

PROCEEDINGS OF SPIE

# ***Vertical-Cavity Surface-Emitting Lasers XXIII***

**Kent D. Choquette**

**Luke A. Graham**

*Editors*

**6–7 February 2019**

**San Francisco, California, United States**

*Sponsored and Published by*  
**SPIE**

**Volume 10938**

Proceedings of SPIE 0277-786X, V. 10938

SPIE is an international society advancing an interdisciplinary approach to the science and application of light.

Vertical-Cavity Surface-Emitting Lasers XXIII, edited by Kent D. Choquette,  
Luke A. Graham, Proc. of SPIE Vol. 10938, 1093801 · © 2019 SPIE  
CCC code: 0277-786X/19/\$18 · doi: 10.1117/12.2531304

Proc. of SPIE Vol. 10938 1093801-1

The papers in this volume were part of the technical conference cited on the cover and title page. Papers were selected and subject to review by the editors and conference program committee. Some conference presentations may not be available for publication. Additional papers and presentation recordings may be available online in the SPIE Digital Library at SPIEDigitalLibrary.org.

The papers reflect the work and thoughts of the authors and are published herein as submitted. The publisher is not responsible for the validity of the information or for any outcomes resulting from reliance thereon.

Please use the following format to cite material from these proceedings:

Author(s), "Title of Paper," in *Vertical-Cavity Surface-Emitting Lasers XXIII*, edited by Kent D. Choquette, Luke A. Graham, Proceedings of SPIE Vol. 10938 (SPIE, Bellingham, WA, 2019) Seven-digit Article CID Number.

ISSN: 0277-786X  
ISSN: 1996-756X (electronic)

ISBN: 9781510625181  
ISBN: 9781510625198 (electronic)

Published by  
**SPIE**  
P.O. Box 10, Bellingham, Washington 98227-0010 USA  
Telephone +1 360 676 3290 (Pacific Time) · Fax +1 360 647 1445  
SPIE.org  
Copyright © 2019, Society of Photo-Optical Instrumentation Engineers.

Copying of material in this book for internal or personal use, or for the internal or personal use of specific clients, beyond the fair use provisions granted by the U.S. Copyright Law is authorized by SPIE subject to payment of copying fees. The Transactional Reporting Service base fee for this volume is \$18.00 per article (or portion thereof), which should be paid directly to the Copyright Clearance Center (CCC), 222 Rosewood Drive, Danvers, MA 01923. Payment may also be made electronically through CCC Online at [copyright.com](http://copyright.com). Other copying for republication, resale, advertising or promotion, or any form of systematic or multiple reproduction of any material in this book is prohibited except with permission in writing from the publisher. The CCC fee code is 0277-786X/19/\$18.00.

Printed in the United States of America by Curran Associates, Inc., under license from SPIE.

Publication of record for individual papers is online in the SPIE Digital Library.

**SPIE. DIGITAL  
LIBRARY**  
SPIEDigitalLibrary.org

---

**Paper Numbering:** *Proceedings of SPIE* follow an e-First publication model. A unique citation identifier (CID) number is assigned to each article at the time of publication. Utilization of CIDs allows articles to be fully citable as soon as they are published online, and connects the same identifier to all online and print versions of the publication. SPIE uses a seven-digit CID article numbering system structured as follows:

- The first five digits correspond to the SPIE volume number.
- The last two digits indicate publication order within the volume using a Base 36 numbering system employing both numerals and letters. These two-number sets start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B ... 0Z, followed by 10-1Z, 20-2Z, etc. The CID Number appears on each page of the manuscript.

# Contents

|     |                      |
|-----|----------------------|
| v   | Authors              |
| vii | Conference Committee |

---

## SESSION 1 VCSEL MODULATION

---

|          |   |
|----------|---|
| 10938 02 | <b>VCSEL modulation speed: status and prospects (Invited Paper)</b> [10938-1]             |
| 10938 03 | <b>VCSELs and 100G links (Invited Paper)</b> [10938-2]                                    |
| 10938 04 | <b>Bandwidth and optical output power of VCSELs and VCSEL arrays</b> [10938-3]            |
| 10938 06 | <b>The influences of ethernet standards on VCSEL technology (Invited Paper)</b> [10938-5] |
| 10938 09 | <b>Watt-class high-power and high-beam-quality VCSEL amplifiers</b> [10938-8]             |

---

## SESSION 2 NOVEL VCSEL STRUCTURES

---

|          |   |
|----------|---|
| 10938 0A | <b>Optically pumped vertical-cavity surface-emitting lasers at 375 nm with air-gap/<math>\text{Al}_{0.05}\text{Ga}_{0.95}\text{N}</math> distributed Bragg reflectors</b> [10938-9] |
|----------|---|

---

## SESSION 3 COMMERCIAL VCSELs

---

|          |  |
|----------|--|
| 10938 0C | <b>Temperature characteristics of all monolithically integrated self-scanning VCSEL array</b> [10938-11]             |
| 10938 0D | <b>VCSEL arrays for quasi-continuous-wave applications</b> [10938-12]  |
| 10938 0E | <b>VCSELs in short-pulse operation for time-of-flight applications</b> [10938-13]                                    |
| 10938 0F | <b>High-power VCSEL arrays with customized beam divergence for 3D-sensing applications</b> [10938-14]                |
| 10938 0G | <b>Tunable vertical-cavity surface-emitting lasers as a light source for diffuse optical spectroscopy</b> [10938-15] |

---

**SESSION 4      VCSELS FOR APPLICATIONS**

---

10938 0J      **Energy efficient 850-nm VCSEL based optical transmitter and receiver link capable of 56 Gbit/s NRZ operation** [10938-18]

---

**SESSION 5      VCSEL PERFORMANCE ANALYSIS**

---

10938 0N      **Comprehensive self-consistent analysis of oxide-confined vertical-cavity surface-emitting lasers** [10938-22]

# Authors

Numbers in the index correspond to the last two digits of the seven-digit citation identifier (CID) article numbering system used in Proceedings of SPIE. The first five digits reflect the volume number. Base 36 numbering is employed for the last two digits and indicates the order of articles within the volume. Numbers start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B...0Z, followed by 10-1Z, 20-2Z, etc.

|                             |                           |
|-----------------------------|---------------------------|
| Agustin, M., 0J             | Moser, Philip, 04         |
| Bacchin, Gianluca, 0D       | Murakami, Akemi, 08       |
| Block, Matthew K., 0D       | Ohno, Seiji, 0C           |
| Caspar, C., 0J              | Okur, Serdal, 0F          |
| Chen, Ping, 0A              | Othman, Hasan, 0F         |
| Chorchos, L., 0J            | Park, Young Jae, 0A       |
| Cole, G. D., 0G             | Ponce, Fernando, 0A       |
| Detchprohm, Theeradetch, 0A | Ralph, Stephen E., 03     |
| Dummer, M. M., 0G           | Rothwell, S. L., 0G       |
| Dupuis, Russell, D., 0A     | Scheller, Maik, 0F        |
| Foresi, James, 0D           | Seurin, Jean-Francois, 0F |
| Ghosh, Chuni, 0F            | Shchukin, V. A., 0J, 0N   |
| Gronenborn, Stephan, 0E     | Shen, Shyh-Chiang, 0A     |
| Gu, Xiaodong, 08            | Simpanen, E., 02          |
| Gu, Xi, 0E                  | Smeets, Michael, 0E       |
| Gudde, Ralph, 0E            | Suzuki, Yoshiyuki, 08     |
| Guo, Baiming, 0F            | Toledo, Kevin, 0D         |
| Guo, Dingkai, 0F            | Tominaga, Daiki, 08       |
| Gustavsson, J. S., 02       | Turkiewicz, J. P., 0J     |
| Haghighi, Nasibeh, 04       | Usami, Hiroyuki, 0C       |
| Haglund, E. P., 02          | Van Leeuwen, Robert, 0F   |
| Haglund, E., 02             | Wang, Jialin, 0A          |
| Hayakawa, Junichiro, 08     | Wang, Shuo, 0A            |
| Helms, Chris J., 0D         | Warren, Mial E., 0D       |
| Herper, Markus, 0E          | Watkins, Laury, 0F        |
| Ho, Zeuku, 08               | Weigl, Alexander, 0E      |
| Jeong, Hoon, 0A             | Xu, Guoyang, 0F           |
| Jewell, Jack, 06            | Yang, Lei, 0D             |
| Johnson, K., 0G             | Yoder, P. Douglas, 0A     |
| Kalosha, V. P., 0J, 0N      |                           |
| Kitsunai, Masaaki, 0C       |                           |
| Koepp, M., 0J               |                           |
| Kolb, Johanna, 0E           |                           |
| Komagata, Shogo, 0C         |                           |
| Kondo, Takashi, 0C          |                           |
| Koyama, Fumio, 08           |                           |
| Kropp, J.-R., 0J            |                           |
| Larsson, A., 02             |                           |
| Lavrencik, Justin, 03       |                           |
| Ledentsov, Jr., N., 0J, 0N  |                           |
| Ledentsov, N. N., 0J, 0N    |                           |
| Lengyel, T., 02             |                           |
| Liu, Yuh-Shiuan, 0A         |                           |
| Lott, James A., 04          |                           |
| Mehta, Karan, 0A            |                           |
| Melgar, Alirio, 03          |                           |
| Miglo, Alexander, 0F        |                           |
| Miller, Michael, 0E         |                           |
| Moench, Holger, 0E          |                           |



# Conference Committee

## *Symposium Chairs*

**Connie J. Chang-Hasnain**, University of California, Berkeley  
(United States)

**Graham T. Reed**, Optoelectronics Research Centre, University of  
Southampton (United Kingdom)

## *Symposium Co-chairs*

**Sailing He**, KTH Royal Institute of Technology (Sweden) and Zhejiang  
University (China)

**Yasuhiro Koike**, Keio University (Japan)

## *Program Track Chair*

**Klaus P. Streubel**, OSRAM GmbH (United States)

## *Conference Chairs*

**Kent D. Choquette**, University of Illinois (United States)

**Luke A. Graham**, Dallas Quantum Devices (United States)

## *Conference Program Committee*

**Aaron James Danner**, National University of Singapore (Singapore)

**Martin Grabherr**, Priolas GmbH (Germany)

**James K. Guenter**, Finisar Corporation (United States)

**Anders Larsson**, Chalmers University of Technology (Sweden)

**Chun Lei**, Lumentum (United States)

**James A. Lott**, Technische Universität Berlin (Germany)

**M. V. Ramana Murty**, Avago Technologies Ltd. (United States)

**Krassimir Panajotov**, Vrije Universiteit Brussel (Belgium)

**Darwin K. Serkland**, Sandia National Laboratories (United States)

**Jean-Francois Seurin**, Princeton Optronics, Inc. (United States)

**Noriyuki Yokouchi**, Furukawa Electric Company, Ltd. (Japan)

**Jongseung Yoon**, The University of Southern California (United States)

**Mial E. Warren**, TriLumina Corporation (United States)

## *Session Chairs*

1 VCSEL Modulation

**Luke A. Graham**, Dallas Quantum Devices (United States)

- 2 Novel VCSEL Structures  
**Kent D. Choquette**, University of Illinois (United States)
- 3 Commercial VCSELS  
**James A. Lott**, Technische Universität Berlin (Germany)
- 4 VCSELS for Applications  
**Chun Lei**, Lumentum (United States)
- 5 VCSEL Performance Analysis  
**Luke A. Graham**, Dallas Quantum Devices (United States)