ferdinand Braun Institut (FBH), Berlin, Germany*

[2]*LUMICS GmbH, Berlin, Germany*

[3]*RRCAT, Indore, India*

[4]*University of Glasgow, Glasgow, UK*

[5]*Institute of Information and Communication Technology,*

Bangladesh University of Engineering and Technology, Dhaka, Bangladesh

*email: paul.crump@fbh-berlin.de

We summarize efforts in the scaling of continuous wave (CW) power conversion efficiency of GaAs-based broad-area lasers (BALs), operating in the 900…1000 nm wavelength range. In the past decade, although efficiency at 20 W CW from BALs with 90…100µm stripes increased 1.5-fold to 57%, peak efficiency has changed little (70+/-5%). Recent experimental studies of BALs indicate a path towards overcoming this limit. Much higher external differential efficiency (~90% for 4 mm resonator) is observed in BALs under cryogenic conditions than at 25°C, and this helps enable efficiency ~80% at these temperatures [1]. New studies of spontaneous emission indicate why: a substantial improvement in uniformity and clamping of carrier density along the resonator is observed at low temperature (150…200K). At these temperatures, modal gain also increases and threshold reduces due to narrowing of the gain spectrum, and following [2], this can directly lead to improved clamping. These results motivate a study of BALs based on extreme-triple-asymmetric (ETAS) epitaxial layer designs that exploit a series of GRIN layers around the active region to achieve comparably high modal gains at 25°C to those seen in cryogenic studies. When these designs are realized as BALs with 4 mm resonator length, we find an external differential efficiency of around 90% is also achieved, for comparable optical efficiency to 200K (but still higher resistance than at 200K). Therefore, if high modal gain ETAS designs can be realized with best-in-class series resistance [3], conversion efficiency of above 80% may well be possible at room temperature.

[1] Frevert et al., in Proc. SPIE LASE San Francisco, CA, USA, (2016).

[2] kaul et al., *IEEE J. Sel. Top. Quantum Electron.*, Vol. 25, No. 6, (2019).

[3] King et al., Physica Scripta, Vol. 99, No. 5, (2024).

Dynamic Optical Injection of Mode-Locked Quantum-Dot Lasers for High-Speed Optical Sampling

Maria Ana Cataluna*, Ana Filipa Ribeiro, Kirill Kabelev, and Tiago Gomes

Heriot Watt University, Edinburgh, United Kingdom

*email: M.Cataluna@hw.ac.uk

We show how dynamic dual-tone optical injection can be used for rapid and wide tunability of the pulse repetition rate of a mode-locked quantum-dot laser. This new approach enabled a broad, continuous and flexible control of the pulse repetition rate – with tuning ranges up to 480 MHz for a 20 GHz laser, representing a maximum fractional tunability of 2.4%. We harness this capability to demonstrate high-speed optical sampling by cavity tuning (OSCAT), achieving a record 20 MHz scan rate. Given the flexibility of dynamic dual-tone optical injection, we were also able to demonstrate another sampling technique at high speeds – PHIRE (parallel heterodyne interferometry via repetition rate exchange. Using direct square-wave frequency modulation of the pulse repetition rate for the first time, we reached scan rates up to 28 MHz, with a modulation frequency of 1 MHz. Finally, we will also show how dynamic sub-harmonic optical injection locking can be used to reduce the bandwidth of the required RF modulation, thus reducing costs and increasing the applicability of the above techniques.

5.2 µm GaSb-based Interband Cascade Laser with Hybrid Superlattice Plasmon-Enhanced Claddings

Borislav Petrović[1*], Andreas Bader[2], Josephine Nauschütz[2], Takuma Sato[3], Stefan Birner[3], Robert Weih[2], Fabian Hartmann[1], and Sven Höfling[1]

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[2] nanoplus Advanced Photonics Gerbrunn GmbH, Oberer Kirschberg 4, 97218 Gerbrunn, Germany

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We present interband cascade lasers (ICLs) with hybrid claddings, emitting at spectral line of nitrous oxide (NO) of 5.2 µm. The 8-stage GaSb-based ICL with hybrid claddings composed of outer plasmon-enhanced and inner InAs/AlSb superlattice claddings, shows an increase in mode confinement of 11.2 % according to the simulation. This is a consequence of a significantly lower refractive index of plasmon-enhanced claddings. The obtained threshold current density is in pulsed operation at room temperature. This is the lowest value reported to date for ICLs emitting at wavelengths longer than 5 µm. We also report close to record value threshold power density of the measured thermal resistance as low as 62 K/W highlights improved heat dissipation of the ICL, which validates a high thermal conductivity of plasmon-enhanced claddings.

New Versatile and Compact Laser Source for Short Pulse Trains at 900nm for 2ph-FLIM

Sylvain Boust[1], Maxime Meghnagi[1], Guillaume Daccord[1], Francois Duport[1], Eva Izquierdo[1], Jean-Pierre Legoec[1], Michel Garcia[1], Olivier Parillaud[1], Dmitri Boiko[2], and Michel Krakowski[1*]

[1]III-V Lab, France

[2]CSEM, Centre Suisse d'Electronique et de Microtechnique SA, Switzerland

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We first present the concept of a new laser source developed in the Horizon Europe HILIGHT project ("Highly Integrated Versatile Laser Source enabling two-photon excitation in digital diagnostics and biomedical research"). This compact source based on a tapered laser diode monolithically integrating several functions will address applications based on two-photon excitation fluorescence lifetime imaging microscopy (2ph-FLIM). This process has two phases: i) a train of pulses excites the dye; ii) the laser is turned off to measure the fluorescence decay. This involves being able to precisely modulate the laser to move from one phase to another. The choice of acridine orange dye requires the choice of wavelength around 880nm-900nm. This source will ultimately be used in two specific use cases: i) instant digital histopathology and ii) biomedical research in the context of cancer diagnosis. We propose a monolithic mode-locked tapered laser diode producing on-demand 10ps pulse trains at 6GHz, with high peak power (>20 W). This source will also be agile: the pulse train can be emitted and turned off (On/Off switching) in less than 0.3 ns. We then present the results obtained on two constituent elements of this laser: two-section laser diode with saturable absorber and tapered laser diode. They allow the design of the HILIGHT laser source and show operations in line with the desired objectives.

How to Build a Monolithically Mode-Locked 200 pJ Laser Enabling Two Photon Excitation Time-Resolved Fluorescence Imaging at 8 Megapixels per Second?

Dmitri Boiko[1*], Severin Oeschger[1], Nicolas Torcheboeuf[1], Sylvain Boust[2], François Duport[2], Michel Garcia[2], Nadja Böhm[3], Zachary Baltzer[4], Alessandro Esposito[5], Alessandro Tontini[6], Leonardo Gasparini[6], Patrick Flückiger[1], Andreas Rauschmayr[3], Philipp Andre[3], and Michel Krakowski[2]

[1]CSEM Centre Suisse d'Electronique et de Microtechnique SA, Switzerland
[2]III-V Lab, France
[3]VivaScope GmbH, Germany
[4]Caliber I.D. Inc, USA
[5]Brunel University London, UK
[6]FBK Fondazione Bruno Kessler, Italy

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We redesign our monolithically mode-locked tapered MLSCL laser build for ESA (200 pJ pulse @ 3 GHz reprate, [JSTQE 2019]) for novel application in a confocal laser scanning microscope (CLSM) with world record pixel acquisition rate of 8 Mpx/s and subcellular tissue resolution. The laser will enable two-photon excitation time-resolved fluorescence imaging. Laser requirements are established by deep analysis of the existing hardware VivaScope 2500 ex-vivo CLSM which so far operated with two CW lasers on fluorescence intensity and tissue reflectance imaging channels, respectively, and have already revolutionized the work of pathologist delivering digital H&E-like staining images in tens of seconds. With partners of HiLight project we are targeting to introduce an additional two-photon excitation fluorescence lifetime imaging channel and improve the tissue penetration depth while preserving the lateral resolution and image pixel acquisition rate. Carefully modelling the laser pulse parameters, two-photon absorption and fluorescence decay processes, image quantization and Poisson noising at low photon numbers, the time-resolved fluorescence images at 52 ns pixel dwell time is shown to be possible with the image SNR of about 10. To achieve this goal, the monolithic laser composed of tapered and straight WG gain sections as well as an absorber section will additionally incorporate a built in pulse burst picker section enabling to produce 15 ns duration bursts of mode-locked pulses. Fluorescence waveforms will be acquired with time-gated SPAD array sensor detecting both fluorescence growth and decay processes for extracting the lifetime at the highest SNR ratio.

Spectral Control in Quantum Walk Frequency Combs from Quantum Cascade Lasers

Diego Piciocchi*, Ina Heckelmann, Alexander Dikopoltsev, Mathieu Bertrand, Mattias Beck, Giacomo Scalari, and Jérôme Faist

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Recently, a new scheme for frequency comb generation in Quantum Cascade Lasers with ring cavity geometries has been proposed. The laser's bias current is modulated with a radio frequency (RF) signal on resonance with the cavity free-spectral range. Said modulation, converted into a phase modulation of the intracavity field by the linewidth enhancement factor, enables the progressive transfer of intensity from the free-running single mode of the device to the neighboring ones. The process stabilizes on a broad frequency-modulated comb spectrum with chirped instantaneous frequency and quasi-constant intensity. This system has been described using an effective tight-binding Hamiltonian for a 1D synthetic lattice, whose sites are constituted by the cavity modes of the system. Interestingly, this mapping reveals the analogy between the dynamics of the population of the modes and the one of a Quantum Random Walk. Furthermore, it becomes possible to interpret the role of the RF as writing the dispersion relation of the system. This feature is exploited to engineer the band structure in synthetic space by introducing additional frequency components in the driving signal. By doing this, the spectrum of the emitted frequency comb is correspondingly manipulated. Two different applications are discussed. In the first one, the driving RF is phase-modulated with a noisy signal, leading to a dynamical evolution of the spectrum and a change in the average spectral envelope. In the second one, driving the system with two frequencies and controlling their relative phase enables the reproducible control of the steady-state spectral envelope.

Modeling VCSEL Modes: from the Beginnings to New Geometries and Future Applications

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In mytalk, I will introduce our VCSELs Electromagnetic Simulation Software Suite (VELMS) and discuss its evolution over the past 25 years since its initial release. At the time, Vertical Cavity Surface Emitting Lasers (VCSELs) had limited market applications. Since then, VCSELs have steadily expanded their presence, gaining significant market share. VELMS has evolved in parallel, incorporating the necessary features to meet the demands of emerging sensing and datacom systems. For instance, position-sensing VCSELs, based on our surface grating proposal and demonstration, are now widely used in laser mice and smartphones. Depending on the application, these devices can range from dozens to several hundred sensing VCSELs. In the sensing domain, where single-mode operation is critical, new applications are rapidly emerging, particularly in autonomous driving and vehicle safety systems. LIDAR technology, which requires high power, has driven the development of multi-(tunnel) junction VCSELs, coupled with traditional oxide confinement techniques. This can be further enhanced by specialized VCSEL transverse array geometries to achieve single-mode operation in a high-order mode through reflection patterning. In this paper, we will present examples of potential geometries. Another major market for VCSELs is datacom, especially in the context of data centers. The demand in this sector is skyrocketing, driven by the growing needs of AI (artificial intelligence) applications, which require the construction of massive new data centers. Of course, faster speeds are also essential. I will share our modeling of dumbbell-shaped oxide-aperture VCSELs, which show promise in achieving 200G datacom via a single VCSEL using PAM-4 modulation.

VCSELS for Chip Scale Rubidium based Atomic Clocks

Inbal R Marciano, Visorian Mikhaelashvili, Amnon Willinger, Lior Gal, Meir Orenstein, and Gadi Eisenstein*

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Chip scale atomic clocks (CSACs) are driven by VCSELs that require a special combination of properties which are usually not important for other applications. We report on such VCSELs that exhibit all the required characteristics surpassing all commercially available VCSELs of this kind. The top emitting VCSEL was designed to have a minimum threshold near 363 K. The spatial mode filtering was determined by a top metal ring electrode and the oxide aperture, both have a diameter of The key characteristics include a negative T_0 leafing to a minimum threshold of 0.6 mA at 90^0C, single mode operation at an exact emission wavelength of 795 nm with a 30 dB side mode suppression ratio and a polarization discrimination of 25-27 dB also at 90^0C. Since CSACs use FM spectroscopy techniques for detection of the atomic transition, it is desirable that in this applications, the a parameter should be large. The a parameter in the present VCSELs is in the range of 8-10 We also studied the correlation between the electrical and optoelectronic characteristics. We found that at moderate bias levels, up to transparency, the current flows in parallel paths along the periphery of the mesa. The conventional exponential current dependence on voltage changes above transparency to a power low dependence when the diode reaches the so called high injection regime. This leads to a nonlinear contribution to the series resistance which is not considered in common models.

Relative Intensity Noise and Four Wave Mixing in Elliptical Oxide Aperture Multi-Mode VCSELs

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We study experimentally and theoretically different 850 nm multimode elliptical VCSELs for 51.126 GBaud PAM4 modulation in MMF. Circular oxide aperture multimode VCSELs present the drawback of emitting several transverse modes distanced by only a few GHz with the drawback of generating beating tones seen as peaks in the Relative Intensity Noise spectrum at frequencies within the receiver bandwidth of about 40 GHz. Elliptical oxide aperture is a solution, because the frequency spacing among higher order modes can be engineered such that beating tones fall in some cases outside the detector bandwidth. While this is a good short-term solution, when the requirement for higher speed arises, the problem of peaks in the RIN is bound to re-emerge. In this work we provide two examples of devices with and without beating tones in the 40GHz bandwidth. For understanding their performance, we have developed a unique multi-mode VCSELs simulator that includes the time domain dynamics of the optical electric field of each lasing transverse mode and of the carrier spatial distribution in the active region. With this model, we simulate the RIN spectrum, and we predict the nontrivial beating tones observed in the RIN. These tones are explained as resulting from a four wave mixing process mediated by carrier beating and spatial hole burning. The FWM process is also proved by measuring the FWM sidebands with a high-resolution optical spectrum analyser and by measuring frequency resolved near-field patterns of the lasing transverse modes and of the generated FWM side bands.

Friday, 17:30-17:50, Session III

Dynamical Behaviour from Short to Long Feedback Delay Regime in Mid-Infrared ICL

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Semiconductor lasers subject to optical feedback can produce a wide variety of dynamical behavior such as low frequency fluctuations (LFFs), regular pulse packages (RPPs), multistability or fully developed chaos. Understanding and exploiting those behaviors are of great importance for several applications. In particular, secure communications, LIDAR systems and parallel random number generation. In this work, we experimentally studied the influence of the feedback delay regarding the obtained dynamical behavior of Fabry-Perot mid-infrared interband cascade lasers (ICLs) grown on GaSb, using different external cavity lengths from 70 cm to 150 cm. Reaching the short delay regime usually requires very short external cavity due to the high relaxation oscillation frequency of typical semiconductor lasers (about 1GHz), which in the present ICLs lies around 100 MHz. Interestingly, in the short delay regime, whenever the feedback delay is shorter than the relaxation oscillation time, we observed the formation of RPPs. These RPPs transitioned towards LFFs for increased feedback delay, experimentally showing the transition between short and long feedback delay regimes. Similar behavior was observed for increased bias at a fixed external cavity length due to the induced increase of the ROF. This work is to our knowledge a first experimental demonstration of RPPs in the short feedback delay regime or ICL and paves the way to the development of mid infrared LIDAR based on ICLs.

Heterogeneous Integration for Silicon Photonics: Techniques and Perspectives

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Heterogeneous integration techniques are important for merging best-in-class materials to improve system performance and functionality, as well as to enable scaling of high-performance components and circuits. For photonics applications, heterogeneous integration approaches based on bonding or direct heteroepitaxy provide a path to intimately integrate optical gain and other active materials based on compound semiconductor with silicon. Silicon photonics (SiPh) has matured significantly in recent years for a variety of applications including telecommunications, data center communications, quantum computing, artificial intelligence (AI), light detection and ranging (LiDAR), and biological sensing, to name a few. Co-packaging and flip-chip integration have been leveraged commercially to integrate lasers with SiPh circuits. These techniques, however, require cumbersome assembly and don't scale for applications requiring high integration density. Wafer and chiplets bonding approaches have also been pursued and provide some scalability, but pose challenges on manufacturing and require expensive compound semiconductor substrates. Direct heteroepitaxy, on the other hand, eliminates the compound semiconductor substrates and can enable frontend process integration. This presentation will summarize efforts to integrate high-performance compound semiconductor materials on silicon through micro-transfer print (MTP) integration and direct heteroepitaxy. Quantum dot (QD) gain materials and their integration will be described, including the advantages for integration on SiPh. Lastly, efforts to scale the direct heteroepitaxy approach for 300mm SiPh platforms will be discussed including the use of selective area heteroepitaxy (SAH) to enable process integration.

InP-based QD-Laser for O-band Telecom Applications

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The InP-based QDs lasers showed already good performance caused by the inherent advantages of QDs due to their atom-like features. However, these advantages have been predominantly demonstrated in the telecom C-band, enabling the development of short-cavity devices for high-speed modulation. Although GaAs-based QD structures have shown promise in the 1.3 µm wavelength range, they still suffer from limited modal gain levels which are typically three times lower than that of their InP-based counterparts. To address this, our work focuses on developing InP-based QD materials using a modified growth technique to achieve high modal gain and temperature stability comparable to C-band QD lasers within the 1.3 µm wavelength range. The grown and fabricated broad area as well as ridge wave guide (RWG) QD lasers emitting in the O-band (1.25 – 1.35 µm) has shown very good performance with modal gain of 15 cm^{-1} per QD layer and internal quantum efficiency of 0.89 W/A comparable to the state-of-the-art 1.55 µm InP QD lasers. The good temperature stability was confirmed by high T_0 value of 333K (20ºC – 40ºC) from a 1 mm RWG, which operated up to 150ºC in pulsed mode. Short 423µm RWG laser works up to 80ºC in CW mode. The frequency response was measured on a shorter 332µm RWG resulting in a 3-dB bandwidth of 10.9 GHz with 120 mA injection current at 15ºC. The short lengths RWG laser operations were possible only due to the high modal gain of this new type of InP-based 1.3 µm QD material.

Saturday, 10:20-10:40, Session IV

InAs Quantum Dot O-band Laser for Ultra-High Temperature Operation

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Efficient O-band InAs quantum dot (QD) lasers are desirable for CMOS/PIC (photonic integrated circuits) integration for harsh and uncooled applications. InAs QD lasers with high-reflective (HR) coatings on cavity facets demonstrated laser operation up to 220 °C [1]. However, such laser devices with HR coatings are not easily implemented into PICs, adding complex and costly fabrication processes. Thus, we demonstrate InAs QD O-band laser operation up to 193 °C and 202 °C for ground and excited states respectively by employing a co-doping scheme within the active region, with a 2 mm cavity length and cleaved uncoated facets. Co-doping combines the advantages of p-modulation doping and direct n-type doping leading to a higher gain, and reduced threshold current compared to conventional undoped InAs QD laser devices [2]. The resulting ultra-high operating temperature allows the development of optical sources in uncooled low-energy PICs and deployment in communications or sensing applications within harsh environments.

[1] Kageyama Takeo et al., "Extremely high temperature (220 °C) continuous-wave operation of 1300-nm-range quantum-dot lasers," The European Conference on Lasers and Electro-Optics. Optica Publishing Group, (2011).

[2] Lydia Jarvis et al., "1.3−μm InAs Quantum Dot Lasers with P-type modulation and direct N-type co-doping," 2022 28th International Semiconductor Laser Conference (ISLC), Matsue, Japan, pp. 1-2, (2022).

Acknowledgements: Device fabrication was carried out in the cleanroom of Institute for Compound Semiconductors (ICS) at Cardiff University. EPSRC funded Future Compound Semiconductor Manufacturing Hub: reference EP/P006973/1 and EPSRC funded QUDOS Programme Grant EP/T028475/1 provided essential resources for this study.

Growth Optimization of InP-based InAs Quantum Dots for High-Performance 1.55 µm Laser Applications

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The InP-material system is crucial for long-wavelength laser applications. InAs-QD lasers were recently researched and exhibit improved properties, like temperature stability, threshold current density and linewidth. However, their potential is not yet fully exploited. This study aims to further optimize InAs-QD morphology and optical properties to narrow the gain spectrum of the ground state transition and improving laser performance. The Initial phase involves growing self-assembled InAs-QDs on InAlGaAs lattice-matched to InP using MBE, followed by AFM characterization and low-temperature PL-spectroscopy to assess size uniformity, emission wavelength, QD density, and reproducibility. Beside the optimization of growth parameters, the impact of an additional sub-monolayer nucleation layer (NL) on the QD formation process and related size homogeneity are investigated. By optimizing growth-rate, temperature, V/III-ratio and introducing a GaAs-NL, PL linewidth of 18 meV at 10 K was obtained. By stacking of QD layers, a record narrow linewidth of 19 meV for six QD-layers was achieved. Laser structures based on a first stage optimized QD layer stack exhibiting PL linewidths of 23 meV (10K) and 52 meV (RT), respectively. Broad area lasers with 100 µm stripe width show internal efficiencies of 71%, a total modal gain of 137 cm^{-1}, i.e., record high 23 cm^{-1}/QD layer and high characteristic temperatures of 556K for T1(40 to 70 °C) and 91K for T0(20 to 110 °C) were obtained, respectively. By integrating the newly developed record-narrow linewidth QD layer stacks into lasers, we expect further improvements in device performance. Updated results will be reported at the workshop.

Very High-Power SOAs Laser Modulator for Access Networks

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We present our InP technologies based on Semi-insulating Buried Heterostructure Waveguide (SIBH). These technologies allow us to achieve excellent performance for different types of active devices such as DFB lasers, externally modulated lasers (EMLs) and semiconductor optical amplifiers (SOAs). Using our technologies, we have developed an EML integrated with a booster SOA - known as an EML-SOA - to increase the modulated output power of the EML. In this study, we have optimized the structures of the EML-SOAs to achieve maximum saturation power in order to reach very high-power levels while still operating in the linear regime of the SOA in both the C-band and O-band wavelength ranges. These high performance EML-SOAs are used for downstream transmission in passive optical networks and next generation high-capacity access networks. For the O-band, we experimentally demonstrate an EML-SOA operating at 1342 nm that is compatible with 50 Gb/s modulation with a saturation power of 20.8 dBm at 200 mA total injected current and a facet modulated power of 15.8 dBm with a dynamic extension more than 10 dB. Similarly, for the C-band wavelength range, we show an EML-SOA operating at 1577nm. A facet modulated output power of 11.5 dBm and a dynamic extension of 10 dB were demonstrated.

Gallium Nitride Lasers for Optical Communications and Quantum Applications

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Gallium nitride distributed feedback (DFB) lasers have been designed, fabricated and characterised for use in optical communications and quantum applications. These devices are used in applications such as free space visible light communication, but also play a key role in underwater and space environments due to the low loss transmission in the blue part of the spectrum. Devices have shown Gbit/s performance making them ideal candidates for low-cost, high speed data transmission. Work is also ongoing to explore the linewidth of these devices for use in quantum applications such as optical atomic clocks. Many systems make use of large, expensive lasers which are power hungry and often frequency doubled to hit key wavelengths or alternatively rely on vibration sensitive external cavity diode lasers (ECDL). Precise wavelengths are required for the atomic cooling process, such as 422 nm for strontium ion optical clocks, and distributed feedback lasers have been realised to hit the required specifications and ultimately reduce the SWaP compared to current systems. Work is continuing to look at modelling the device epitaxy and grating structure to improve performance further and also explore surface emitting lasers for these applications and beyond.

Effect of Direct Modulation on the Spatial and Temporal Coherence of a Semiconductor Laser with Optical Feedback

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Semiconductor lasers with optical feedback are nonlinear dynamical systems exhibiting diverse behaviors influenced by feedback parameters. Optical feedback can reduce laser linewidth but also induce mode-switching, multi-mode emission, and chaotic output. Near the lasing threshold, low-frequency fluctuations (LFFs) occur due to mode hopping between stable and unstable external cavity modes. At higher pump currents, coherence collapse (CC) leads to spectral broadening. Recent studies have investigated feedback-induced effects on the temporal and spatial coherence of laser light using spectral and speckle analysis [1] and [2]. Speckle, a spatial noise structure from the interference of coherent waves in a diffusive medium, degrades image quality in imaging applications. Consequently, significant efforts have been focused on mitigating speckle. Strong optical feedback has been observed to reduce the laser threshold and induce an abrupt transition to coherent emission, discernible through speckle analysis. Feedback affects the coherence of the emitted laser light and thus the speckle contrast. As the current increases, regions of low speckle contrast alternate with high contrast regions, where the laser emission is single-mode. This study explores the impact of direct modulation of laser current to reduce speckle contrast under optical feedback. By applying sinusoidal modulation to the pump current, we compare optical spectra and speckle contrast across several modulation amplitudes and frequencies. We find that current modulation does not further reduce the contrast, but under appropriate modulation parameters, the regions of high speckle contrast are fully suppressed and the contrast remains low in all the range of pump currents studied.

[1] Gijón et al., Optics Express, Vol. 31, Issue 3, pp.3857-3864, (2023).

[2] Gijón et al., Optics Express, Vol. 31, Issue 13, pp.21954-21961, (2023).

Performance Improvement of 1.55µm AlInGaAs on InP through Introduction of Electron Blocking Layers

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The use of edge-emitting semiconducting lasers in high temperature environments is increasing, with many use cases having restrictions for device cooling. The improved conduction band offset of the AlInGaAs alloy in quantum wells allows for improved laser efficiency at elevated temperatures by increasing the energy barrier for thermal charge carrier leakage from the QW. However, this conduction band offset causes the AlInGaAs confinement layers surrounding the QWs to have a small or negative energy barrier with the InP cladding layer, offering a leakage path for electrons. To mitigate this leakage path, an electron blocking layer (EBL) can be added to the layer stack. While EBLs are typically included in publications on AlInGaAs lasers their functionality is infrequently verified in a one-on-one comparison. According to our best knowledge, a statistical efficacy analysis has not been reported in the literature. To determine the influence of EBLs we have fabricated a variety of AlInGaAs-based broad area lasers, comparing a reference without EBLs to the performance of the same stack with one or two InAlAs EBLs added at the InP – AlInGaAs interface. In an analysis of nearly 1000 lasers we report an increase in performance for slope efficiency, threshold current, thermal roll-over level, as well as the maximum of emitted optical power at elevated temperatures, when EBLs are used. The highest performance improvement is achieved when symmetrical blocking layers on the P and N side of the confinement region are used. The use of EBLs shows a measurable increase in the series resistance.

Design of DBR BRW lasers for parametric fluorescence

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The development of sources of entangled photons is of vital interest in quantum cryptography. One possibility for the generation of entangled photons is spontaneous parametric down conversion (SPDC), which requires phase matching of the involved waves. The semiconductor material AlGaAs has been shown to be a promising source due to its high nonlinear coefficient χ(2) and the possibility of laser integration. However, due to the lack of birefringence in AlGaAs, phase matching can only be achieved through properly designed waveguides. One promising device is the Bragg reflection waveguide (BRW), which supports a leaky mode, called Bragg mode, at 775 nm and properly guided modes at 1550 nm. Phase matching is enabled by the fact, that the effective index of the Bragg mode is smaller than the refractive indices of the core and the reflector layers, which compensates for the dispersion of the refractive index of AlGaAs. The high optical confinement in the core region also allows for laser integration through the introduction of an active region and appropriate doping. The SPDC process being highly frequency-sensitive means, that a minor change in the lasing frequency can prevent the creation of entangled photons. This can occur through current induced shifts or mode hopping inherent to Fabry-Pérot (FP) lasers. Therefore, we designed a distributed Bragg reflection (DBR) laser to stabilize the lasing wavelength and to select the pump wavelength for the SPDC process. The surface Bragg grating provides high reflectivity (>50%) within a narrow wavelength bandwidth (<0.4 nm) depending on the etch depth.

Saturday, 14:00-15:20, Poster Session, P2

Design of high-power photonic crystal surface emitting lasers with an all-semiconductor photonic crystal

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Photonic crystal (PC) surface emitting lasers (PCSELs) are an emerging class of semiconductor laser which incorporate a 2D PC in a semiconductor laser structure to provide large area feedback and surface emission. It was recently shown that by scaling the cavity diameter of a PCSEL to 3 mm an output power of 50 W could be achieved in continuous wave operation in a narrow circular beam [1]. However, in order to be widely utilised in industrial applications the power conversion efficiency of PCSELs must be substantially improved (currently ca. 30%), and the reliability and large-scale manufacturability demonstrated.

All of the high-power PCSELs reported have utilised a high-contrast PC grating between semiconductor material and air-voids. In this paper we will present design options for an alternative approach for high-power GaAs-based PCSELs, based on all-semiconductor (GaAs/InGaP) PC, emitting at 1070 nm. Using coupled-wave-theory for PCSELs and a newly realised design tool [2], we will show that through appropriate PC unit cell design and device size scaling (1 mm < L < 3 mm), all-semiconductor PCSELs have potential to be realised with both large mode discrimination and high external efficiency, comparable to best in-class void-containing PCSELs. We will discuss some of the design challenges in all-semiconductor PCSELs and how they can be overcome, and provide an outlook on the manufacturability and potential benefits of these devices.

[1] M. Yoshida, et al., Nature 618, 727–732 (2023).

[2] M. Radziunas, et al., IEEE Photonics Journal 16, 1-9 (2024)

Numerical study of the phase dynamics of mutually coupled lasers in a photonic integrated circuit for quantum random number generation

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Quantum random number generators (QRNGs) have been extensively explored as a solution for obtaining true random numbers. One option to implement them relies on the phase diffusion (PD) effect. PD-QRNGs extract the randomness from the phase of spontaneously emitted photons and constitute an example of photonic QRNGs implementation.

Our work involves a PD-QRNG based on an Indium Phosphide (InP) Photonic Integrated Circuit (PIC) with two lasers, a multi-mode interferometer (MMI) and two photodetectors. The PIC is currently commercialised by Quside Technologies and is capable of generating random numbers at 1GHz. A particularity in its operation is that the lasers' light entering the MMI can be reflected backwards into the lasers, causing self-feedback and coupling, which can induce synchronisation of the phases and thus a loss of randomness of the PD-QRNG. Similar phenomena have been modelled in laser dynamics research, but there is not much work combining simulations and experiments, and additionally, there is almost no research in the context of QRNGs.

The work consists of two parts: simulation of the system's rate equations, and experimental measurements of the complete device. In this contribution, we present the results of simulations, and in particular, the results obtained for the lasers' stochastic phase dynamics as a function of key parameters: the detuning and the coupling strength.

The simulations aim to identify the optimal conditions for the operation of the InP PIC as a high-speed quantum random number generator (i.e., a high-speed photonic entropy source).

Automated Assembly and Alignment of NIR and MIR External Cavity Diode Laser Systems

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Laser systems in the NIR and MIR spectral regime developed within the last three decades into an important tool for a large number of measurement and detection applications. One of the limiting factors is the high cost of manufacturing. We report on an automated assembly and alignment approach of NIR and MIR external cavity diode laser systems which allows significantly reducing the time duration and costs of alignment. Furthermore, our approach provides a significant improvement in qualitly, reproducibility and accuracy of the production.

State-of-the-Art manufacturing processes are carried out using a manual operator, which may result into significant variations of the laser performance. A solution suitable for industrial use is a fully automated production concept based on a fully automated assembly robot. This high-precision approach applied on the alignment of collimation lenses and on external cavity components provides a significant improvement of performance and reproducibility of the laser system.

The presented solution provides positioning accuracy better than 100 nm in all three translation degrees and angle accuracy better than 1/100°. In-situ monitoring of the optical and spectral performance of each of the assembly and alignment steps results into the best possible performance and reproducibility.

Key-point of a successful laser cavity alignment is a symmetrical laser beam with well-defined divergency angles of each of the beam axis. This is essential for a successful cavity alignment with Volume-Bragg-Grating or MEMS-Actuator as cavity mirror element. As example of this procedure, we present the performance of NIR VBG lasers with two different cavity length.

Topologically Stabilized VCSEL Arrays

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Topological Photonics is an emerging and novel field of research, adapting concepts from condensed matter physics to photonic systems adding new degrees of freedom. After the first demonstrations of topological photonic insulators, the field has moved on to study and exploit the inherent non-hermiticity of photonic systems and the interplay with their topological nature. In this context, I will discuss topological lasers as a prime example of using topological concepts potentially for new technologies in the broad context of synthetic (photonic) matter. In III-V semiconductor microresonators, exciton-polaritons – hybrid states of light and matter – can emerge in the strong coupling regime. By choosing precise lattice geometries we can tailor optical band structures realizing novel photonic lattices. The specific geometry as well as the hybrid light-matter nature allow for ways to break time-reversal symmetry and implement topologically non-trivial systems. Following this works, I will discuss recent advances towards electrical operation and lasing from a topological defects. In addition, so-called corner modes, fully localized higher-order topological defects in a two-dimensional lattice in breathing Kagome and 2D-SSH lattices are discussed, with a particular focus on the robustness against (deterministic) fabrication imperfections. For the implementation of the densely packed Kagome and 2D-SSH lattices, a novel design technique for polaritonic optical lattices was realized. Finally, recent advances in using polarization degrees of freedom in the context of artificial gauge fields and the realization of the (pseudo-)spin quantum Hall effect of light are discussed.

Room-Temperature Continuous-Wave Operation of a Semiconductor Nanolaser with Extreme Dielectric Confinement

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The development of nanolasers is driven by the demand for compact, energy-efficient light sources suitable for integrated photonics applications, such as on-chip optical interconnects. Photonic crystal nanocavities have been prominent due to their high quality factor-to-mode volume (Q/V) ratios. In recent years, a new type of nanocavity has emerged, allowing to confine light in a dielectric to a mode volume below what was previously believed to be the so-called "diffraction limit". Such cavities, coined Extreme Dielectric Confinement (EDC) cavities, achieve mode volumes more than an order of magnitude below the diffraction limit, while still reaching high Q-factors on par with photonic crystal nanocavities. Although silicon has been the primary material for such research, recent developments have utilized III-V to create EDC cavities with a Q/V ratio as high as 10^3(λ/2n)^(−3). Here, we presents the first demonstration of an EDC laser operating at room temperature in a continuous-wave excitation, representing an important advancement in nanolaser technology.

Time-Dependent Simulation of Photonic Crystal Surface Emitting Lasers

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Photonic crystal surface-emitting lasers (PCSELs) are devices that utilize a two-dimensional photonic crystal to achieve single-mode operation and a narrow far-field even at high output powers [1]. A major challenge in designing these devices is ensuring a large threshold gain separation between the fundamental mode and higher-order modes. This is important for maintaining single-mode operation at high current densities, where phenomena like spatial hole burning become significant. To investigate these effects, a coupled wave model was developed [1]. The influence of the photonic crystal is represented by a 4×4 complex coupling matrix, which can be efficiently calculated using an analytical transfer-matrix method [2]. Whilst the threshold gain separation can already be determined by solving the stationary coupled wave equations as in [2], it remains unclear how large this separation must be to ensure single-mode operation above threshold. To address this problem, we developed a new time-dependent model which consists of the time-dependent coupled wave equations and an equation governing the dynamics of the excess carriers in the active layer. Additionally, we model current spreading by solving a three-dimensional Laplace problem at each time step, which has been used previously for the simulation of broad-area laser diodes [4]. While recent simulations by Inoue et al. [3] have focused on PCSELs with double-lattice air-hole photonic crystal structures, we will present results for all-semiconductor PCSELs using a newly developed simulation tool.

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