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# Sunday, 10 October 2021

13:00-15:00

Workshop SuP1 — Current and future of photo detection technology
Presider — Nobu Nishiyama, *Tokyo Institute of Technology, Japan*

## 13:00-13:15 | Current and perspective on "classic" photodiodes for telecommunications applications (SuP1.1)...N/A

Masahiro Nada
*NTT research lab, Japan*

In this talk, we will review the achievements on “classic” photodiodes that denote discrete, pin based, and responsivity-bandwidth limited photodiodes for optical communications. Concurrently, we will introduce the perspectives on such classic photodiodes and some cutting-edge works that represents them, and discuss their expanding applications.

## 13:15-13:30 | Highly efficient InP-based waveguide photodetectors for optical communication systems (SuP1.2)...N/A

Hideki Yagi
*Sumitomo Electric Industries, Ltd., Japan*

We comprehensively review the wide bandwidth and high responsivity of InP-based waveguide photodetectors using butt-joint regrowth. In this review, the recent progresses of p-i-n photodiodes integrated with the 90° hybrid for digital coherent detection and avalanche photodiodes for 400 Gbit Ethernet are discussed.

## 13:30-13:45 | High performance Ge photodetector with Franz-Keldysh effect on Si-photonics platform for data communication (SuP1.3)...N/A

Junichi Fujikata
*Tokushima University, Japan*

We report a high-speed and high-efficiency Ge photodetector, using Franz-Keldysh effect. With decreasing the Ge width less than 1 µm, around 60 GHz bandwidth has been achieved. With optimizing the doping profile in the lateral pin-junction, Franz-Keldysh effect appeared and enhanced photoresponsivity with low applied voltage.

## 13:45-14:00 | Miniaturizing atomic systems for timing and sensing applications (SuP1.4)...N/A

Markus Krutzik
*Ferdinand-Braun-Institut gGmbH, Germany*

We will discuss recent progress in atomic quantum sensors for frequency metrology, timing and sensing applications. The talk will point out the major role of semiconductor based photonics to successfully drive the second quantum revolution.

## 14:00-14:15 | CMOS-based SWIR 2D/3D sensing with GeSi technology (SuP1.5)...N/A

Erik Chen
*CEO Artilux Inc, Taiwan*

This talk will review the progress of GeSi technology and its implication for the growing SWIR imaging applications for consumers, industrial and automotive markets.

### 14:15-14:30 | On-chip spectroscopy with a single tunable photodetector (SuP1.6)...N/A

Fengnian Xia
*Yale University, USA*

I will introduce a mid-infrared spectrometer in the 2-9 µm spectral range, utilizing a single tunable black phosphorus photodetector with an active area footprint of only 9×16 µm2, along with a unique spectral learning procedure. Its reconfigurable nature may open up a new pathway for mid-infrared spectroscopy.

### 14:30-15:00 | Panel discussions

15:00-15:30 | Coffee break

15:30-17:45

Workshop SuP2 **Workshop SuP2: Automotive LiDAR: status and technology**
Presider David Schleuning, *Waymo LLC*

### 15:30-15:45 | FMCW LiDAR for high speed autonomous vehicles (SuP2.1)...N/A

Stefan Heinemann, Craig Benko, Emil Kadlec, Zeb Barber, and Randy Reibel
*Aurora Innovations Inc., USA*

Automotive frequency-modulated continuous-wave (FMCW) lidar technology (Aurora's FirstLight) is presented. The approach is eye-safe, long-range and uses a coherent detection system that is sensitive to optical frequency and phase, and insensitive to solar loading and interference. Requirements and prospects for semiconductor laser sources are reviewed.

### 15:45-16:00 | Laser light sources for LiDAR (SuP2.2)...1

Martin Behringer[1], Klein Johnson[2]
*[1]OSRAM Opto Semiconductors GmbH, Germany; [2]VIXAR Inc., USA*

Lasers for many applications were established long ago. Recently, LIDAR became more important as very important sensor for autonomous driving. High resolution, high power and efficiency enable real-time environment surveillance. We present status and outlook on EEL and VCSEL for near IR light sources.

### 16:00-16:15 | Addressable high-performance multi-junction VCSEL arrays for automotive and mobile LiDAR (SuP2.3)...3

Eric Hegblom, Guowei Zhao, Jun Yang, Yeyu Zhu, Ajit Barve, Benjamin Kesler, Suning Xie, Mike Dolganov, Yuefa Li, Cho-Shuen Hsieh, Sean Burns, Kelvin Zhuang, Matthew G. Peters, Jay Skidmore
*Lumentum, USA*

We demonstrate VCSEL arrays for LiDAR applications with high peak optical power densities >1.5 kW per $mm^2$ of die area, and high slope efficiency, >6 W/A, under pulsed operation. Arrays are contacted electrically as a single-section or multiple stripes of emitters or as a 2D matrix-addressable grid.

## 16:15-16:30 | Semiconductor lasers and optical amplifiers for LiDAR photonic integrated circuits (SuP2.4)...5

Ergun Canoglu[1], Yongkang Gao[1], Xing Pan[1], Mark Dayel[1], Rob Carney[1], Marcel Boudreau[2], Koji Yamada[3]

*[1]NeoPhotonics, USA; [2]NeoPhotonics, Canada; [3]NeoPhotonics, Japan*

Silicon photonics based lidar sensors can enable chip scale sensors for high volume 3D sensing applications. These sensors require narrow linewidth and high optical power semiconductor devices to power long range lidars. Experimental results from 1550 nm high power SOAs and narrow linewidth lasers are presented.

## 16:30-16:45 | Development of on-chip LiDAR based on slow light (SuP2.5)...N/A

Toshihiko Baba

*Yokohama National University, Japan*

Slow light waveguide gratings enhance the angular dispersion and enable wide-range high-resolution beam scanning. On-chip solid-state FMCW LiDAR is available by integrating the scanner with a modulator, switches, and photodiodes. It allows the 3D imaging as well as scanning velocimeter and vibrometer operations.

## 16:45-17:00 | Diode lasers with internal wavelength stabilization for LiDAR applications (SuP2.6)...7

Andrea Knigge

*Ferdinand-Braun-Institut gGmbH, Germany*

The development of diode lasers with internal wavelength stabilization and powered by inhouse electrical drivers generating 2 ns to 10 ns long electrical pulses is reviewed. Different power classes ranging from single emitters providing >40 W to 48-emitter bars with >600 W pulse power are discussed.

## 17:15-17:45 | Panel discussions

## 18:30-20:30 | Welcome reception

# Monday, 11 October 2021

08:30-08:45

Session MA1 **VCSEL**
Presider Anders Larsson, *Chalmers University of Technology, Sweden*

## 08:30-08:45 | Ultra-compact VCSEL beam scanner with large field of view and its 2D beam scanning function (MA1.1)...9

Ruixiao Li[1], Xiaodong Gu[1,2], Satoshi Shinada[3], Fumio Koyama[1]

*[1]Tokyo Institute of Technology, Japan; [2]Ambition Photonics Inc., Japan; [3] National Institute of Information and Communications Technology, Japan*

We realized the solid-state 1D-beam scanner with field of view of 56° × 14° and resolution points number of >1000 by using electrically-driven solid-state beam scanner and DOE. We also demonstrated 2D-beam scanning with field of view of 9° × 6° by integration of beam scanners array.

## 08:45-09:00 | Low power consumption 1060 nm single-mode intracavity metal aperture VCSEL with transverse resonance (MA1.2)...11

Hameeda R Ibrahim[1,2], Ahmed M. A. Hassan[1,3], Xiodong Gu[1,4], Satoshi Shinada[5], Moustafa Ahmed[2], Fumio Koyama[1]

*[1]Tokyo Institute of Technology, Japan; [2]Minia University, Egypt; [3]Al-Azhar University, Egypt; [4]Ambition Photonics Inc., Japan; [5]National Institute of Information and Communications Technology, Japan*

We demonstrate low power consumption 1060 nm intracavity metal-aperture VCSELs with high-speed modulations of NRZ 40 Gbps and PAM4 60 Gbps in single-mode operations. The intracavity metal-aperture causes the transverse resonance which provides the modulation bandwidth-enhancement. We achieve a record low power consumption of less than 42 fJ/bit.

## 09:00-09:15 | Novel multi-aperture VCSELs for optical wireless and multimode fiber communication (MA1.3)...13

Nikolay Ledentsov Jr.[1,2], Oleg Yu. Makarov[1], Łukasz Chorchos[1,2], Marwan Bou Sanayeh[1], Vitaly A. Shchukin[1], Vladimir P. Kalosha[1], G. Schaefer[1], Jarosław P. Turkiewicz[2], Nikolay N. Ledentsov[1]

*[1]VI Systems GmbH, Germany; [2]Warsaw University of Technology, Poland*

We report on 4× VCSEL multi-aperture arrays in the SWDM range suitable for high power high coupling efficiency multimode fiber (MMF) transmission at current densities as low as 6.7 kA/cm$^2$ at 25 Gbaud (4 mW optical power in the MMF) and 16.5 kA/cm$^2$ at 50 Gbaud (7 mW).

## 09:15-09:30 | Bidirectional electrostatic MEMS tunable VCSELs (MA1.4)...15

Arnhold Simonsen[1], Søren Engelberth Hansen[1], Masoud Payandeh[1], Andrey Marchevsky[1], Gyeong Cheol Park[2], Hitesh Kumar Sahoo[1], Elizaveta Semenova[1], Ole Hansen[1], Kresten Yvind[1]

*[1]Technical University of Denmark, Denmark; [2]Electronics and Telecommunications Research Institute, South Korea*

Bidirectional actuation using large voltages on the static electrodes allow linear tuning and reduction of AC voltage for stiff MEMS actuators. We use this to achieve 3.44 % fractional bandwidth at 2.73 MHz, which results in a record-breaking one-way sweep-rate of fractional bandwidth (%) pr. µsec.

### 09:30-09:45 | Multiple wavelength VCSEL array with intra-cavity grating (MA1.5)...17

Antoine Pissis[1,2], Urs Siegenthaler[1], Donato Bonfrate[1], Pratyush Das Kanungo[1], Evgeny Zibik[1]
*[1]II-VI Laser Enterprise, Switzerland; [2]University of Glasgow, Glasgow, UK*

We present a novel concept of tuning the emission wavelength of VCSELs by altering the cavity optical thickness with an intra-cavity grating pattern of varying fill factor. We demonstrate a multiple wavelength VCSEL array with emission wavelengths spanned across ~20 nm range around 940 nm.

### 09:45-10:00 | Quantification of coherent-coupling in photonic crystal vertical cavity laser arrays (MA1.6)...19

Nusrat Jahan, William North, and Kent D. Choquette
*University of Illinois, USA*

We compute and compare the coupling coefficient from the extracted optical power for coupled photonic crystal VCSEL arrays. Increasing cavity diameter is found to increase the coupled output leading to higher coupling coefficient of the array supermodes.

### 10:00-10:30 | Optical mode engineering in VCSELs | Invited Talk (MA1.7)...21

Kent D. Choquette
*University of Illinois, USA*

We discuss control of index-guided and anti-guided optical modes in vertical cavity surface emitting lasers and arrays using control of refractive index and the spatial extent of gain. Applications of non-Gaussian modes are highlighted.

10:30-11:00 | Coffee break

11:00-13:00

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| Session MA2 | Amplifiers & GaN |
| Presiders | Boon S. Ooi[1] and Johann Peter Reithmaier[2]<br>*[1]King Abdullah University of Science and Technology, Saudi-Arabia;*<br>*[2]Universität Kassel, Germany* |

### 11:00-11:15 | Progress on pure AlGaN based UVB LEDs and our approach toward deep-ultraviolet (DUV) LDs (MA2.1)...23

M. Ajmal Khan, Noritoshi Maeda, Masafumi Jo, and Hideki Hirayama
*RIKEN Cluster for Pioneering Research (CPR), Japan*

Recent progress on pure AlGaN ultraviolet-B (UVB) LED with a record maximum EQE of 9.6 % on wafer was provided. Besides, 273 nm-band abnormally oscillating deep-ultraviolet (DUV) Laser grown on low cost AlN template on C-Sapphire with injection current density of 48 kA/cm$^2$ is also reported.

### 11:15-11:30 | Narrow emission of blue GaN-based vertical-cavity surface-emitting lasers with a curved mirror (MA2.2)...25

Kentaro Hayashi, Tatsushi Hamaguchi, Jared Kearns, Eiji Nakayama, Yukio Hoshina, Tatsuro Jyokawa, Maho Ohara, Noriko Kobayashi, Shouetsu Nagane, Koichi Sato, Yuki Nakamura, Takumi Watanabe, Tomohiro Makino, Maiko Ito, Rintaro Koda, Hidekazu Kawanishi, Noriyuki Futagawa
*Sony Group Corporation, Japan*

We report a narrow divergence angle of 3.9° from a gallium-nitride-based vertical-cavity surface-emitting laser with a curved mirror and an emission wavelength of 450.9 nm. This record width is enabled by the large mirror radius of curvature of 988 µm, almost 10x higher than previously demonstrated.

### 11:30-11:45 | Compact semiconductor optical amplifier with U-turn shape deep-ridge passive waveguide for Si photonic circuits (MA2.3)...27

Masahiro Yoshida, Kazuomi Maruyama, Kazuaki Kiyota, Masaki Kohtoku
*Furukawa Electric Co. Ltd., Japan*

We propose an SOA with U-turn shape deep-ridge passive waveguide for integration on a silicon photonics platform. We fabricated the U-turn waveguide with the bending radius of 75 µm, and good gain characteristics were obtained in the entire C-band.

### 11:45-12:00 | AlGaN-based UV-B laser diode fabricated on AlN with 1 µm periodic concave and convex patterns (MA2.4)...29

Ayumu Yabutani[1], Tomoya Omori[1], Moe Shimokawa[1], Ryota Hasegawa[1], Sho Iwayama[1,2], Motoaki Iwaya[1], Tetsuya Takeuchi[1], Satoshi Kamiyama[1], and Hideto Miyake[2]
*[1]Meijo University, Japan;[2]Mie University, Japan*

In this study, we fabricated a UV-B laser diode on high-quality AlGaN fabricated on AlN with periodic concave and convex patterns. The lasing wavelength and threshold current density of the laser diode were 301 nm and 22 $kAcm^{-2}$, respectively.

### 12:00-12:15 | 1.3 µm InGaAsP/InP semiconductor optical amplifier compatible with an active/passive integration technology (MA2.5)...31

Joel Hazan[1], Stefanos Andreou[2], Dzmitry Pustakhod[1], Steven Kleijn[2], Kevin Williams[1], Erwin Bente[1]
*[1]Eindhoven University of Technology, The Netherlands;[2]Smart Photonics, The Netherlands*

We present our latest results on 1300 nm band optical amplifiers and Fabry-Perot lasers in the development of a 1300 nm active\passive photonic integration platform on InP. Modal gain, material transparency, temperature dependence are reported and analyzed for amplifiers that are optimized for low butt-joint reflections.

### 12:15-12:30 | Quantum coherent revival in a room-temperature quantum-dot optical amplifier: a route towards practical quantum information processing (MA2.6)...33

Igor Khanonkin[1], Johann Peter Reithmaier[2], Gadi Eisenstein[1]
*[1]Russell Berrie Nanotechnology Institute, Israel; [2]University of Kassel, Germany*

The hallmark quantum-optics phenomenon: quantum coherent revival was demonstrated in room-temperature quantum dot optical amplifiers. The revival originates from coherent excitation of, and interaction among, homogeneous subgroups within an inhomogeneous ensemble, which play the role of a multi qubits platform for practical quantum information processing.

### 12:30-13:00 | Progress in GaN-based VCSEL | Invited Talk (MA2.7)...N/A

Tatsuya Takeuchi
*Meijo University, Japan*

GaN-based VCSELs have been intensively developed. We adopted an AlInN/GaN DBR using in-situ wafer curvature monitoring and a current/optical confinement structure with a few nm height step. Room-temperature continuous-wave operations of GaN-based VCSELs with apertures up to 30 µm diameter have been demonstrated.

13:00-14:00 | Lunch break

14:00-15:15

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| Session MP1 | Plenary 1 |
| Presiders | Paul Crump[1] and Akihiko Kasukawa[2]<br>*[1]Ferdinand-Braun-Institut gGmbH, Germany;*<br>*[2]Furukawa Electric Co, Japan* |

### 14:00-14:30 | VCSEL Photonics: Current state of the art and future prospects | Legend Talk (MP1.1)...35

Fumio Koyama
*Tokyo Institute of Technology, Japan*

VCSEL research and developments over 40 years opened up various applications of VCSEL photonics, including 3D sensing and optical interconnects in datacenter networks. In this talk, the current state and future prospects of VCSELs are addressed, focusing on high-speed, high-power VCSEL photonics and new functionalities.

### 14:30-15:15 | Ultrawide bandgap semiconductors lasers: materials, devices, and AI innovations | Plenary Talk (MP1.2)...N/A

Nelson Tansu
*The University of Adelaide, Australia*

The paper discusses the challenges and progress of ultrawide bandgap semiconductor lasers in the deep ultraviolet spectral regime. Several key advances based on material, device, and nanoscale innovations will be presented. An artificial-intelligence approach in designing photonics and nanoscale structures will be presented.

15:15-15:45 | Coffee break

15:45-18:00

Session MP2 InP/Si

Presider Yuqing Jiao,
*Eindhoven University of Technology, The Netherlands*

## 15:45-16:00 | III-V gain region/Si external cavity hybrid tunable lasers with InP-based two-storied ridge structure (MP2.1)...37

Takuo Hiratani[1], Naoki Fujiwara[1,2,3], Takehiko Kikuchi[1,2], Naoko Inoue[1], Tsutomu Ishikawa[1], Toshiyuki Nitta[1,2], Moataz Eissa[2], Yoshitaka Oiso[2], Nobuhiko Nishiyama[2], and Hideki Yagi[1,3]

*[1]Sumitomo Electric Industries Ltd., Japan; [2]Tokyo Institute of Technology, Japan; [3]Optoelectronics Industry and Technology Development Association, Japan*

III-V/Si hybrid tunable lasers with the InP-based two-storied ridge structure are demonstrated as a light source for the next generation photonic integrated circuits. The wide wavelength tuning range (56.2 nm) and single-mode operation (SMSR > 41 dB) for this wavelength range are achieved.

## 16:00-16:15 | In-situ light measurement in heterogeneous gain media (MP2.2)...39

Sudharsanan Srinivasan, Di Liang, Raymond Beausoleil
*Hewlett Packard Enterprise, USA*

We demonstrate the feasibility of using a metal-oxide-semiconductor capacitor (MOSCAP) junction to monitor light inside the gain section of heterogeneous lasers/amplifiers.

## 16:15-16:30 | Lateral optical confinement enhanced GaInAsP membrane laser on Si for on-chip optical interconnection (MP2.3)...41

Naoki Takahashi, Weicheng Fang, Yoshitaka Ohiso, Tomohiro Amemiya, and Nobuhiko Nishiyama
*Tokyo Institute of Technology, Japan*

To reduce energy consumption of GaInAsP membrane laser on Si, we propose to introduce buried-ridge-waveguide (BRW) structure to enhance lateral optical confinement. By comparing the BRW structure with the conventional flat structure, 20 % reduction of threshold current and 35 % of differential resistance were demonstrated.

## 16:30-16:45 | Lasers on an InP/SOI platform with dislocation-free in-plane InP sub-micron bars and membranes (MP2.4)...43

Zhao Yan[1], Yu Han[1], Liying Lin[1], Ying Xue[1], Chao Ma[2], Wai Kit Ng[2], Kam Sing Wong[2], and Kei May Lau[1]

*[1]Department of Electronic and Computer Engineering, Hong Kong University of Science and Technology, China; [2]Department of Physics and William Mong Institute of Nano Science and Technology, Hong Kong University of Science and Technology, China*

We report a monolithic InP on SOI platform through the selective growth of dislocation-free in-plane InP nano-bars and large-dimension membranes on commercial (001) silicon-on-insulator (SOI) wafers. We demonstrated optically pumped InP nano-lasers and micro-disk lasers on this platform.

## 16:45-17:00 | Epitaxially-grown InP micro-ring lasers (MP2.5)...45

Wei Wen Wong[1], Zhicheng Su[1], Naiyin Wang[1], Chennupati Jagadish[1,2], Hark Hoe Tan[1,2]

*[1]Department of Electronic Materials Engineering, The Australian National University, Australia; [2]ARC Centre of Excellence for Transformative Meta-Optical System, The Australian National University, Australia*

We report epitaxially-grown InP micro-ring lasers with a low room-temperature lasing threshold of around 50 μJ cm-2 per pulse. By controlling the vertical ring height and optimizing the cavity design, we demonstrate

tunability of the whispering gallery mode in the micro-ring lasers.

### 17:00-17:15 | Dynamics and tolerance to external optical feedback of III-V/Si hybrid lasers with dispersive narrowband mirror (MP2.6)...47

Mariangela Gioannini[1], Lorenzo L. Columbo[1], Cristina Rimoldi[1], Sebastian Romero-García[2], Jock Bovington[3]

*[1]Politecnico di Torino, Italy; [2]CISCO Optical, Germany; [3]CISCO Systems, USA*

We report how external cavity III-V/Si hybrid lasers operate in regimes of ultra-damped relaxation oscillations or in unstable regimes as consequence to the dispersive mirror, non-zero linewidth enhancement factor and four-wave mixing in the gain medium. Tolerance to external optical feedback is also discussed.

### 17:15-17:30 | Optically-pumped InP quantum dot lasers grown on (001) silicon (MP2.7)...49

Wei Luo, Liying Lin, Jie Huang, Yu Han, Kei May Lau

*Hong Kong University of Science and Technology, China*

In this report, we demonstrated room temperature continuous-wave (CW) lasing of InP quantum dot (QD) microdisk lasers (MDLs) grown on (001) silicon (Si). Ultra-low threshold of 500 nW of MDLs on Si has been achieved without considering the absorption efficiency of pump power.

### 17:30-18:00 | 100-GHz-class directly modulated membrane lasers on SiC substrate | Invited Talk (MP2.8)...51

Suguru Yamaoka[1], Nikolaos-Panteleimon Diamantopoulos[1], Hidetaka Nishi[1], Takuro Fujii[1], Koji Takeda[1], Tatsurou Hiraki[1], Takuma Tsurugaya[1], Shigeru Kanazawa[2], Hiromasa Tanobe[2], Takaaki Kakitsuka[1,3], Tai Tsuchizawa[1], Fumio Koyama[4], and Shinji Matsuo[1]

*[1]NTT Device Technology Labs, NTT Corporation, Japan; [2]NTT Device Innovation Center, NTT Corporation,, Japan; [3]now with Graduate School of Information, Production and Systems, Waseda University, Japan; [4]Tokyo Institute of Technology, Japan.*

We describe directly modulated membrane lasers on high-thermal-conductivity SiC exhibiting a 42 GHz fr and intrinsic 60 GHz bandwidth, thanks to the high optical confinement and low device thermal resistance. Utilizing a photon-photon resonance effect at 95 GHz, we demonstrate a 108 GHz bandwidth and 132 Gbit/s NRZ modulation.

18:00-18:30 | Coffee break

18:30-19:45

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| Session MP3 | Plenary 2 |
| Presiders | Paul Crump and Akihiko Kasukawa<br>*[1]Ferdinand-Braun-Institut gGbmH, Germany;*<br>*[2]Furukawa Electric Co, Japan* |

### 18:30-19:00 | 40 years of progress in high-coherent-power lasers: from antiguided to high-index-contrast photonic-crystal lasers | Legend Talk (MP3.1)...53

Dan Botez

*University of Wisconsin-Madison, USA*

Mode-dependent radiation losses allowed single-element diode lasers to reach 100 mW quasi-CW, single-mode

power (1982). Resonant leaky-wave coupling in ROW arrays, actual photonic-crystal lasers, led to 10 W pulsed and 1.6 W CW near-diffraction-limited powers (2000). Quantum-cascade-laser ROW arrays provide 5.3 W diffraction-limited power (2019).

### 19:00-19:45 | Enabling progress in quantum technology: current and future demands on semiconductor light sources | Plenary Talk (MP3.2)...N/A

Kai Bongs
*University of Birmingham, United Kingdom*

Quantum Sensors are a key emerging technology. An overview is presented of the applications targeted by the UK National Quantum Technology Hub in Sensors and Timing. The demands on semiconductor light sources and photonics arising when moving from low-volume high-value to mass-market opportunities are reviewed.

19:45-21:15 | Dinner (on own)

21:15-23:00

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| Rump session | Material limits for lasers |
| Presider | Paul O. Leisher, *Freedom Photonics, USA* |

# Tuesday, 12 October 2021

08:30-10:15

Session TuA1 PCSEL & functional
Presider Jens Buus, *Retired, Gayton Photonics Ltd. UK*

## 08:30-08:45 | Low-threshold single-mode lasing from InP-based double-lattice photonic crystal surface emitting lasers with high-aspect-ratio air holes (TuA1.1)...55

Yuhki Itoh[1, 2], Naoya Kono[1, 2], Naoki Fujiwara[1, 2], Hideki Yagi[1], Tomokazu Katsuyama[1], Daisuke Inoue[1, 2], Kosuke Fujii[1], Mitsuru Ekawa[1], Hajime Shoji[1], Takuya Inoue[2], Menaka De Zoysa[2], Kenji Ishizaki[2] and Susumu Noda[2]

*[1]Sumitomo Electirc Industries Ltd., Japan; [2]Kyoto University, Japan*

We demonstrate low-threshold and single-mode operation of 1.3-μm-wavelength InP-based photonic-crystal surface-emitting lasers. A low threshold current of 21 mA and a high side-mode suppression ratio of over 50 dB are obtained. The narrow single-lobe-beam emission is achieved by introducing a double-lattice photonic crystal structure.

## 08:45-09:00 | Neural network computing using a large-area VCSEL (TuA1.2)...57

Xavier Porte[1], Anas Skalli[1], Nasibeh Haghighi[2], Stephan Reitzenstein[2], James A. Lott[2], and Daniel Brunner[1]

*[1]Université Bourgogne Franche-Comté CNRS, France ; [2]Technische Universität Berlin, Germany*

We implement a fully parallel photonic neural network based on the spatially distributed modes of a large-area vertical-cavity surface-emitting laser. All photonic connections are realized in hardware and the system is capable of autonomous operation.

## 09:00-09:15 | Mid-IR surface-emitting quantum cascade laser with photonic crystal (TuA1.3)...59

Kei Kaneko[1], Rei Hashimoto[1], Tsutomu Kakuno[1], Shinji Saito[1], Yuanzhao Yao[2], Naoki Ikeda[3], Yoshimasa Sugimoto[2], Takaaki Mano[2], Takashi Kuroda[2], Hirotaka Tanimura[4], Shigeyuki takagi[4], and Kazuaki Sakoda[2]

*[1]Toshiba Corporation, Japan; [2]Research Center for Functional Materials, National Institute for Materials Science, Japan; [3]Research Network and Facility Services Division, National Institute for Materials Science, Japan; [4]Tokyo University of Technology, Japan*

Mid-IR Quantum Cascade Lasers were grown on InP substrates by molecular beam epitaxy, and were evaluated by X-ray diffraction and 3D atom probe tomography. Surface-emission lasing was realized with QCL devices using two-dimensional photonic crystals driven under pulsed operation.

## 09:15-09:30 | Broad-area semiconductor laser for ultrafast parallel random number generation (TuA1.4)...61

Stefan Bittner[1], Kyungduk Kim[2], Yongquan Zeng[3], Stefano Guazzotti[4], Ortwin Hess[4], Qi Jie Wang[3], Hui Cao[2]

*[1]CentraleSupélec and Université de Lorraine, France; [2]Yale University, USA; [3]Nanyang Technological University, Singapore; [4]Trinity College Dublin, Ireland*

We present random bit generation in 127 parallel bit streams with a total rate of 250 Tb/s from a broad-area semiconductor laser in data post-processing. The special stable-cavity geometry allows lasing in hundreds of transverse modes, creating a spatio-temporal emission pattern with random, ultra-fast fluctuations.

### 09:30-09:45 | Band structure of holographically modulated photonic crystal lasers (TuA1.5)...63

Kazuyoshi Hirose, Yoshitaka Kurosaka, Hiroki Kamei, and Takahiro Sugiyama
*Hamamatsu Photonics K.K., Japan*

A band structure is caused by scattering of a periodic structure. Here, we show photonic band structures can be replicated in arbitrary wavevectors using holographic modulation of photonic crystal lasers where each air hole is locally shifted from a lattice point in a holographic manner.

### 09:45-10:00 | Circular beam oxide-confined high-index-contrast ridge waveguide edge-emitting lasers (TuA1.6)...65

Jinyang Li[1], Justin Welter[1], Paul Leisher[2], Douglas C. Hall[1]
*[1]University of Notre Dame, USA; [2]Freedom Photonics LLC, USA*

We demonstrate deep-etched oxide-confined 870 nm AlGaAs HIC RWG edge-emitter lasers with stable single-spatial-mode total output >165 mW. With 3.25 µm ridges, ~0.5 µm of sidewall-smoothing oxide yields a nearly perfect 1.9 µm 1/e2 circular mode and circularly symmetric ~30° FWHM, M2~1.2 output beam.

### 10:00-10:15 | Linewidth reduction of a semiconductor laser nodule to 6 Hz by locking to a fiber Mach-Zehnder interferometer (TuA1.7)...67

Artiom Sydnev, Gadi Eisenstein
*Russell Berrie Nanotechnology Institute, Israel*

We demonstrate large linewidth reduction in semiconductor lasers, from 20 kHz to the single-Hz regime, by locking to an unstabilized all-fiber Mach-Zehnder interferometer with a short path length imbalance. The results rival solutions using scrupulously stabilized ultra-high-Q cavities thereby enabling new practical applications for highly-coherent sources.

10:15-10:45 | Coffee break

10:45-12:45

| | |
|---|---|
| Session TuA2 | THz/QCL |
| Presider | Mathieu Bertrand, *ETH Zurich, Switzerland* |

### 11:00-11:15 | Femtosecond pulses from a mid-infrared quantum cascade laser (TuA2.2)...69

Philipp Täschler, Mathieu Bertrand, Barbara Schneider, Matthew Singleton, Pierre Jouy, Mattias Beck, Jérôme Faist
*ETH Zurich, Switzerland*

We report on the generation of near-transform-limited femtosecond pulses from a mid-infrared quantum cascade laser by external pulse compression. The temporal nature of these pulses is assessed by means of a novel optical sampling method, coherent beatnote interferometry and interferometric autocorrelation.

### 11:15-11:30 | Reverse-taper mid-IR quantum cascade lasers for coherent power scaling (TuA2.3)...71

Jae Ha Ryu[1], Benjamin Knipfer[1], Jeremy D. Kirch[1], Robert A. Marsland[2], Steve Jacobs[2], Dan Botez[1], Tom Earles[2], Morgan Turville-Heitz[2], Chris Sigler[1], Axel Strömberg[3], Yan-Ting Sun[3], Sebastian Lourdudoss[3], and Luke J. Mawst[1*]
*[1]Univ. of Wisconsin-Madison, USA; [2]Intraband LLC, USA; [3]KTH-Royal Institute of Technology, Sweden*

Novel-geometry, 4.6 µm-emitting BH QCLs were fabricated, where a tapered region scales the output power and, ahead of the emitting aperture, a narrow section provides mode filtering for suppressing high-order spatial modes. Beam-stability measurements indicate a small degree of collimated-beam centroid motion (< 0.25 mrad).

### 11:30-11:45 | Over 1 Watt THz QCLs with high doping concentration and variable Al composition in active structure (TuA2.4)...73

Tsung-Tse Lin[1], Li Wang[1], Ke Wang[2,1], Thomas Grange[3], Stefan Birner[3], and Hideki Hirayama[1]
*[1]RIKEN Center for Advanced Photonics (RAP), Japan; [2]Nanjing University, China; [3]Nextnano GmbH, Germany*

A 1.31 W peak power and 52 mW average power THz QCL is presented by variable Al composition active structure with high doping concentration based on NEGF method design. Device has thick growth active layers and large mesa size with the consideration of heat dissipation.

### 11:45-12:00 | Lateral far-field characteristics of interband cascade laser frequency combs (TuA2.5)...75

Lukasz A. Sterczewski[1,2], Mahmood Bagheri[1], Clifford Frez[1], Mathieu Fradet[1], Igor Vurgaftman[3], Charles D. Merritt[3], Chadwick L. Canedy[3], Chul Soo Kim[3], Mijin Kim[4], William W. Bewley[3], and Jerry R. Meyer[3]
*[1]California Institute of Technology, USA; [2]Wroclaw University of Science and Technology, Poland; [3]Naval Research Laboratory, USA; [4]Jacobs Corporation, USA*

The far-field characteristics of mid-infrared interband cascade laser frequency combs with different ridge widths are studied. We find that narrow-ridge devices that suffer from pronounced modal leakage exhibit anomalous deterioration of the vertical far-field profile, with periodically-occurring fringes.

### 12:00-12:15 | Design, fabrication and characterisation of monolithic, optically-coupled, multi-section mid-IR quantum cascade lasers (TuA2.6)...77

Kamil Pierściński, Dorota Pierścińska, Grzegorz Sobczak, Aleksandr Kuźmicz, Piotr Gutowski, Krzysztof Chmielewski
*Łukasiewicz Research Network - Institute of Microelectronics and Photonics, Poland*

In this work design, fabrication and characterization of multi-section, coupled cavity mid-IR quantum cascade lasers is presented. To achieve stable, single mode emission 3-section coupled cavity QCL design is proposed. Devices allow tuning of ~3 cm-1 with 35 dB side mode suppression ratio.

### 12:15-12:45 | Frequency comb generation with inter-band cascade lasers | Invited Talk (TuA2.7)...N/A

Benedikt Schwarz
*TU Wien, Austria*

Frequency combs are ideal candidates to build chip integrated spectrometers without moving parts. I will give an overview on comb generation in the mid-infrared using interband cascade lasers, including self-starting frequency modulated combs and actively mode-locked combs for picosecond pulse generation.

### 12:45-13:45 | Lunch break

13:45-15:00

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|---|---|
| Session TuP1 | Plenary 3 |
| Presiders | Paul Crump and Akihiko Kasukawa<br>[1]*Ferdinand-Braun-Institut gGmbH, Germany,*<br>[2]*Furukawa Electric Co, Japan* |

## 14:15-15:00 | Micro- and nano-scale semiconductor lasers | Plenary Talk (TuP1.2)...N/A

Toshihiko Baba
*Yokohama National University, Japan*

This presentation gives an overview of miniature semiconductor lasers, including VCSEL, microdisk, photonic crystal, plasmonics and related structures. It discusses the phenomena arising from a tiny cavity close to the optical wavelength and comparably small active region, and applications to interconnects, computing and sensing.

15:00-15:30 | Coffee break

15:30-17:45

| | |
|---|---|
| Session TuP2 | High power 1 |
| Presider | Berthold Schmidt, *TRUMPF Laser Technology GmbH* |

## 15:30-15:45 | Highly asymmetric epitaxial designs for increased power and efficiency in kW-class GaAs-based diode laser bars (TuP2.1)...79

Md. Jarez Miah, Anisuzzaman Boni, Dominik Martin, Pietro Della Casa, and Paul Crump
*Ferdinand-Braun-Institut gGmbH, Germany*

1-cm single quantum well laser bars at 910-940 nm wavelengths are presented, using extremely asymmetric layer designs for increased power. In quasi-CW testing, bars with 4 mm resonators provide output power >1.8 kW with 67 % maximum efficiency at 298 K and >2.2 kW with 74 % maximum efficiency at 203 K.

## 15:45-16:00 | Origin of the longitudinal current crowding effect in high power diode lasers (TuP2.2)...81

Paul O. Leisher, Michelle Labrecque, Kevin McClune, Elliot Burke, Daniel Renner, and Jenna Campbell
*Freedom Photonics LCC, USA*

Longitudinal current crowding is a recently discovered power saturation phenomenon in edge emitting diode lasers. We present results showing the root cause of this effect is nonuniformity in the longitudinal temperature distribution and that controlling the longitudinal current profile significantly affects laser efficiency.

## 16:00-16:15 | Efficiency optimization of high-power GaAs lasers by balancing confinement and threshold (TuP2.3)...83

Anisuzzaman Boni, Pietro Della Casa, Dominik Martin and Paul Crump
*Ferdinand-Braun-Institut gGmbH, Germany*

Studies balancing modal gain (confinement) and facet reflectivity in high power 940 nm lasers using extreme-triple-asymmetric epitaxial designs enable > 70% efficiency at 12 W output and low temperature sensitivity. Insight into carrier losses that limit device performance are discussed.

## 16:15-16:30 | Investigations on operational reliability of 808 nm QCW laser diode half-bars for space-borne applications (TuP2.4)...85

Karl Häusler, Christoph Stölmacker, Andre Maaßdorf, Peter Ressel, Ralf Staske, Günther Tränkle and Paul Crump
*Ferdinand-Braun-Institut gGmbH, Germany*

Laser diode half-bars with 16 emitters were manufactured and qualified for pulsed high-power operation on the satellite MERLIN. Stress accelerated life tests of 20 laser half-bars were performed for 5·109 shots. No single emitter failure was detected resulting in 99.99 % reliability over mission lifetime.

## 16:30-16:45 | The impact of longitudinal spatial hole burning on the carrier density profile in high-power lasers (TuP2.5)...87

Seval Arslan[1], Hans Wenzel[1], Jörg Fricke[1], Andreas Thies[1], Arnim Ginolas[1], Andre Maaßdorf[1], Christopher Mayo[2], Bernd Eppich[1], Günther Tränkle[1], Paul Crump[1]
*[1]Ferdinand-Braun-Institut gGmbH, Germany; [2]University of Surrey, UK*

Spatially resolved spontaneous emission intensity and spectrum were used to demonstrate the longitudinal-spatial-hole-burning (LSHB)-induced non-uniform carrier density along the resonator in high power lasers. The impact of high bias is analyzed. Spontaneous emission spectra are calculated to separate the effect of carrier density, and temperature.

## 16:45-17:00 | Narrow lateral far field divergence obtained with spatially modulated broad-area lasers (TuP2.6)...89

Anissa Zeghuzi[1], Jan-Philipp Koester[1], Mindaugas Radziunas[2], Heike Christopher[1], Hans Wenzel[1*], Andrea Knigge[1]
*[1]Ferdinand-Braun-Institut gGmbH, Germany; [2]Weierstrass Institute for Applied Analysis and Stochastics, Germany*

A laser design combining longitudinal-lateral gain-loss modulation with additional phase tailoring is presented. Under pulsed operation simulations predict a single-lobed far field angle of = 0.4° at 100 A and far-field measurements confirm a substantial enhancement of radiation within the central angular range.

## 17:00-17:15 | Demonstration of high brightness and reliability at 20 W from a 976 nm, 150 µm emitter width laser diode (TuP2.7)...91

Xi Liu, Ayesha Jamil, Ching-long Jiang, Joseph Nguturi, Yihan Xiong, Xiaohang Liu, Stewart McDougall
*TRUMPF Photonics Inc, USA*

We show operation at 20 W of a 150 µm, 976 nm chip with beam parameter product 5.5 mm.mrad designed for application in a 200 W, 130 µm fiber laser pump, NA<0.18. With accelerated life test data we predict MTTF of 172 khrs operation at this power.

## 17:15-17:45 | Coherent beam combining architectures for high-power laser semiconductor sources | Invited Talk (TuP2.8)...N/A

Gaëlle Lucas-Leclin
*Universite Paris-Saclay, France*

Coherent beam combining consists in the constructive addition of optical laser fields, which results in the increase of the total optical power while maintaining the spectral and spatial properties of the beams. We describe our recent achievements with high-brightness tapered amplifiers under different operation regimes.

17:45-19:00

Session TuP3 Poster presentations (in person)
Presider Erwin Bente, *Eindhoven University of Technology, The Netherlands*

Pablo López-Querol, Clara Quevedo-Galán, Antonio Pérez-Serrano, Jose Manuel G. Tijero, Ignacio Esquivias
*Universidad Politécnica de Madrid, Spain*

We report flat and wide low-frequency Optical Frequency Combs generated by pulsed gain-switching of optically injected semiconductor lasers. Combs as wide as 133 GHz at 100 MHz repetition rate and good quality combs at a record low frequency of 10 MHz were obtained.

## Quantum optical characterization of high-$\beta$ silver-coated InGaAsP-based multiple quantum well metallic nanolasers (TuP3.7)...105

A. Koulas-Simos[1], K. Laiho[1], G. Sinatkas[1,2], T. Zhang[3], J. Xu[3], J Buchgeister[4], M. Drechsler[4], F. Lohof[4], C. Gies[4], W. W. Chow[5], F. Jahnke[4], C.-Z. Ning[2,6] and S. Reitzenstein[1]

*[1]Technische Universität Berlin, Germany; [2]Aristotle University of Thessaloniki, Greece; [3]Tsinghua University, China; [4]University of Bremen, Germany; [5]Sandia National Laboratories, USA; [6]Arizona State University, USA.*

We verify the transition from thermal to coherent emission in excitation-dependent optical measurements on InGaAsP-based multiple quantum well (MQW) metallic nanolasers under continuous-wave excitation in the thresholdless regime and observe distinctive lasing features for the resonance modes through temperature-dependent series with excellent theoretical agreement.

## Frequency comb operation of a Y-coupled planarized THz quantum cascade laser (TuP3.9)...107

Urban Senica, Tudor Olariu, Paolo Micheletti, Mattias Beck, Jérôme Faist, Giacomo Scalari
*ETH Zurich, Switzerland*

We present a Y-coupled planarized double metal waveguide THz quantum cascade laser, featuring frequency comb operation and broadband phase locking of the two arms, as confirmed by characteristic interference patterns measured in the far-field.

## Shifted wave interference fourier transform spectroscopy of harmonic and fundamental RF injection-locked THz quantum cascade laser frequency combs (TuP3.10)...109

Andres Forrer[1], Sara Cibella[2], Urban Senica[1], Guido Torrioli[2], Mattias Beck[1], Jérôme Faist[1], Giacomo Scalari[1]

*[1]ETH Zürich, Switzerland; [2]CNR-Istituto di Fotonica e Nanotecnologie, Italy*

Shifted Wave Interference Fourier Transform Spectroscopy allows us to reveal the temporal intensity profiles of RF injection-locked fundamental and harmonic comb states of a broadband, multi-stack THz Quantum Cascade Laser. Depending on the injection power and frequency AM and FM modulated emission can be observed.

## Direct measurement of the linewidth enhancement factor of distributed feedback mid-IR QCLs (TuP3.11)...111

Mathieu Bertrand, Martin Franckié, Andres Forrer, Mattias Beck, Jérôme Faist
*ETH Zürich, Switzerland*

The measurement of the linewidth enhancement factor of mid-IR DFB-QCL assisted by shifted-waves interference Fourier Transform spectroscopy together with its modeling give us insight of the mechanisms responsible on the broadening of the emission and the comb formation process.

## THz intersubband emitter based on silicon (TuP3.12)...113

David Stark[1], Muhammad Mirza[2], Luca Persichetti[3], Michele Montanari[3], Sergej Markmann[1], Mattias Beck[1], Thomas Grange[4], Stefan Birner[4], Michele Virgilio[5], Chiara Ciano[3], Michele Ortolani[6], Cedric Corley[7], Giovanni Capellini[3,7], Luciana Di Gaspare[3], Monica De Seta[3], Douglas J. Paul[2], Jérôme Faist[1],

and Giacomo Scalari[1]

[1]*ETH Zürich, Switzerland;* [2]*University of Glasgow, United Kingdom;* [3]*Universita Roma Tre, Italy;*
[4]*Inextnano GmbH, Germany;* [5]*Universita di Pisa, Italy;* [6]*Sapienza University of Rome, Italy;*
[7]*IHP - Leibniz-Institut für innovative Mikroelektronik, Germany*

We present THz quantum cascade emitters realized on a Si substrate. The emission centered at 3.4 and 4.9 THz originates from L-valley transitions in strain-compensated n-type Ge/SiGe heterostructures. This is an important step towards the realization of Si-based THz quantum cascade lasers.

## Terahertz quantum cascade detection through regenerative amplification (TuP3.13)...114

Paolo Micheletti, Jerome Faist, Tudor Olariu, Mattias Beck, Giacomo Scalari
*ETH Zurich, Switzerland*

The photon-driven nature of the transport in terahertz quantum cascade laser can be exploited to detect light. Responsivities higher than 15 V/W are demonstrated on a patch-array antenna coupled device. The ~ps lifetimes also allows ultrafast operation. Preliminary studies suggest bandwidth higher than 5 GHz.

## Microsecond-pulse master oscillator – power amplifier at 828 nm for a water-vapor differential absorption lidar (TuP3.14)...116

Sylvie Janicot[1], Qin Liu[1], Jeremy Lagarrigue[2], Patrick Chazette[2], Julien Totems[2], Gaëlle Lucas-Leclin[1]

[1]*Université Paris-Saclay, Institut d'Optique Graduate School, CNRS, Laboratoire Charles Fabry, France;* [2]*Université Paris-Saclay, Laboratoire des Sciences du Climat et de l'Environnement (LSCE), CEA-CNRS-UVSQ, France*

We describe the design and characterization of a master oscillator – power amplifier laser system operating under µs-pulse regime at 828 nm, with a view to its integration in an airborne lidar for tropospheric water-vapor measurements. The output energy reaches 6.2 µJ per pulse.

## Quantum Cascade Lasers emitting at ~11 µm band with mirrors formed by etching (TuP3.15)...N/A

Grzegorz Sobczak[1]*, Krzysztof Chmielewski[1], Patryk Mitura[1], Katarzyna Krajewska[1], Michał Nagowski[1], Krzysztof Michalak[1], Joanna Branas[1], Aleksandr Kużmicz[1], Piotr Gutowski[1], Dorota Pierścińska[1], Kamil Pierściński[1]

[1]*Łukasiewicz Research Network – Institute of Microelectronics and Photonics, Poland*

Coupled cavity quantum cascade lasers emitting at ~11 µm with uncleaved rear mirror are presented. In such design the reactive ion etching has been used for rear mirror defining. The optoelectrical and spectral characteristics are shown in comparison with typical laser with cleaved mirrors.

19:30-21:00 | Conference banquet, including award presentation and hand-over to ISLC 2022

Mövenpick Restaurant, Zur Historischen Mühle

# Wednesday, 13 October 2021

08:30-09:45

Session WA1 — Communication lasers
Presiders — Milan Mashanovitch[1] and Nobu Nishiyama[2]
*[1]Freedom Photonics, USA; [2]Tokyo Institute of Technology, Japan*

## 08:30-08:45 | 38-fJ/bit direct modulation of a 5-µm-long active region membrane DBR laser on SiO2/Si substrate (WA1.1)...118

Erina Kanno[1], Koji Takeda[1], Takuro Fujii[1], Takaaki Kakitsuka[1, 2] and Shinji Matsuo[1]
*[1]NTT Corporation, Japan; [2]Now with Waseda University, Japan*

We fabricated a 5-µm-long active region DBR laser integrated with a spot-size convertor on a $SiO_2$/Si substrate. The device exhibits a threshold current of 51 µA, maximum fiber coupled output power of 76 µW, and 38-fJ/bit energy cost with 25.8 Gbit/s NRZ signal modulation.

## 08:45-09:00 | 106 Gb/s PAM4 uncooled operation (25-85 ºC) of directly modulated DFB lasers in the CWDM range (WA1.2)...120

Masaru Onga, Takayuki Nakajima, Yuji Sekino, Akira Nakanishi, Noriko Sasada, Ryosuke Nakajima, Hironori Sakamoto, and Kazuhiko Naoe
*Lumentum Japan, Inc., Japan*

106-Gb/s PAM4 operation was demonstrated from 25 to 85 ºC using four directly modulated DFB lasers over a 1.3 µm CWDM range. Eye openings were achieved in BTB and after 500 m and 2 km SMF transmissions up to 85 ºC.

## 09:00-09:15 | Low-phase-noise optical negative feedback laser for long-distance ranging with high signal-to-noise ratio (WA1.3)...122

Nobuhide Yokota, Hiroki Kiuchi, Hiroshi Yasaka
*Tohoku University, Japan*

We demonstrate FMCW LiDAR measurements using a low-phase-noise optical negative feedback laser with a minimum phase noise of $1\times10^3$ $Hz^2/Hz$. A ranging with a fiber length of 124 m and signal-to-noise ratio of 23 dB is achieved by directly modulating the optical negative feedback laser.

## 09:15-09:30 | Analysis of the relative intensity noise in a Fabry-Perot interband cascade laser revealing relaxation oscillations (WA1.4)...124

Pierre Didier[1,2], Olivier Spitz[1], Daniel Andres Diaz-Thomas[3], Alexei N. Baranov[3], Laurent Cerutti[3], Frédéric Grillot[1,4]
*[1]Télécom Paris, France; [2]Centre d'intégration NanoInnov, France; [3]Université de Montpellier, France; [4]University of New-Mexico, USA*

ICLs are promising mid-infrared semiconductor lasers that could address many applications. However, current knowledge about their intrinsic properties is scarce. Here, we demonstrate a clear relaxation process when studying the noise properties of an ICL, which contributes to the fundamental characterization of this semiconductor structure.

09:30-09:45 | Type-II GaAs1-xBix/GaNyAs1-y “W” quantum wells for strain-compensated GaAs-based telecom lasers (WA1.5)...126

Zoe C. M. Davidson[1*], Thilo Hepp[2], Judy M. Rorison[1], Stephen J. Sweeney[3], Kerstin Volz[2], and Christopher A. Broderick[4,5]

*[1]University of Bristol, U.K.; [2]Philipps-Universitat Marburg, Germany; [3]University of Surrey, U.K.;*
*[4]Tyndall National Institute, University College Cork, Ireland;*
*[5]Department of Physics, University College Cork, Ireland*

We discuss a new class of type-II quantum wells (QWs) that exploit the impact of Bi and N on the GaAs band-structure. Via growth, experiment, and theoretical calculations we highlight the properties of $GaAs_{1-x}Bi_x/GaN_yAs_{1-y}$ “W” QWs, demonstrating a potential pathway to uncooled telecom-wavelength laser operation.

09:45-10:15 | Coffee break

10:15-12:30

Session WA2 PICs & tunable
Presiders Ute Troppenz[1] and Eugene Avrutin[2]
*[1]Fraunhofer-Instituts für Nachrichtentechnik, Germany;*
*[2]University of York, United Kingdom*

10:15-10:30 | 2 µm wavelength superstructure grating active DBR laser with < 2.5 dB fluctuation of light intensity across whole tuning range of over 50 nm (WA2.1)...128

Takahiko Shindo[1], Yuta Ueda[1], Makoto Shimokozono[2], Tomonari Sato[2], Wataru Kobayashi[2], Shigeru Kanazawa[1], Mingchen Chen[1], and Hideaki Matsuzaki[2]

*[1]NTT Device Innovation Center, NTT Corporation, Japan; [2]NTT Device Technology Labs, NTT Corporation, Japan*

We could demonstrate a 2.0 µm wavelength superstructure grating active DBR laser with stable single mode operation and small fluctuations of light intensity < 2.5 dB across a whole tuning range of over 50 nm due to the power compensation effect of the active DBR structure.

10:30-10:45 | SGDBR tunable laser on gallium arsenide for 1030 nm lidar applications (WA2.2)...130

Paul Verrinder[1], Lei Wang[1], Fengqiao Sang[1], Joseph Fridlander[1], Victoria Rosborough[1], Michael Nickerson[1], Guangning Yang[2], Mark Stephen[2], Larry Coldren[1], Jonathan Klamkin[1]

*[1]University of California, USA; [2]NASA Goddard Space Flight Center, USA*

A sampled grating distributed Bragg reflector tunable laser with a center wavelength of 1032 nm is demonstrated on a gallium arsenide photonic integrated circuit platform. The laser demonstrates a 32 nm tuning range, 37 dB side-mode suppression ratio, and 20 mW of output power.

10:45-11:00 | 10-Hz-intrinsic-linewidth hybridly-integrated semiconductor ring laser using generic foundry platforms (WA2.3)...132

Daniel N. Duplat[1], Mónica Far Brusatori[1], Iterio Degli-Eredi[1], Lars Nielsen[1], Peter L. Tønning[1], Nicolas Volet[1], Martijn J. R. Heck[1,2]

*[1]Aarhus University, Denmark; [2]Eindhoven University of Technology, The Netherlands*

This work demonstrates a 10-Hz-linewidth hybridly-integrated semiconductor ring laser with an internal high-Q $Si_3N_4$ disc resonator using commercially available generic foundry platforms: an active III-V platform for InP combined with a passive low-loss platform for $Si_3N_4$.

### 11:00-11:15 | Data-driven model to extend tuning range: from 1474 nm to 1568 nm in a monolithic laser (WA2.4)...134

Rastko Pajković, Tom Reep, Kevin Williams, Erwin Bente
*Technical University of Eindhoven, The Netherlands*

A monolithic laser with a variable outcoupler is tuned from 1474 nm to 156 nm. A data-driven model was developed that accurately predicts the laser tuning range. This model shows that a 4-arm filter and a variable outcoupler can increase the tuning range over 120 nm.

### 11:15-11:30 | C-band tunable dual-wavelength laser with a quantum Dot SOA (WA2.5)...136

Wataru Masuda[1], Kissho Iwanaga[1], Atsushi Matsumoto[2], and Tomohiro Kita[1]
*[1]Waseda University, Japan; [2]National Institute of Information and Communications Technology, Japan*

A C-band tunable dual-wavelength laser for a RoF light source is demonstrated. The difference frequency was tunable in the range of 22.6 GHz to 192.0 GHz. The generated dual-wavelength laser amplified by EDFA could be converted to a corresponding radio frequency through a high-speed photodetector.

### 11:30-11:45 | 33 nm wavelength tuning of a 1550 nm VCSEL in CW operation based on the liquid crystal micro-cells technology (WA2.6)...138

C. Paranthoen[1], C. Levallois[1], B. Boisnard[2], T. Camps[2], J.-B. Doucet[2], K. Tavernier[1], N. Chevalier[1], S. Bouchoule[3], L. Dupont[4], M. Alouini[1], and V. Bardinal[2]
*[1]Univ Rennes, INSA Rennes, CNRS, France; [2] Univ Toulouse, CNRS, France; [3]Université Paris-Sud, France; [4]IMT Atlantique, France*

We present CW operation of a tunable InP based Vertical Cavity Surface Emitting Laser, integrating a liquid crystal micro-cell. In comparison with previous work, a larger 33 nm tuning and stable operation are obtained, according to major improvements presented in this paper.

### 11:45-12:00 | A six-section photonic integrated transmitter with chirp control for transmission reach extension (WA2.7)...140

Ankit Sharma[1, 2], Mohab N. Hammad[1], Aleksandra Kaszubowska-Anandarajah[3, 1], Gaurav Jain[2], Michael Wallace[2], Jules Braddell[2], Frank Smyth[2] and Prince M. Anandarajah[1, 3]
*[1]Photonics Systems and Sensing Lab., Dublin City University, Ireland;*
*[2]Pilot Photonics, Dublin City University, Ireland;*
*[3]CONNECT Research Centre, Trinity College Dublin, Ireland*

We demonstrate direct modulation of a six-section PIC, with a unique master-slave architecture for chirp reduction. This enables transmission of 10 Gb/s signals over 50 km of fiber with a BER below the HD-FEC limit.

### 12:00-12:30 | Integrated phase-locked lasers and photonic integrated circuits for remote gas sensing | Invited Talk (WA2.8)...142

Jonathan Klamkin[1], Fengqiao Sang[1], Joseph Fridlander[1], Victoria Rosborough[1], Fabrizio Gambini[2], Simone Tommaso Šuran Brunelli[1], Larry Coldren[1], Jeffrey R. Chen[2], Stephan Kawa[2], Kenji Numata[2], Mark Stephen[2]
*[1]University of California Santa Barbara, USA; [2]NASA Goddard Space Flight Center, USA*

An indium phosphide photonic integrated circuit for integrated path differential absorption lidar remote gas sensing was developed. Phase locking of the two integrated lasers and measurement of a carbon dioxide absorption line centered at 1572.335 nm was demonstrated.

12:30-13:30 | Lunch break

13:30-14:45

Session WP1 — Poster presentations (virtual) & international networking

Presider — Erwin Bente,
*Eindhoven University of Technology, The Netherlands*

InGaAs/AlGaAs based broad stripe LDs that have failed during the operation with external optical feedback has been investigated. Unusual failure which is accompanied by the extension of DLD from rear-facet to front has been confirmed. Failure mechanism of rear-facet DLD is discussed.

## Mico-photoluminescence of surface plasmon enhanced emissions from semi-polar InGaN/GaN quantum wells (WP1.6)...154

Kento Ikeda[1*], Kanata Kawai[1], Tetsuya Matsuyama[1], Kenji Wada[1], Narihito Okada[2], Kazuyuki Tadatomo[2], Koichi Okamoto[1]

*[1]Osaka Prefecture University, Japan; [2]Yamaguchi University, Japan*

We have reported that enhancement of blue/green emission by SP resonance of InGaN/GaN quantum wells (QWs) on the polar-GaN substrate. In this study, we investigate SP enhanced light emissions also for InGaN/GaN QWs on semi-polar GaN substrate, where further enhancements can be expected.

## Experimental research of optical absorption in semiconductor laser waveguide layers (WP1.7)...156

Yulia K.Bobretsova, Dmitrii A.Veselov, Natalia A.Rudova, Natalia V.Voronkova, Marina G.Rastegaeva, Sergei O.Slipchenko, Nikita A.Pikhtin

*Ioffe Institute, Russia*

We measure the free-carrier absorption in heterostructures simulating $Al_{0.23}Ga_{0.77}As$ laser waveguide via probe radiation coupling. The obtained spectral, temperature and carrier concentration dependences of the absorption coefficient are presented.

## Heterostructure designs for high-power 1450 nm lasers (WP1.8)...158

Dmitrii Veselov[1], Yulia Bobretsova[1], Andrey Lyutetskii[1], Kirill Bakhvalov[1], Maxim Ladugin[2], Yuri Ryaboshtan[2], Nikita Volkov[2], Vladimir Svetogorov[2], Alexander Marmalyuk[2], Sergei Slipchenko[1], Nikita Pikhtin[1]

*[1]Ioffe Institute, Russia; [2]Sigm Plus Co., Russia*

The experimental results of 1450 nm high-power semiconductor laser heterostructures development are presented. Via optimizing doping concentration profile and active region design we achieved the increase of pulse output power from 9 to 25 W, and high temperature stability: $T_0$=70 K, $T_1$=330 K.

## Tunable operating regimes in passively mode-locked QD laser under CW optical injection (WP1.9)...160

Ana Filipa Ribeiro, Adam Forrest, Maria Ana Cataluna

*Heriot-Watt University, United Kingdom*

We present three distinct regimes, locked mode-locking, locked Q-switching, and locked multiple pulsing, in a passively mode-locked quantum-dot laser under CW optical injection. These regimes are shown to be dependent on the bias conditions of the quantum-dot laser and tunable with injection wavelength.

14:45-15:15 | Coffee break

15:15-17:15

Session WP2 High power 2
Presider Martin Behringer, *OSRAM GmbH, Germany*

## 15:15-15:30 | 29-W continuous-wave operation of photonic-crystal surface-emitting laser (PCSEL) (WP2.1)...191

Shumpei Katsuno[1], Masahiro Yoshida[1], Koki Izumi[1], Takuya Inoue[2], Kenji Ishizaki[1], Menaka De Zoysa[2], Ranko Hatsuda[1], John Gelleta[1], Kentaro Enoki[3], and Susumu Noda[1,2]

*[1]Department of Electronic Science and Engineering, Kyoto University, Japan;*
*[2]Photonics and Electronics Science and Engineering Center, Kyoto University, Japan;*
*[3]On leave from Mitsubishi Electric Corporation, Japan, to Kyoto University*

We demonstrate 29 W continuous-wave operation of a photonic-crystal surface-emitting laser with a double lattice structure and a circular resonator diameter of 2 mm. A very narrow divergence angle operation (<0.4°) has been successfully achieved even at 29 W of output power.

## 15:30-15:45 | Surface grating loaded VCSEL-integrated amplifier/beam scanner with quasi-single mode output power of over 4 W and scan resolution of over 200 (WP2.2)...193

Shanting Hu[1], Xiaodong Gu[1,2], Ahmed Hassan[1,3], Masanori Nakahama[1,2] Satoshi Shinada[4] and Fumio Koyama[1]

*[1]Tokyo Institue of Technology, Japan; [2]Ambition Photonics Inc., Japan; [3]Al-Azhar University, Assuit, Egypt;*
*[4]National Institute of Information and Communications Technology, Japan*

We demonstrate a 1st-order surface-grating loaded VCSEL-integrated amplifier/beam scanner. A record quasi-single-mode power of over 4 W under pulsed operations are achieved. We also obtained a continuous fan-beam steering of 9°, a diffraction-limited beam divergence angle of 0.04° and hence over 200 resolution points.

## 15:45-16:00 | High-power VCSEL-array with integrated backside optics (WP2.3)...195

Stephan Gronenborn, Xi Gu, Markus Herper, Johanna Kolb, Stefan Wabra, Alexander Weigl, Roman Koerner and Armand Pruijmboom

*TRUMPF Photonic Components GmbH, Germany*

We present a 940 nm-emitting VCSEL-array with integrated optics to tailor the beam to a square shaped top-hat far-field profile. The presented array is realized on a technology platform enabling a huge variety of integrated optics to allow flexible beam shaping without additional optics.

## 16:00-16:15 | 2.7 W continuous wave nearly-diffraction-limited output 1550 nm tapered laser diode amplifier (WP2.4)...197

Jenna Campbell, Michelle Labrecque, Daniel Renner, Leif Johannson, Milan Mashanovitch, and Paul O. Leisher

*Freedom Photonics LCC, USA*

We have demonstrated world record diffraction-limited output from a 1550 nm tapered diode laser. Over 2.7 W continuous wave is achieved at room temperature. The result is enabled by a novel structured contact which permits geometric scaling of the chip dimensions while preserving beam quality.

### 16:15-16:30 | 940 nm high power single transverse mode coherent VCSEL array with tunnel junction lithographic aperture (WP2.5)...199

Antoine Pissis[1,2], Urs Siegenthaler[1], Donato Bonfrate[1], Pratyush Das Kanungo[1], Evgeny Zibik[1]
*[1]II-VI Laser Enterprise, Switzerland; [2]University of Glasgow, UK*

We report a high power single transverse mode coherent VCSEL array emitting at ~940 nm. The phase coupled emitters are defined by patterning a tunnel junction located in the cavity. Single transverse mode power of ~12.5 mW out of an array with 7 emitters is demonstrated.

### 16:30-16:45 | Watt-class, COMD-free ridge waveguide lasers at 885 nm (WP2.6)...201

Jenna Campbell, Michelle Labrecque, Fatt Foong, Daniel Renner, Milan Mashanovitch, and Paul Leisher
*Freedom Photonics, USA*

Mitigation of catastrophic optical mirror damage is critical to scaling the output power of diffraction-limited ridge waveguide diode lasers. A novel long cavity facet-passivated 885 nm diode laser delivers a record output power of >1.8 W with extreme robustness.

### 16:45-17:00 | High-power single-mode VCSEL-array (WP2.7)...203

Sven Bader, Alexander Weigl, Robert van der Kloet, Stephan Gronenborn, Markus Herper, Ulrich Weichmann, Roman Koerner and Armand Pruijmboom
*TRUMPF Photonic Components GmbH, Germany*

We present a 940 nm-emitting VCSEL-array with 12 emitters for high optical output powers. The output characteristics show spectral single-mode behavior as well as a Gaussian-shaped far-field profile. The densely packed emitter design measures up to 3850 emitters/mm$^2$ and is easily scalable for high-power applications.

### 17:00-17:15 | Injection- and temperature-dependence of type-II 1.2-1.3 µm (GaIn)As/Ga(AsSb) “W”-lasers (WP2.8)...205

Dominic A. Duffy[1], Igor P. Marko[1], Christian Fuchs[2], Timothy D. Eales[1], Jannik Lehr[2], Wolfgang Stolz[2], and Stephen J. Sweeney[1]
*[1]University of Surrey, United Kingdom; [2]Philipps-Universität Marburg, Germany*

Type-II (GaIn)As/Ga(AsSb) “W”-lasers offer the possibility to develop efficient and thermally stable near-infrared lasers. In this work, we investigate the temperature- and injection-dependent properties of “W”-lasers operating between 1200-1260 nm and use this to quantify the influence of radiative and non-radiative recombination on device performance.

17:15-17:45 | Coffee break

17:45-19:15

Session WP3
Presiders

Memorial talks (PDPs + poster prize award + closing remarks)
Paul Crump and Akihiko Kasukawa
[1]*Ferdinand-Braun-Institut gGmbH, Germany;*
[2]*Furukawa Electric Co, Japan*

## 17:45-18:00 | A tribute to Markus Amann (WP3.1)...N/A

Ralf Meyer
*Walter Schottky Institut, Technische Universität München, Germany*

Markus-Christian Amann made major contributions to numerous aspects of semiconductor laser theory, design and technology over a career spanning 4 decades, in both industry and academia. We show examples of his work, adding some personal comments on Christian as a friend and as a colleague.

## 18:00-18:15 | A tribute to the active regions of Peter Zory (WP3.2)...N/A

Kent D. Choquette
*University of Illinois, USA*

Peter Zory (1936-2020) contributed to ISLC from the very first conference (1967, Las Vegas). Peter was involved in the evolutionary development of semiconductor active regions from his early efforts to commercialize laser diodes, continuing until after he became a Professor at the University of Florida.

## 18:15-18:27 | 8-channel hybrid III-V/silicon DFB laser array with highly uniform 200 GHz spacing and power (WP3.3)...N/A

Duanni Huang*, Ranjeet Kumar*, Xinru Wu, Kimchau N. Nguyen, Guan-Lin Su, Meer Sakib, Chaoxuan Ma, John Heck, Haisheng Rong
*Intel Corporation, USA*

*These authors contributed equally to this work

We demonstrate an eight-channel DFB array with 200 GHz spacing with excellent power (+/- 0.25 dB) and channel spacing uniformity (+/- 13 GHz). The laser array is fully integrated on silicon and suitable for high-volume, multiwavelength applications such as co-packaged optics or optical I/O.

## 18:27-18:39 | Monolithic all-semiconductor PCSELs emitting at 1.3 µm (WP3.4)...207

Calum Hill[1]*, Jonathan R. Orchard[1], Ibrahim Javed[1], Connor W. Munro[1], Daehyun Kim[2], Zijun Bian[2], Adam F. McKenzie[2], Neil D. Gerrard[2], Katherine J. Rae[2], Pavlo Ivanov[1], Richard J. E. Taylor[1], Richard A. Hogg[2], David T. D. Childs[1]

*[1]Vector Photonics, United Kingdom; [2]James Watt School of Engineering, University of Glasgow, United Kingdom*

We demonstrate for the first time a monolithic all-semiconductor photonic crystal surface emitting WDM laser device operating across the O-band between 1298 and 1340 nm with SMSR exceeding 35 dB on all channels.

## 18:39-18:51 | Internally wavelength stabilized GaAs-based diode lasers with epitaxially-stacked multiple active regions and tunnel junctions for LiDAR applications (WP3.5)...209

H. Wenzel, J. Fricke, A. Maaßdorf, R. Staske, N. Ammouri, H. Christopher, C. Zink, D. Martin, M. Weyers, A. Knigge
*Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, Germany*

We present a bipolar-cascade distributed-Bragg reflector laser emitting near 905 nm with a high slope efficiency. The wavelength stabilization by a surface grating was achieved by placing three active regions and two tunnel junctions into the nodes and antinodes, respectively, of the third-order vertical waveguide mode.

## 18:51-19:03 | 970 nm DBR broad-area semiconductor lasers with 60 % conversion efficiency (WP3.6)...211

Paul Crump, Md. Jarez Miah, Jörg Fricke, Martin Wilkens, Sabrina Kreutzmann, Hans Wenzel, and Andrea Knigge
*Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, Germany*

Progress in epitaxial design to enhance power and efficiency of spectrally-stabilized broad-area lasers at operating wavelength 970 nm is presented. 200 µm wide and 4 mm long DBR lasers with a highly-asymmetric epitaxy provide 14 W CW-mode power at 60 % efficiency with 0.6 nm spectral width (95 % power).

## 19:03-19:15 | Poster prize announcement & brief closing remarks