PROCEEDINGS OF SPIE

Gallium Nitride Materials and Devices XV

Hiroshi Fujioka Hadis Morkoç Ulrich T. Schwarz Editors

4–6 February 2020 San Francisco, California, United States

Sponsored and Published by SPIE

Volume 11280

Proceedings of SPIE 0277-786X, V. 11280

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 *Gallium Nitride Materials and Devices XV*, edited by Hiroshi Fujioka, Hadis Morkoç, Ulrich T. Schwarz, Proceedings of SPIE Vol. 11280 (SPIE, Bellingham, WA, 2020) Sevendigit Article CID Number.

ISSN: 0277-786X

ISSN: 1996-756X (electronic)

ISBN: 9781510633230

ISBN: 9781510633247 (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

51 IL.OIG

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

vii ix	Authors Conference Committee
	GROWTH I: BULK GROWTH AND EPITAXY
11280 02	Recent progress of large size and low dislocation bulk GaN growth (Invited Paper) [11280-1]
	GROWTH II: CHARACTERIZATION AND DISLOCATIONS
11280 09	Dislocation density reduction in (10 $\overline{11}$) GaN at a high temperature using tri-halide vapor phase epitaxy [11280-8]
	MATERIAL CHARACTERIZATION: POINT DEFECTS
11280 OB	Origin and dynamic properties of major intrinsic nonradiative recombination centers in wide bandgap nitride semiconductors (Invited Paper) [11280-10]
11280 OC	Control of vacancy-type defects in Mg implanted GaN studied by positron annihilation spectroscopy (Invited Paper) [11280-11]
11280 OE	Degradation and recovery of high-periodicity InGaN/GaN MQWs under optical stress in short-circuit condition [11280-13]
	VCSEL AND RCLED
11280 OH	Blue semipolar III-nitride vertical-cavity surface-emitting lasers (Invited Paper) [11280-15]
11280 01	Nonpolar GaN-based VCSELs with lattice-matched nanoporous distributed Bragg reflector mirrors (Invited Paper) [11280-16]
11280 OM	GaN-based vertical-cavity surface-emitting laser incorporating a TiO $_2$ high-index-contrast grating [11280-20]
	LED: LIGHT EXTRACTION AND EFFICIENCY
11280 00	PECVD grown SiN photonic crystal micro-domes for the light extraction enhancement of GaN LEDs [11280-22]

IN-PLANE LASER DIODES AND NONLINEAR OPTICS

	IN 1 LANE EASEN DIODES AND NONLINEAR OF IICS
11280 OS	Blue and green InGaN semiconductor lasers as light sources for displays [11280-26]
11280 OT	Angular resolved far-field dynamics of (Al,In)GaN laser diodes [11280-27]
	IN-PLANE LASER DIODES: VISIBLE AND UV
11280 OY	Critical discussion of the determination of internal losses in state-of-the-art (Al,In)GaN laser diodes [11280-32]
11280 OZ	Degradation mechanisms of 1.6 W blue semiconductor lasers: effect on subthreshold optical power and power spectral density [11280-33]
11280 10	Monolithically p-down nitride laser diodes and LEDs obtained by MBE using buried tunnel junction design [11280-34]
	UV LED
11280 15	Role of defects in the mid-term degradation of UV-B LEDs investigated by optical and DLTS measurements [11280-39]
11280 18	Enhancement of light extraction efficiency of 280-nm deep-UV LEDs using SiO_2 microsphere and microlens arrays [11280-42]
	MICROLED AND NANOSTRUCTURED DEVICES I
11280 1C	Analysis of InGaN surfaces after chemical treatments and atomic layer deposition of Al $_2$ O $_3$ for μ LED applications [11280-46]
	MICROLED AND NANOSTRUCTURED DEVICES II
11280 1E	Application of porous GaN for microLED (Invited Paper) [11280-48]
11280 1F	The photonic properties of micro/mini LED arrays with different substrate thickness (Invited Paper) [11280-49]

ELECTRONIC DEVICES

Out-diffusion of Pd as a potential degradation mechanism in GaN HEMTs with Ni-Pd-Au Schottky contacts [11280-52]

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.

Altuntaş, İ., 00 Amano, H., 15 Aragon, Andrew A., 01 Avrutin, V., 00 Avdınlı, A., 00 Back, Joonho, OH Banayeem, Hassan, OT Bengtsson, Jörgen, OM Bharadwaj, Shyam, 10 Brodie, Miles, 11 Bruederl, Georg, 0T Buffolo, M., OZ Cadot, Stéphane, 1C Caria, Alessandro, 0E Chang, Feng-Pin, 1F Chang, Tsu-Chi, 0M Chao, Chia-Hsin, 1F Chen, Chen, 1E Chen, Hong, 0E Chen, Yu-Sheng, 1F

Chichibu, Shigefusa F., 0B, 0C

Chlipala, Mikolaj, 10 Choi, Joo Won, 1E Chu, Chun-Wen, 1F Cohen, Daniel A., 0H Damm, Matthias, 0T Deki, M., 15 Demir, İ., 0O

DenBaars, Steven P., 0H
De Santi, Carlo, 0E, 0Z, 15
Dickmann, Marcel, 0C
Egger, Werner, 0C
Elagöz, S., 0O
Enatsu, Yuuki, 02
Fang, Yen-Hsiang, 1F
Feezell, Daniel F., 0I
Fu, Houqiang, 0E
Genç, M., 0O
Gheeraert, Etienne, 1C

Gülseren, O., 00 Gür, E., 00

Gustavsson, Johan, 0M Haglund, Åsa, 0M Hajdel, Mateusz, 10 Hara, Yoshihiro, 0S Hashemi, Ehsan, 0M Hirao, Tsuyoshi, 0S Huang, Xuanqi, 0E Hubbard, William, 11 Hugenschmidt, Christoph, 0C

Ikeda, Hirotaka, 02
Ishibashi, Shoji, 0B, 0C
Ishinabe, Takayuki, 02
Iso, Kenji, 02, 09
Izumisawa, Satoru, 02
Jena, Debdeep, 10
Kagamitani, Yuji, 02
Kearns, Jared A., 0H
Kido, Yuka, 09
Kohlstedt, Raphael, 0Y

Kojima, Kazunobu, OB König, Harald, OT Koukitu, Akinori, 09 Kubota, Kohei, 02 Kunzmann, Dominic J., 0Y Kushimoto, M., 15 Le Maoult, Corentin, 1C Lee, SeungGeun, 0H Lin, Chien-Chuna, 1F Lingley, Zachary, 11 Liu, Cheng, 18 Lu, Tien-Chang, 0M Luk, Ting S., Ol Martin, François, 1C Martinez, Eugénie, 1C Masui, Shingo, OS

Meneghesso, Gaudenzio, 0E, 0Z, 15 Meneghini, Matteo, 0E, 0Z, 15

Mikawa, Yutaka, 02

Melanson, Bryan, 18

Mishkat-Ul-Masabih, Saadat M., Ol

Miyata, Erina, 09 Mochizuki, Tae, 02 Monavarian, Morteza, 0l

Morkoç, H., 00 Mu, Yijie, 0T

Murakami, Hisashi, 09 Muziol, Grzegorz, 10 Nagahama, Shin-ichi, 0S

Nagao, Yoji, 0S Nakamura, Shuji, 0H Nakatsu, Yoshitaka, 0S Nolot, Emmanuel, 1C

Nowakowski-Szkudlarek, Krzesimir, 10

Ohtaki, Shoma, 09 Özgür, Ü., 0O

Palmquist, Nathan C., 0H

Piva, F., 0Z, 15

Schwarz, Ulrich T., OT, OY Sheremet, V., 00 Shibata, N., 15 Shima, Kohei, OB Siekacz, Marcin, 10 Sin, Yongkun, 11 Sitzman, Scott, 11 Skierbiszewski, Czeslaw, 10 Song, Jie, 1E Stanczyk, Szymon, 10 Taffarel, M., 0Z Takahashi, Tatsuya, 02 Tautz, Soenke, OT Tomozawa, H., 15 Tsukada, Yusuke, 02 Turski, Henryk, 10 Uedono, Akira, 0B, 0C Uhlig, Tino, 0Y Vaufrey, David, 1C Veksler, Dmitry, 11 Wang, Kai, 1E Wang, Po-Hsun, 1F Wu, Chih-I, 1F Wu, Dan, 1E Xing, Huili, 10 Yanamoto, Tomoya, OS Yang, Shu-Mei, 1F Zak, Mikolaj, 10 Zamperetti, Filippo, 0E Zanoni, Enrico, OE, OZ, 15 Zhang, Jing, 18 Zhao, Yuji, 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-Hasnain, University of California, Berkeley (United States)

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

Program Track Chairs

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

Conference Chairs

Hiroshi Fujioka, Institute of Industrial Science, The University of Tokyo (Japan)

Hadis Morkoç, Virginia Commonwealth University (United States) **Ulrich T. Schwarz**, Technische Universität Chemnitz (Germany)

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)

Jen-Inn Chyi, National Central 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)

Jung Han, Yale University (United States)

Hideki Hirayama, RIKEN (Japan)

Ray-Hua Horng, National Chiao Tung University (Taiwan)

Chih-Fang Huang, National Tsing Hua University (Taiwan)

Motoaki Iwaya, Meijo University (Japan)

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, CEA-INAC (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, Centre de Nanosciences et de Nanotechnologies (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

- Growth I: Bulk Growth and Epitaxy

 Tim Wernicke, Technische Universität Berlin (Germany)
- 2 Growth II: Characterization and Dislocations Shigefusa F. Chichibu, Tohoku University (Japan)
- 3 Material Characterization: Point Defects Michal Bockowski, Institute of High Pressure Physics (Poland)
- 4 VCSEL and RCLED Piotr Perlin, Institute of High Pressure Physics (Poland)
- LED: Light Extraction and Efficiency
 Daniel F. Feezell, The University of New Mexico (United States)
- In-Plane Laser Diodes and Nonlinear Optics
 Åsa Haglund, Chalmers University of Technology (Sweden)
- 7 In-Plane Laser Diodes: Visible and UV **Lucja Marona**, Institute of High Pressure Physics (Poland)
- 8 UV LED
 Andreas Waag, Technische Universität Braunschweig (Germany)

- 9 MicroLED and Nanostructured Devices I Martin D. Dawson, Fraunhofer UK Research Ltd. (United Kingdom)
- 10 MicroLED and Nanostructured Devices IIZlatko Sitar, North Carolina State University (United States)
- 11 Electronic Devices **Hiroshi Fujioka**, Institute of Industrial Science, The University of Tokyo (Japan)