Thursday, September 15

All talks will be held in the Zuiten (East) room

8:15-10:15 Session: PICs and Quantum Dot Lasers

Session Co-Chairs: **Stephen Sweeney** *(Univ. of Surrey)*
Koichi Akahane *(National Institute of Information and Communications Technology)*

8:15 ThA1 (Invited) – "Photonic Integrated Laser Systems in the 1.6 to 2.0 Micrometer Wavelength Range on InP"

Erwin Bente, Sylwester Latkowski, Yuqing Jiao, Bauke Tilma, Domenico d'Agostino, Hadi Rabbani-Haghighi, Renee van Veldhoven, Peter Thijs, Huub Ambrosius, Meint Smit, Kevin Williams, Richard Noetzel
Technische Universiteit Eindhoven, The Netherlands

InP photonic integration technology has been adapted for operation down to 2 microns enabling the development of integrated laser systems for specific applications. Strained quantum well and quantum dot gain media have been used to demonstrate tunable lasers for coherence tomography and gas detection.

8:45 ThA2 – "External-Cavity Quantum-Dot Laser with Silicon Photonics Waveguide Mirror for Four-Wavelength Simultaneous Oscillation with an 800 GHz Channel Spacing"

Nami Yasuoka[1], Mitsuru Ishida[1], Kazumasa Takabayashi[1], Ayahito Uetake[1], Teruo Kurahashi[1], Masaomi Yamaguchi[2], Kenichi Nishi[2], Keizo Takemasa[2], Kan Takada[2], Tsuyoshi Yamamoto[1], Mitsuru Sugawara[2], Yasuhiko Arakawa[3]
[1]Fujitsu Laboratories Ltd., Japan, [2]QD Laser, Inc., Japan, [3]The Univ. of Tokyo, Japan

Stable four-wavelength simultaneous oscillation with an 800 GHz channel spacing and low relative intensity noise (RIN) were demonstrated using a single external-cavity laser combined with a silicon photonic nanowire waveguide chip and a 1.3 µm quantum dot (QD) gain chip integrated with a spot-size converter.

9:00 ThA3 – "Dot State Properties of 1.3 µm Low-loss InAs Quantum Dot Lasers Grown Directly on Si"

Stella N Elliott[1], Samuel Shutts[1], Angela Sobiesierski[1], Peter Rees[1], Peter M Smowton[1], Mingchu Tang[2], Jiang Wu[2], Huiyun Liu[2]
[1]Cardiff Univ., UK, [2]Univ. College London, UK

In the first comparison of identical 1.3µm InAs/AlGaAs quantum-dot structures grown on silicon (with defect filter layers, but no germanium) and GaAs substrates, both demonstrate dot-state emission of similar intensity, spectral breadth and areal dot density (3.3-3.5X10^{10}cm^{-2}) with a 35nm blue shift on silicon.

9:15 ThA4 – "Electrically Pumped Continuous-Wave III-V Quantum Dot Lasers Monolithically Grown On Silicon"

Siming Chen[1], Jiang Wu[1], Wei Li[2], Mengya Liao[1], Mingchu Tang[1], Qi Jiang[1], Samuel Shutts[3], Stella Elliott Elliott[3], Angela Sobiesierski[3], Ian Mark Ross[2], Peter Smowton[3], Alwyn Seeds[1], Huiyun Liu[1]
[1]Univ. College London, UK, [2]The Univ. of Sheffield, UK, [3]Cardiff Univ., UK

We demonstrate electrically pumped continuous-wave InAs/GaAs quantum dot lasers monolithically grown on silicon substrates with a low threshold current density of 62.5 Acm^{-2}, a room temperature output exceeding 105 mW, operation up to 120 °C, and long extrapolated lifetime exceeding 100,000 h.

9:30 ThA5 – "A Wafer-bonded Hybrid Silicon Quantum Dot Laser"

Geza Kurczveil, Di Liang, Marco Fiorentino, Ray Beausoleil
Hewlett Packard Labs, USA

We present a wafer-bonded hybrid-silicon quantum-dot laser. Continuous-wave operation up to 100 °C and a threshold current density of 227 A/cm^2 at room temperature are observed. Efficient coupling to a passive silicon waveguide is demonstrated. These devices are a key component in next generation supercomputers.

9:45 ThA6 – "Transverse-Magnetic Laser Oscillation from Highly Stacked InAs/GaAs Quantum Dots"

Toshiyuki Kaizu, Masaya Suwa, Takaya Andachi, Yukihiro Harada, Takashi Kita
Kobe Univ., Japan

We studied electroluminescence and net-modal gain in 40-stacked InAs/GaAs quantum dot (QD) laser devices. Since the electronic coupling between the QDs enhanced the transverse-magnetic (TM) component, the [110] waveguide devices exhibited a laser oscillation in the TM component as well as the transverse-electric (TE) component.

10:00 ThA7 – "1-um InAs Quantum Dot Micro-disk Lasers Directly Grown on Exact (001) Si"

Kei May Lau[1], Yating Wan[1], Qiang Li[1], Alan Y. Liu[2], Weng W Chow[3], Arthur C. Gossard[2], John E. Bowers[2], Evelyn L. Hu[4]
[1]Hong Kong Univ. of Science and Technology, Hong Kong, [2]Univ. of California, Santa Barbara, USA, [3]Sandia National Laboratories, USA, [4]Harvard Univ., USA

Capitalizing on our novel epitaxial processes, we demonstrate subwavelength micro-disk lasers 1 µm in diameter on exact (001) silicon substrates. Under continuous wave optical pumping at 10 K, low thresholds down to 35 µW were obtained together with a high spontaneous emission factor of 0.3.

10:15-10:35 Coffee Break

10:35-12:50 Session: Heterogeneous Lasers on Silicon

Session Co-Chairs: **Larry Coldren** *(Univ. of California, Santa Barbara)*
Takahiro Nakamura *(Photonics Electronics Technology Research Association)*

10:35 ThB1 (Invited) – "Heterogeneous Integration of III-V on Silicon for System-in-Package Photonic Transceivers"

G. Fish, B. R. Koch, E. J. Norberg, J. E. Roth, A. Ramaswamy, J. Hutchinson, J. Shin, A. Fang
Aurrion Inc., USA

Heterogeneous integration enables high performance active components such as lasers, modulators, and photodetectors to be elegantly integrated on a silicon photonics platform with high performance passive components. This platform also offers the unique capability to combine different types of active devices with separately optimized materials on the same wafer, die, and photonic integrated circuit. Experimental demonstrations show that these active components can achieve performance on par with commercially available discrete III-V components. Furthermore, the technique enables the consolidation of a complete optical transceivers onto a singular silicon substrate enabling the development of system-in-package architectures and assembly processes that are indistinguishable from those used in standard electronic packaging. In this paper we will discuss the advantages of this heterogeneous integration platform and discuss prototype demonstrations.

11:05 ThB2 – "Narrow-Linewidth Lasers Using On-Chip High-Q Resonators"

Tin Komljenovic[1], Daryl T. Spencer[1], Michael L. Davenport[1], Sudharsanan Srinivasan[2], John E. Bowers[1]

[1]Univ. of California, Santa Barbara, USA, [2]Aurrion Inc., USA

We present heterogeneously integrated widely-tunable semiconductor lasers with narrow-linewidth. 50 kHz integrated linewidth was demonstrated, and sub-kHz Lorentzian linewidths are predicted using high-Q ring resonators made in Si. Low-frequency noise was suppressed by more than 30 dB using an ultra-high Q Si3N4 resonator.

11:20 ThB3 – "High Asymmetric Light Output Characteristics of Membrane Distributed-Reflector Laser on Si Substrate"

Takuo Hiratani, Daisuke Inoue, Takahiro Tomiyasu, Kai Fukuda, Tomohiro Amemiya, Nobuhiko Nishiyama, Shigehisa Arai
Tokyo Institute of Technology, Japan

High asymmetric light output ratio between the front and the rear of 14.5 as well as an improved differential quantum efficiency of 29% at the front was obtained for GaInAsP/InP membrane distributed-reflector laser on Si with 50 µm-long DFB and 100 µm-long DBR sections.

11:35 ThB4 – "Enhanced Modulation Bandwidth of Heterogeneously Integrated III-V-on-silicon DFB Laser for 40 Gb/s NRZ-OOK Direct Modulation"

Amin Abbasi[1], Jochem Verbist[2], Xin Yin[2], Francois Lelarge[3], Guang Hua Duan[3], Johan Bauwelinck[2], Gunther Roelkens[1], Geert Morthier[1]
[1]Ghent Univ. – IMEC, Belgium, [2]Ghent Univ. – iMinds – IMEC, Belgium, [3]III-V lab, a joint lab of 'Alcatel-Lucent Bell Labs', 'Thales Research and Technology' and 'CEA Leti', France

We present 40 Gb/s non-return-to-zero on-off keying direct modulation of a heterogeneously integrated III-V-on-silicon DFB laser. Leveraging the photon-photon resonance effect, the modulation bandwidth is increased to 27 GHz. We demonstrate error free transmission over 2 km non-zero dispersion shifted fiber.

11:50 ThB5 – "Lasing Characteristics of GaInAsP Laser Diode Grown on Directly Bonded InP/Si Substrate"

Tetsuo Nishiyama, Keiichi Matsumoto, Jyunya Kishikawa, Yuya Onuki, Naoki Kamada, Kazuhiko Shimomura
Sophia Univ., Japan

We have obtained lasing characteristics of GaInAsP double-hetero laser grown on directly bonded InP/Si substrate through the InP-Si interface carrier injection. The InP/Si substrate was prepared by 1µm InP and Si substrate. Threshold current and spectrum of laser on InP/Si and InP substrate are discussed.

12:05 ThB6 – "Passively Mode-Locked Iii-V-on-silicon Laser with 1 GHz Repetition Rate"

Kasper SJ Van Gasse[1], Zhechao Wang[1], Valentina Moskalenko[2], Sylwester Latkowski[2], Bart Kuyken[1], Erwin Bente[2], Gunther Roelkens[3]
[1]IMEC, Belgium, [2]Technical Univ. of Eindhoven, The Netherlands, [3]Ghent Univ., Belgium

We present an on-chip III-V-on-silicon mode-locked laser at 1.6 µm with a 1 GHz repetition rate and -6 dBm output in the waveguide. The optical spectrum showed a 10.8 nm wide comb, the corresponding pulses showed an autocorrelation trace FWHM of 11 ps.

12:20 ThB7 – "Membrane Distributed-Reflector Lasers with 20-µm-long DFB Section and Front/Rear DBRs on Si Substrates"

Erina Kanno, Koji Takeda, Takuro Fujii, Koichi Hasebe, Hidetaka Nishi, Tsuyoshi Yamamoto, Takaaki Kakitsuka, Shinji Matsuo
NTT Corporation, Japan

We have developed distributed reflector lasers that include a 20-µm-long DFB section on SiO2/Si substrates to reduce power consumption. By employing DBRs for both sides of the DFB section, we achieve a threshold current of 0.66 mA with a grating coupling coefficient of 820 cm^{-1}.

12:35 ThB8 – "Impedance Analysis of High-speed Lateral-current-injection Membrane DFB Laser on Silicon"

Daisuke Inoue, Takuo Hiratani, Kai Fukuda, Takahiro Tomiyasu, Tomohiro Amemiya, Nobuhiko Nishiyama, Shigehisa Arai
Tokyo Institute of Technology, Japan

Impedance characteristics of a membrane DFB laser were measured to reveal an effect of parasitics on the modulation bandwidth. The cutoff frequency was obtained to be 13.7 GHz by measuring reflection S11. Additionally, 18 Gbit/s direct modulation was performed at a bias current of 1.5-mA.

12:50-13:50 Lunch (Lunch box is served)

13:50-15:35 Session: Photonic Crystal Lasers

Session Co-Chairs: **Jerry Meyer** *(Naval Research Laboratory)*
Weng Chow *(Sandia National Laboratories)*

13:50 ThC1 (Invited) – "Membrane DFB and Photonic Crystal Lasers on Si"

Shinji Matsuo, Koji Takeda, Takuro Fujii, Hidetaka Nishi, Takaaki Kakitsuka
NTT Corporation, Japan

We have developed lateral current injection membrane DFB and photonic crystal lasers, in which a buried heterostructure is used. Effective confinements of photons and carriers are essential to achieve low-operating-energy directly modulated lasers. We have also demonstrated heterogeneous integration of membrane lasers on $SiO2/Si$ substrates.

14:20 ThC2 – "Tunable 1D Photonic Crystal Nanolaser and its Capability of Stretching Sensing"

Tsan-Wen Lu, Chun Wang, Chi-Fan Hsiao, Po-Tsung Lee
National Chiao Tung Univ., Taiwan

Tunable nanolasers via 1D nanoblocks embedded within polydimethylsiloxane are demonstrated, which show large wavelength tunability of 7.65nm per 1% stretching and high reliability under repeating stretching/relaxing tests. Wide tuning range over 80nm is achieved. As a stretching sensor, minimum detectable stretching of 0.072% is obtained.

14:35 ThC3 – "Photonic Crystal Nanolaser as an Iontronic Sensor"

Takumi Watanabe, Yu Hasegawa, Toshihiko Baba
Yokohama National Univ., Japan

We found that GaInAsP semiconductor photonic crystal nanolaser can detect the electric charge in a solution from its emission intensity change. It will be applicable to sensing pH, chemical elements, hydrophobicity/hydrophilicity, bio-molecules, cells, etc.

14:50 ThC4 – "In-plane Mutual Wavelength Locking of Photonic Crystal Lasers"

Menaka De Zoysa[1], Taiga Kobayashi[1], Masahiro Yoshida[1], Masato Kawasaki[2], Kenji Ishizaki[1], Ranko Hatsuda[1], Susumu Noda[1]
[1]Kyoto Univ., Japan, [2]Mitsubishi Electric Corporation, Japan

In-plane mutual wavelength locking phenomena of photonic crystal lasers are investigated by simultaneously driving spatially separated areas. Although each area has a slightly different wavelength, single mode lasing can be achieved during simultaneous operation. Such locking behavior becomes the basis for large-area single mode operation.

15:05 ThC5 – "Mode Control in Photonic Crystal Surface Emitting Lasers Through In-Plane Feedback"

Richard James Edward Taylor[1], Guangrui Li[2], Pavlo Ivanov[2], David Childs[2], Benjamin Stevens[3], Bret Harrison[3], Nasser Babazadeh[2], Olesya Ignatova[2], Richard Andrew Hogg[2]
[1]The Univ. of Tokyo, Japan, [2]Univ. of Glasgow, UK, [3]The Univ. of Sheffield, UK

Mode control in photonic crystal surface emitting lasers is demonstrated through the use of distributed, varying phase feedback introduced through cleaved facets.

15:20 ThC6 – "Realization of Two-dimensional Beam Steering by Position-modulated Photonic-crystal Lasers"

Daiki Yasuda[1], Kyoko Kitamura[2], Susumu Noda[1]
[1]Kyoto Univ., Japan, [2]Kyoto Institute of Technology, Japan

We demonstrate two-dimensional beam steering operation by position-modulated photonic-crystal lasers. We show that maximum beam steering angle can be ±45 degrees, and that a range of two-dimensional beam steering can be achieved smoothly for various directions. The results promise to further development of laser-scanning applications.

15:35-15:55 Coffee Break

15:55-17:40 Session: Wide Bandgap Lasers

Session Co-Chairs: **Atsushi Yamaguchi** *(Kanazawa Institute of Technology)*
Uwe Strauss *(OSRAM GmbH)*

15:55 ThD1 – "Low-threshold Chip-scale Aluminum Nitride Raman Laser"

Xianwen Liu[1], Changzheng Sun[1], Bing Xiong[1], Jian Wang[1], Lai Wang[1], Yanjun Han[1], Zhibiao Hao[1], Hongtao Li[1], Yi Luo[1], Jianchang Yan[2], Tongbo Wei[2], Yun Zhang[2], Junxi Wang[2]
[1]Tsinghua Univ., China, [2]Chinese Academy of Sciences, China

Raman lasing is observed in epitaxial aluminum nitride microring with loaded quality factor of ~1.2×106. The threshold pump power is ~8.7 mW, with unidirectional slope efficiency of ~5.1%. Raman frequency shifts of ~612 and ~657 cm^{-1} are observed for incident light with different polarization.

16:10 ThD2 – "Thresholdless Lasing of Nitride Nanobeam Cavities on Silicon"

Stefan Thomas Jagsch[1], Noelia Vico Triviño[2], Gordon Callsen[1], Stefan Kalinowski[1], Ian Michael Rousseau[2], Jean-François Carlin[2], Raphaël Butté[2], Axel Hoffmann[1], Nicolas Grandjean[2], Stephan Reitzenstein[1]
[1]Technical Univ. of Berlin, Germany, [2]École Polytechnique Fédérale de Lausanne, Switzerland

We present a temperature dependent optical and quantum-optical characterization of close-to-ideal lasing in GaN-based nanobeam cavities. Measuring the photon statistics of emission allows us to prove high-β lasing at room temperature, and thresholdless lasing at 156K.

16:25 ThD3 – "Nonpolar GaN-Based Vertical-Cavity Surface-Emitting Lasers"

Charles A Forman, John T Leonard, Erin C Young, Seunggeun Lee, Daniel A Cohen, Benjamin P Yonkee, Robert M Farrell, Tal Margalith, Steven P DenBaars, James S Speck, Shuji Nakamura
Univ. of California, Santa Barbara, USA

This is a report of recent progress on GaN-based vertical-cavity surface-emitting lasers (VCSELs). Ion implanted aperture VCSELs with tunnel junction intracavity contacts outperformed dielectric apertures with indium tin oxide intracavity contacts. A novel buried tunnel junction design offers a solution for current and optical confinement.

16:40 ThD4 – "1.7-mW Nitride-Based Vertical-Cavity Surface-Emitting Lasers Using AlInN/GaN Bottom DBRs"

Takashi Furuta[1], Kenjo Matsui[1], Yugo Kozuka[1], Shotaro Yoshida[1], Natsumi Hayashi[1], Takanobu Akagi[1], Norikatsu Koide[1], Tetsuya Takeuchi[1], Satoshi Kamiyama[1], Motoaki Iwaya[1], Isamu Akasaki[2]
[1]Meijo Univ., Japan, [2]Meijo Univ. and Nagoya Univ., Japan

We demonstrated 1.7 mW nitride-based vertical-cavity surface-emitting lasers (VCSELs) using AlInN/GaN distributed Bragg reflectors (DBRs). The threshold current was 4.5 mA, and the external differential quantum efficiency was estimated to be 11.5%.

16:55 ThD5 – "Underwater 6.4-m Optical Wireless Communication with 8.8-Gbps Encoded 450-nm GaN Laser Diode"

Yu-Chieh Chi[1], Tsai-Chen Wu[1], Che-Yu Lin[2], Hai-Han Lu[2], Hao-Chung Kuo[3], Gong-Ru Lin[1]
[1]National Taiwan Univ., Taiwan, [2]National Taipei Univ. of Technology, Taiwan, [3]National Chiao Tung Univ., Taiwan

6.4-m underwater optical wireless communication based on a GaN blue laser diode under direct 8.8-Gbps QAM-OFDM encoding is demonstrated with an average signal-to-noise ratio of 16 dB and a bit error rate of 3.8×10-3.

17:10 ThD6 – "High Efficiency Semipolar III-Nitride Lasers for Solid State Lighting"

Daniel Becerra, Daniel Cohen, Robert Farrell, Steven DenBaars, Shuji Nakamura
Univ. of California, Santa Barbara, USA

An approach is proposed to improve high power CW semipolar III-nitride lasers. Performance was improved after moving to a 2 QW active region, and compensation of the Mg acceptor by oxygen in the EBL was identified as a source of carrier leakage and excess voltage.

17:25 ThD7 – "Realization of Over 10% EQE AlGaN Deep-UV LED by Using Transparent p-AlGaN Contact Layer"

Hideki Hirayama[1], Takayoshi Takano[1,2], Jun Sakai[1,2], Takuya Mino[1,2], Kenji Tsubaki[1,2], Norihiko Maeda[1], Masafumi Jo[1], Yuuya Kanazawa[1,3], Issei Ohshima[1,3], Takuma Matsumoto[1,3], Norihiko Kamata[3]
[1]RIKEN, Japan, [2]Panasonic Corporation, Japan [3]Saitama Univ., Japan

The improvement of light-extraction efficiency (LEE) is major subject for AlGaN deep-ultraviolet light-emitting diodes (DUV-LEDs). We demonstrated over 10% external quantum efficiency in an AlGaN DUV-LED by improving LEE by introducing transparent p-AlGaN contact layer.

17:40- Post Deadline Paper
Closing Ceremony

Session Co-Chairs: **Luke J. Mawst** *(Univ. of Wisconsin-Madison)*
Akihiko Kasukawa *(Furukawa Electric Co., Ltd.)*