PROCEEDINGS OF SPIE

Vertical-Cavity Surface-Emitting Lasers XXIV

Luke A. Graham Chun Lei Editors

5–6 February 2020 San Francisco, California, United States

Sponsored and Published by SPIE

Volume 11300

Proceedings of SPIE 0277-786X, V. 11300

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

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 XXIV*, edited by Luke A. Graham, Chun Lei, Proceedings of SPIE Vol. 11300 (SPIE, Bellingham, WA, 2020) Seven-digit Article CID Number.

ISSN: 0277-786X

ISSN: 1996-756X (electronic)

ISBN: 9781510633636

ISBN: 9781510633643 (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

Copyright © 2020, 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 \$21.00 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. 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/20/\$21.00.

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.



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 vii	Authors Conference Committee
SESSION 1	COMMERCIAL HIGH-POWER VCSELS
11300 02	Performance, manufacturability, and qualification advances of high-power VCSEL arrays at TriLumina Corporation (Invited Paper) [11300-1]
11300 05	Lasertel VCSEL development progress for automotive lidar [11300-4]
11300 06	Quality control optical characterization of NIR VCSEL based light sources for 3D imaging applications [11300-5]
SESSION 2	SINGLE-MODE APPLICATIONS
11300 09	Zero-order-free 2D beam pattern projecting on-chip lasers (Invited Paper) [11300-7]
11300 OB	Strain-controlled impurity-induced disordered apertures for high-power single-mode VCSELs [11300-9]
11300 OC	76X-nm VCSELs with wide tuning range designed for TDLAS [11300-10]
SESSION 3	HIGH-SPEED VCSELS: COMMERCIAL
11300 OE	20 and 40 Gbps data transmission with small VCSEL arrays [11300-12]
11300 OF	1×4 VCSEL arrays with uniform spectral and noise properties by using rotationally asymmetric oxide aperture for 400 Gbit/s applications [11300-13]
11300 OG	100Gb/s PAM4 oxide VCSEL development progress at Broadcom [11300-14]
SESSION 4	HIGH-SPEED VCSELS: EXPERIMENTAL
11300 OH	Quantum-dot oxide-confined 850-nm VCSELs with extreme temperature stability operating at 25 Gbit/s up to 180°C (Invited Paper) [11300-15]

11300 OJ	Comparison of 850 nm VCSEL oxide aperture designs [11300-17]
11300 OK	Oxidation stress induced birefringence in vertical cavity surface emitting lasers [11300-18]
SESSION 5	VCSELS IN NOVEL MATERIAL SYSTEMS
11300 OM	Tunable room-temperature continuous-wave mid-infrared VCSELs (Invited Paper) [11300-20]
SESSION 6	MEMS AND HIGH-CONTRAST GRATING DEVICES
11300 OR	MEMs-HCG VCSELs for emerging sensing and datacoms applications (Invited Paper) [11300-26]
11300 OS	Widely tunable electrically pumped 1050nm MEMS-VCSELs for optical coherence tomography (Invited Paper) [11300-27]
	POSTER SESSION
11300 OW	894nm high orthogonal polarization suppression ratio vertical cavity surface emitting laser [11300-30]

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.

Aoki, Takeshi, 0F Bacchin, Gianluca, 02

Bandyopadhyay, Neelanjan, OR

Boher, Pierre, 06 Borova, Iana, 0S Bramham, Nate, 0S

Burgner, Christopher B., OM, OS

Cai, Xinle, 0G Caliva, B., 05 Carter, John, 0S

Cazabat, Anthony, 0M, 0S

Chase, Chris, OR
Chen, Hung Kai, OR
Cheng, An-Nien, OG
Cheng, Sam, OR
Cherkashin, N., OH
Chorchos, L., OH, OK
Chu, Jason, OG
Chung, Michael, 02

Collomb-Patton, Véronique, 06

Dallesasse, John M., 0B Dolfi, David W., 0G Earls, Jeff, 02 Ellafi, Dalila, 0R Fanning, Thomas R., 02 Feng, Zheng-Wen, 0G Foresi, James, 02 Gębski, Marcin, 0J Gerfers, F., 0K Giovane, Laura M., 0G

Grabherr, M., OC Haghighi, Nasibeh, OE, OJ Hasnain, Ghulam, OR

Hecht, U., OK
Heermeier, Niels, OJ
Helms, Christopher J., 02
Hirose, Kazuyoshi, 09
Hsiao, Fu-Chen, 0B
Huang, Mike, OR
Inoue, Daisuke, OF
Ishizuka, Takashi, OF
Jayaraman, V., OM, OS

Kalosha, V. P., OH, OK Kamei, Hiroki, O9 Kan, Qiang, OW Kim, Sam Sangho, OR Koh, Gim-Hong, OG Kolasa, B., OM Kropp, J. -R., OH, OK Kubota, Ryosuke, 0F Kurosaka, Yoshitaka, 09

Kurth, P., OK Lascola, K., OM

Ledentsov, N. N., 0H, 0K Ledentsov, N., Jr., 0H, 0K Lehman Harren, Ann, 0G

Leong, Nelvin, 0G Leroux, Thierry, 06 Li, Ming, 0W

Lindblad, Chad, 0M, 0S Lopez, Jacob, 02 Lott, James A., 0E, 0J Maillard, J. M., 05 Makarov, O., 0H, 0K Maynard, John, 02 Moser, Philip, 0E, 0J Murty, M. V. Ramana, 0G Nomoto, Yoshiro, 09 O'Brien, Thomas, Jr., 0B Pikul, Kevin P., 0B Podva, David, 02 Qiu, Pingping, 0W Riaziat, Majid, 0J Ruben, E., 05

Segal, S., OM Shchukin, V. A., OH, OK Shoji, Hajime, OF Sridhara, Aadi, OG Su, Patrick, OB

Sugiyama, Takahiro, 09 Takiguchi, Yu, 09 Taslim, Sumtro-Joyo, 0G Thiagarajan, P., 05 Towner, F., 0M Turkiewicz, J. P., 0H, 0K Uenoyama, Soh, 09 Walker, R., 05 Wang, Jingyi, 0G Wang, Qiuhua, 0W Warren, Mial E., 02

Wong, Ping-Show, 0J

Xie, F., 0M Xie, Yiyang, 0W

West, L., 05

Yanagisawa, Masaki, OF

Yang, Lei, 02 Yang, Michael, 0R Zorn, Martin, 0E

Conference Committee

Symposium Chairs

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

Yasuhiro Koike, Keio University (Japan)

Symposium Co-chairs

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

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

Program Track Chair

Klaus P. Streubel, OSRAM GmbH (United States)

Conference Chairs

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

Conference Program Committee

Kent D. Choquette, University of Illinois (United States)
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)
James A. Lott, Technische Universität Berlin (Germany)
M. V. Ramana Murty, Broadcom Incorporated (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)

Session Chairs

1 Commercial High-Power VCSELS Luke A. Graham, Dallas Quantum Devices (United States)

Mial E. Warren, TriLumina Corporation (United States)

- Single-Mode ApplicationsJames Guenter, Finisar Corporation (United States)
- 3 High-Speed VCSELs: Commercial **Chun Lei**, Lumentum (United States)
- 4 High-Speed VCSELs: Experimental Martin Grabherr, Priolas Gmbh (Germany)
- VCSELs in Novel Material Systems
 Kent D. Choquette, University of Illinois (United States)
- 6 MEMs and High-Contrast Grating Devices

 James A. Lott, Technische Universität Berlin (Germany)