

PROCEEDINGS OF SPIE

Gallium Nitride Materials and Devices XIV

Hiroshi Fujioka
Hadis Morkoç
Ulrich T. Schwarz
Editors

4–7 February 2019
San Francisco, California, United States

Sponsored and Published by
SPIE

Volume 10918

Proceedings of SPIE 0277-786X, V. 10918

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

Gallium Nitride Materials and Devices XIV, edited by Hiroshi Fujioka, Hadis Morkoç,
Ulrich T. Schwarz, Proc. of SPIE Vol. 10918, 1091801 · © 2019 SPIE
CCC code: 0277-786X/19/\$18 · doi: 10.1117/12.2531211

Proc. of SPIE Vol. 10918 1091801-1

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 SPIDigitalLibrary.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 *Gallium Nitride Materials and Devices XIV*, edited by Hiroshi Fujioka, Hadis Morkoç, Ulrich T. Schwarz, Proceedings of SPIE Vol. 10918 (SPIE, Bellingham, WA, 2019) Seven-digit Article CID Number.

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

ISBN: 9781510624788
ISBN: 9781510624795 (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. 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**

SPIDigitalLibrary.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

vii	<i>Authors</i>
ix	<i>Conference Committee</i>

GROWTH II

10918 0A	Enhanced optical and structural properties of MBE-grown AlGa_N nanowires on Si substrate by H⁺ ion implantation and UV ozone treatment [10918-9]
----------	--

MATERIAL CHARACTERIZATION I

10918 0E	III-nitride vertical resonant cavity light-emitting diodes with hybrid air-gap/AlGa_N-dielectric distributed Bragg reflectors [10918-13]
10918 0I	Optically pumped room temperature low threshold deep UV lasers grown on native AlN substrates [10918-17]

MATERIAL CHARACTERIZATION II

10918 0M	Green InGa_N/Ga_N based LEDs: high luminance and blue shift [10918-21]
10918 0O	Investigation of the device degradation for commercial light-emitting diodes (LEDs) using spatially and time-resolved electro- and photoluminescence [10918-23]
10918 0Q	Analysis on light extraction property of AlGa_N-based flip-chip ultraviolet light-emitting diodes by the use of self-assembled SiO₂ microsphere array [10918-25]

NANOSTRUCTURES

10918 0Z	New physics in Ga_N resonant tunneling diodes (Invited Paper) [10918-34]
10918 14	Demonstration of uniform and reliable Ga_N p-i-p-i-n separate-absorption and multiplication ultraviolet avalanche photodiode arrays with large detection area [10918-39]

ELECTRON DEVICES

10918 16	Vertical power devices enabled by bulk Ga_N substrates (Invited Paper) [10918-41]
----------	--

- 10918 17 **Degradation physics of GaN-based lateral and vertical devices (Invited Paper)** [10918-42]
- 10918 19 **Simple ohmic contact formation in HEMT structures: application to AlGaIn/GaN** [10918-44]
- 10918 1A **Normally-off p-GaN gate InAlIn/GaN HEMTs grown on silicon substrates** [10918-45]
- 10918 1B **Electrical and structural characteristics of aged RF GaN HEMTs and irradiated high-power GaN HEMTs with protons and heavy ions** [10918-46]

LASER DIODES

- 10918 1D **High-efficiency blue and green laser diodes for laser displays (Invited Paper)** [10918-48]
- 10918 1F **Influence of sandwiched GaN/AlGaIn/GaN lower quantum barrier on crystallinity and luminescence of an asymmetric GaN-based high-power laser diode** [10918-50]

VCSEL I

- 10918 1H **Room temperature continuous wave lasing of GaN-based green vertical-cavity surface-emitting lasers (Invited Paper)** [10918-52]

VCSEL II

- 10918 1J **Recent progress in GaN-based vertical-cavity surface-emitting lasers with lateral optical confinement due to an incorporated curved mirror (Invited Paper)** [10918-54]
- 10918 1L **Influence of Al ion implantation on electrical and optical properties in nitride TJ VCSEL** [10918-56]
- 10918 1M **Development of nanopore-based near ultraviolet vertical-cavity surface emitting lasers** [10918-57]

MICRO LEDs I

- 10918 1O **GaN monolithic integration for lighting and display (Invited Paper)** [10918-59]
- 10918 1Q **Advanced solutions for high-performance GaN MicroLED displays (Invited Paper)** [10918-61]

MICRO LEDs II

10918 1R **Growth of monolithic full-color light-emitting diode and its applications (Invited Paper)**
[10918-62]

UV LEDs

10918 1X **Functional integrity and stable high-temperature operation of planarized ultraviolet-A $\text{Al}_x\text{Ga}_{1-x}\text{N}/\text{Al}_y\text{Ga}_{1-y}\text{N}$ multiple-quantum-disk nanowire LEDs with charge-conduction promoting interlayer** [10918-68]

LEDs

10918 22 **Suppression of indium clustering and quantum confined stark effect of InGaN LED on silicon (111)** [10918-73]

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.

Alatawi, Abdullah A., 1X
Albadri, Abdulrahman M., 1X
Albrecht, John D., 0I
Alfaraj, Nasir, 1X
Alhamoud, Abdullah A., 1X
Alyamani, Ahmed Y., 1X
Anderson, Travis J., 16
Ayon, Arturo A., 19
Babu, Sachidananda, 14
Bakhtiary-Nooddeh, Marzieh, 14
Barbato, Alessandro, 17
Barbato, Marco, 17
Bayram, Can, 22
Bédoin, Alexis, 1Q
Bernard, Jeannet, 1Q
Biswas, Mahitosh, 0A
Bonsall, Jeremy, 1B
Borga, Matteo, 17
Bozok, Berkay, 1A
Brodie, Miles, 1B
Butun, Bayram, 1A
Canato, Eleonora, 17
Caplet, Stéphane, 1Q
Cetnar, John S., 19
Chakrabarti, Subhananda, 0A
Chen, J. C., 1R
Chen, Songtao, 1M
Cheung, Y. F., 1O
Chiocchetta, Francesca, 17
Cho, Sang June, 0I
Choi, H. W., 1O
Daami, Anis, 0M
Dalmau, Rafael, 0I
Das, Debabrata, 0A
De Santi, Carlo, 17
Detchprohm, Theeradetch, 0E, 14
Dhar, Nibir K., 14
Dupré, Ludovic, 0M
Dupuis, Russell D., 0E, 14
ElAfandy, Rami T., 1M
El-Ghoroury, Hussein S., 1R
Encomendero, Jimmy, 0Z
Fabris, Elena, 17
Feigelson, Boris N., 16
Foran, Brendan, 1B
Fu, W. Y., 1O
Gallagher, James C., 16
Ghasempour, Askari, 0O
Ghuman, P. Parminder, 14
Gulseren, Melisa Ekin, 1A
Haas, Helge, 1Q
Hamaguchi, Tatsushi, 1J
Han, Jung, 1M
Hartensveld, Matthew, 0Q
Hayashi, Kentaro, 1J
Heller, Eric, 19
Henry, Franck, 0M
Hirao, Tsuyoshi, 1D
Hite, Jennifer K., 16
Hobart, Karl D., 16
Huang, Rui, 1F
Ito, Masamichi, 1J
Jacobs, Alan G., 16
Janjua, Bilal, 1X
Jena, Debdeep, 0Z
Jeong, Hoon, 0E, 14
Ji, Mi-Hee, 14
Jyokawa, Tatsuro, 1J
Kalapala, Akhil R. K., 0I
Kayal, Omer Ahmet, 1A
Kobayashi, Noriko, 1J
Koda, Rintaro, 1J
Koehler, Andrew D., 16
Kozuru, Kazuma, 1D
Kub, Francis J., 16
Kumar, Raman, 0A
Kumar, Ravinder, 0A
Kurt, Gokhan, 1A
Lan, Tian, 1F
Le Calvez, Stéphanie, 0M
Lewis, Jay, 14
Li, K. H., 1O
Li, Ying, 1F
Licitra, Christophe, 0M
Lingley, Zachary, 1B
Liu, Cheng, 0Q
Liu, Dong, 0I
Liu, J. P., 1H
Liu, Richard, 22
Long, H., 1H
Look, David C., 19
Luna, Lunet E., 16
Ma, Zhenqiang, 0I
Masin, Fabrizio, 17
Masui, Shingo, 1D
Mato, Tatsuya, 1J
McCormick, Callan, 22
Mehta, Karan, 0E

Mei, Y., 1H
 Melanson, Bryan, 0Q
 Meneghesso, Gaudenzio, 17
 Meneghini, Matteo, 17
 Mi, Zetian, 0A
 Moody, Baxter, 0I
 Nagahama, Shin-ichi, 1D
 Nagao, Yoji, 1D
 Nakajima, Hiroshi, 1J
 Nakajima, Yoshitake, 1R
 Nakatsu, Yoshitaka, 1D
 Nardo, Arianna, 17
 Ndi, Francis, 0O
 Ng, Tien Khee, 1X
 Nurmikko, Arto, 1M
 Ohara, Maho, 1J
 Okahisa, Eiichiro, 1D
 Olivier, François, 0M
 Ooi, Boon S., 1X
 Ooi, Yu Kee, 0Q
 Ozbay, Ekmel, 1A
 Ozturk, Mustafa, 1A
 Pan, Xinhua, 0O
 Panda, Debiprasad, 0A
 Park, Jeongpil, 0I
 Park, Young-Jae, 0E
 Priante, Davide, 1X
 Price, Alain, 0O
 Rahimi, Nassim, 0O
 Rampazzo, Fabiana, 17
 Ruzzarin, Maria, 17
 Sarzata, R. P., 1L
 Shen, Shyh-Chiang, 0E, 14
 Sin, Yongkun, 1B
 Sitzman, Scott, 1B
 Sood, Ashok K., 14
 Śpiewak, P., 1L
 Tajalli, Alaleh, 17
 Tanaka, Masayuki, 1J
 Templier, François, 0M, 1Q
 Tsou, Chuan-Wei, 0E
 Upadhyay, Sourabh, 0A
 Ural, Sertac, 1A
 Vazquez-Colon, Clarissa D., 19
 Veksler, Dmitry, 1B
 Wang, Congcong, 1F
 Wang, Jialin, 0E
 Wang, Zhiyong, 1F
 Wasiak, M., 1L
 Watanabe, Hideki, 1J
 Xing, Hui Grace, 0Z
 Xu, R. B., 1H
 Yan, Anru, 1F
 Yanamoto, Tomoya, 1D
 Yanashima, Katsunori, 1J
 Yeh, Milton, 1R
 Ying, L. Y., 1H
 Yoder, P. Douglas, 0E
 Zanoni, Enrico, 17
 Zhang, B. P., 1H
 Zhang, Cheng, 1M
 Zhang, Jerry, 1M
 Zhang, Jing, 0Q
 Zhao, Deyin, 0I
 Zhao, Songrui, 0A
 Zheng, Z. W., 1H
 Zhou, Guangzheng, 1F
 Zhou, Weidong, 0I

Conference Committee

Symposium Chairs

Connie J. Chang-Hasnain, University of California, Berkeley
(United States)
Graham T. Reed, Optoelectronics Research Center (United Kingdom)

Symposium Co-chairs

Sailing He, KTH Royal Institute of Technology (Sweden) and Zhejiang
University (China)
Yasuhiro Koike, Keio University (Japan)

Program Track Chairs

James G. Grote, Photonics Consultant (United States)
Shibin Jiang, AdValue Photonics, Inc. (United States)

Conference Chairs

Hiroshi Fujioka, The University of Tokyo (Japan)
Hadis Morkoç, Virginia Commonwealth University (United States)
Ulrich T. Schwarz, Technische Universität Chemnitz (Germany)

Conference Co-chairs

Jen-Inn Chyi, National Central University (Taiwan)
Jung Han, Yale University (United States)
Motoaki Iwaya, Meijo University (Japan)

Conference Program Committee

Frank Bertram, Otto-von-Guericke-Universität Magdeburg (Germany)
Michal Bockowski, Institute of High Pressure Physics (Poland)
Raffaella Calarco, Paul-Drude-Institut für Festkörperelektronik
(Germany)
Mitch M. C. Chou, National Sun Yat-Sen University (Taiwan)
Martin Feneberg, Otto-von-Guericke-Universität Magdeburg
(Germany)
Mitsuru Funato, Kyoto University (Japan)
Bernard Gil, Laboratoire Charles Coulomb (France)
Nicolas Grandjean, Ecole Polytechnique Fédérale de Lausanne
(Switzerland)
Hideki Hirayama, RIKEN (Japan)

Ray-Hua Horng, National Chiao Tung University (Taiwan)
Chih-Fang Huang, National Tsing Hua University (Taiwan)
Michael Kneissl, Technische Universität Berlin (Germany)
Elison Matioli, Ecole Polytechnique Fédérale de Lausanne
 (Switzerland)
Koh Matsumoto, Taiyo Nippon Sanso Corporation (Japan)
Hideto Miyake, Mie University (Japan)
Eva Monroy, Commissariat à l'Énergie Atomique (France)
Yong-Tae Moon, LG Electronics Inc. (Korea, Republic of)
Yasushi Nanishi, Ritsumeikan University (Japan)
Ümit Özgür, Virginia Commonwealth University (United States)
Piotr Perlin, Institute of High Pressure Physics (Poland)
Fan Ren, University of Florida (United States)
Tae-Yeon Seong, Korea University (Korea, Republic of)
Bo Shen, Peking University (China)
Jong-In Shim, Hanyang University (Korea, Republic of)
Maria Tchernycheva, Université Paris-Sud 11 (France)
Akio Wakejima, Nagoya Institute of Technology (Japan)
Chih-Chung Yang, National Taiwan University (Taiwan)
Euijoon Yoon, Seoul National University (Korea, Republic of)

Session Chairs

- 1 Growth I
Ulrich T. Schwarz, Technische Universität Chemnitz (Germany)
- 2 Growth II
Ferdinand Scholz, Universität Ulm (Germany)
- 3 Material Characterization I
Frank Bertram, Otto-von-Guericke-Universität Magdeburg (Germany)
- 4 Material Characterization II
Ulrich T. Schwarz, Technische Universität Chemnitz (Germany)
- 5 Material Characterization III
Jesús Zúñiga-Pérez, Centre de Recherche sur l'Hétéroépitaxie et ses
 Applications (France)
- 6 Doping
Russell D. Dupuis, Georgia Institute of Technology (United States)
- 7 Nanostructures
Pierre Ruterana, Centre de Recherche sur les Ions, les Matériaux et la
 Photonique (France)

- 8 Electron Devices
Hiroshi Fujioka, Institute of Industrial Science, The University of Tokyo
(Japan)
- 9 Laser Diodes
Tetsuya Takeuchi, Meijo University (Japan)
- 10 VCSEL I
Martin D. Dawson, Fraunhofer UK Research Ltd. (United Kingdom)
- 11 VCSEL II
Motoaki Iwaya, Meijo University (Japan)
- 12 Micro LEDs I
Jung Han, Yale University (United States)
- 13 Micro LEDs II
François Templier, Université Grenoble Alpes, CEA-LETI (France)
- 14 UV LEDs
Zlatko Sitar, North Carolina State University (United States)
- 15 LEDs
Vitaliy Avrutin, Virginia Commonwealth University (United States)

