PROCEEDINGS OF SPIE

Light-Emitting Devices, Materials, and Applications XXIV

Jong Kyu Kim Michael R. Krames Martin Strassburg Editors

3–6 February 2020 San Francisco, California, United States

Sponsored and Published by SPIE

Volume 11302

Proceedings of SPIE 0277-786X, V. 11302

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 *Light-Emitting Devices, Materials, and Applications XXIV*, edited by Jong Kyu Kim, Michael R. Krames, Martin Strassburg, Proceedings of SPIE Vol. 11302 (SPIE, Bellingham, WA, 2020) Seven-digit Article CID Number.

ISSN: 0277-786X

ISSN: 1996-756X (electronic)

ISBN: 9781510633674

ISBN: 9781510633681 (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

vii ix	Authors Conference Committee
	MICRO LED DISPLAY
11302 02	Emissive displays with transfer-printed microscale LEDs and ICs (Invited Paper) [11302-1]
11302 04	Mojo Vision NanoLEDs for Invisible Computing (Invited Paper) [11302-3]
	NOVEL ELECTROLUMINESCENT SEMICONDUCTOR MATERIALS AND DEVICES FOR SSL I
11302 08	High intensity photodegradation of lead halide perovskite nanocrystals [11302-7]
	LED APPLICATIONS AND SOLID-STATE LIGHTING
11302 0A	Challenges and improvements in LED-pumped luminescent concentrators [11302-9]
11302 OB	Limitations to emission spot size in laser lighting [11302-10]
11302 OC	Analysis and design of extreme intensity irradiation devices for research applications [11302-11]
11302 0D	OpticStudio TrueFreeform TM optimization for complex illumination systems [11302-12]
	NANOMATERIALS AND NANOSTRUCTURES FOR LEDS
11302 OH	Nano structured light emitting diodes through 3D mold (Invited Paper) [11302-16]
	LED MANUFACTURING/EPITAXIAL GROWTH
11302 ON	Challenges and opportunities of MOVPE and THVPE/HVPE for nitride light emitting devices (Invited Paper) [11302-22]

-	NOVEL ELECTROLUMINESCENT SEMICONDUCTOR MATERIALS AND DEVICES FOR SSL II
11302 OP	WS ₂ monolayer based light emitting devices fabricated by scalable deposition techniques (Invited Paper) [11302-24]
	EFFICIENCY CHALLENGES IN III-NITRIDE LEDS
11302 0X	Dependence of degradation on InGaN quantum well position: a study based on color coded structures [11302-32]
	NIR/IR-EMITTING LEDS
11302 OY	Red surface-emitting SLEDs (Invited Paper) [11302-33]
11302 OZ	Tunable spectral asymmetry at the facets of a chirped tapered quantum-dot superluminescent diode [11302-34]
11302 12	Fast-responding mid-IR light emitter using suspended multilayer graphene [11302-37]
	LIGHT-BASED SENSORS AND COMMUNICATION
11302 13	Advanced LiFi technology: laser light (Invited Paper) [11302-38]
11302 14	Bidirectional data transfer in VLC links [11302-39]
11302 16	Automotive LiDAR pollution detection system based on total internal reflection techniques [11302-41]
	UV/DUV LEDS AND THEIR APPLICATIONS
11302 1F	Hermetic SMD-type reflector cavity packaging for DUV LEDs [11302-49]
	WAVELENGTH CONVERSION MATERIALS AND COMPONENTS
11302 1M	Paving the way to the high-performance red phosphor SALON (Invited Paper) [11302-79]
11302 1N	Static ceramic phosphor assemblies for high-power, high-luminance SSL-light sources for digital projection and specialty lighting [11302-53]

11302 10	Static crystal phosphor for high power projection applications [11302-54]
	NOVEL TECHNOLOGIES FOR LED DESIGN AND FABRICATION
11302 1P	Photonic crystal based control of directionality in GaN based LEDs (Invited Paper) [11302-58]
11302 1R	Coupling of WGM modes of two ZnO microspheres in contact: experiment and simulation [11302-60]
11302 18	Laser-excited phosphor light recycling using parabolic reflectors [11302-61]
	POSTER SESSION
11302 1U	High-precision color uniformity based on 4D transformation for micro-LED [11302-63]
11302 1V	Advanced optical characterization of automotive interior materials for premium visual quality [11302-64]
11302 1W	Experimental and theoretical investigation of Mn-doped CsPbCl ₃ with orange light emission [11302-65]
11302 1X	Green light emission in CsPbBr3 quantum dots: theoretical and experimental insight [11302-66]
11302 1Z	Strong crystal field splitting and polarization dependence observed in the emission from Eu $^{3+}$ ions doped into GaN [11302-68]
11302 21	Characterization of micro-pixelated InGaP/AlGaInP quantum well structures [11302-70]
11302 26	Reconstruction method of gradient-index field with background-oriented schlieren [11302-75]

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.

Abdelbaky, Mohamed, 0P Andrzejewski, Dominik, 0P

Arimura, T., 0N Austin, H., 1Z Bacher, Gerd, OP Bailey, Christopher G., 08 Baken, Jannie, 0A Bardella, Paolo, OZ Barnes, Jean-Paul, 21 Beckmann, Yannick, OP Ben Bakir, Badhise, 21 Benoy, Dany, 0A Biarlin Jensen, Ole, 0B Blankenbach, K., 1V Bonafede, S., 02 Boussadi, Younes, 21 Bower, C. A., 02 Bruls, Dominique, 0A

Cataluna, Maria Ana, 0Z Chakrabarti, Subhananda, 1W, 1X

Chang, Yia-Chung, 1R
Chang, Yung Peng, 1O
Charlton, Martin D. B., 08, 1P
Chien, Ching-Hang, 1R
Copelman, S., 1Z
Dalla Torre, Francesco, 0X

De Santi, Carlo, 0X Dierolf, V., 1Z

Caria, Alessandro, 0X

Dongre, Suryansh, 1W, 1X Dughiero, Fabrizio, 0C Durlinger, Ivo, 0A Ferrandis, Philippe, 21 Forrest, Adam F., 0Z Forzan, Michele, 0C Fujii, Takeo, 12 Fujiwara, Y., 1Z Gay, Shawn, 0D

Gomez-Iglesias, Alvaro, 0Y Grundmann, Annika, 0P Gyenge, Oliver, 1F Haas, Harald, 13 Haenen, Ludo, 0A Hagemann, Volker, 1N Hansen, Anders Kragh, 0B

Hansen, Ulli, 1F Hertlein, F., 1V Heuken, Michael, 0P Hoelen, Christoph, 0A Hoerder, Gregor J., 1M Hu, Xiaodong, 1F Huppertz, Hubert, 1M Ichikawa, S., 1Z Ikeda, Katsumoto, 0D Islim, Mohamed Sufyan, 13 Ito, Yoshinobu, 12

Jansen, Jan, 0A
Jentzsch, Bruno, 0Y
Jian, Xu, 0B
Kadijk, Simon, 0A
Kalisch, Holger, 0P
Kanaras, Antonios G., 08
Keum, Changmin, 1U
Keur, Wilco, 0A
Kim, Chanyul, 1U
Kim, Je Won, 0H
Kim, Kwangdon, 1U
Koop, K., 1V
Koseki, S., 0N

Krakowski, Michel, 0Z

Krasnoshchoka, Anastasiia, OB

Krishnan, Chirenjeevi, 1P

Krongard, B., 02

Kumar, Abhishek, 1W, 1X Kümmell, Tilmar, 0P

Lagoudakis, Pavlos G., 08, 1P

Lee, Changmin, 13 Li, Kenneth, 10, 1S Licitra, Christophe, 21 Lim, Taegyu, 1U Liu, Chia-Liang, 1R Louro, P., 14 Marti, Dominik, 0B Martin, Paul S., 04 Marx, Sebastian, 1F Masenelli, Bruno, 21 Matsumoto, K., 0N Maus, Simon, 1F McLaurin, Melvin, 13 Meitl, M. A., 02

Meneghesso, Gaudenzio, 0C, 0X Meneghini, Matteo, 0C, 0X Mercier, Thomas M., 08, 1P

Mishima, A., 0N Mitchell, B., 1Z Mos, Barry, 0A Musselman, Kevin, 0P Nagata, Takaaki, 12 Najiba, F., 1V

Nakamura, Tenkai, 12

Neumann, Cornelius, 16

Ohno, Hiroshi, 26

Pandey, Nivedita, 1W, 1X

Park, Cheolseong, 1U

Park, Seihan, 1U

Pearson, A., 02

Peterseim, Tobias, 16

Petersen, Paul Michael, OB

Pizzolato, Alberto, OC

Poplawsky, J. D., 1Z

Queisser, Marco, 1F Radauscher, E., 02

Raring, James, 13

Raymond, B., 02

Reichel, S., 1V

Kelchel, 3., 1 v

Renso, Nicola, 0X

Rochat, Névine, 21

Rudy, Paul, 13

Sasaki, Tatsuaki, 12

Seidl, Albrecht, 1N

Shah, Binith, 13

Shaw, Peter J., 08, 1P

Sparks, Adrian, 13

Suyama, Motohiro, 12

Tatebayashi, J., 1Z

Thorseth, Anders, OB

Timmerman, D., 1Z

Tokunaga, H., 0N

Tomita, Y., 0N

Tonkikh, Alexander, 0Y

Trierweiler, Manuel, 16

Trivellin, Nicola, 0C

Ulrich, M., 1V

van Grunsven, Eric, 0A

Verreen, C., 02

Vescan, Andrei, OP

Vick, E., 02

Videv, Stefan, 13

Vieira, M. A., 14

Vieira, M., 14

Waite, M., 1Z

Weeks, T., 02

Weidmann, Günter, 1N

Witzigmann, Bernd, OY

Yamaguchi, A., 0N

Yamaoka, Y., 0N

Yano, Y., 0N

Yeow, Travis, OP

Yu, Joan, 0A

Zanoni, Enrico, OC, OX

Zecchin, Lorenzo, 0X

viii

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

Jong Kyu Kim, Pohang University of Science and Technology (Korea, Republic of)

Michael R. Krames, Arkesso, LLC (United States)

Martin Strassburg, OSRAM Opto Semiconductors GmbH (Germany)

Conference Program Committee

Jim R. Bonar, Facebook Technologies, LLC (United States)

Yong-Hoon Cho, KAIST (Korea, Republic of)

Aurelien David, Soraa, Inc. (United States)

Amélie Dussaigne, CEA-LETI (France)

Kolja Haberland, LayTec AG (Germany)

Michael Heuken, AIXTRON SE (Germany)

Christoph G. A. Hoelen, Signify N.V. (Netherlands)

Soo Min Lee, Veeco Compound Semiconductor Inc. (United States)

Yun-Li Li, National Taiwan University (Taiwan)

Tien-Chang Lu, National Chiao Tung University (Taiwan)

Hee Jin Kim, Lumileds, LLC (United States)

Juanita N. Kurtin, OSRAM Opto Semiconductors (United States)

Matteo Meneghini, Università degli Studi di Padova (Italy)

Sungwon D. Roh, LG Innotek (Korea, Republic of)

Klaus P. Streubel, OSRAM GmbH (United States)

Tetsuya Takeuchi, Meijo University (Japan)

Rie Togashi, Tokyo University of Agriculture and Technology (Japan)

Li-Wei Tu, National Sun Yat-Sen University (Taiwan)

Marie Anne van de Haar, Seaborough Research B.V. (Netherlands)

Dong-Sing Wuu, National Chung Hsing University (Taiwan)

Erin C. Young, University of California, Santa Barbara (United States)

Session Chairs

1 Micro LED Display

Michael R. Krames, Arkesso, LLC (United States)
Jim R. Bonar, Facebook Technologies, LLC (United States)

2 Novel Electroluminescent Semiconductor Materials and Devices for SSL I

Martin Strassburg, OSRAM Opto Semiconductors GmbH (Germany)

- 3 LED Applications and Solid-State Lighting Jong Kyu Kim, Pohang University of Science and Technology (Korea, Republic of)
- 4 Nanomaterials and Nanostructures for LEDs **Aurelien David**, Soraa, Inc. (United States)
- 5 2D Optoelectronics MaterialsDebdeep Jena, Cornell University (United States)
- 6 LED Manufacturing/Epitaxial Growth Martin Strassburg, OSRAM Opto Semiconductors GmbH (Germany)
- 7 Novel Electroluminescent Semiconductor Materials and Devices for SSL II

Soo Min Lee, Veeco Instruments Inc. (United States)

- 8 Efficiency Challenges in III-Nitride LEDs Aurelien David, Soraa, Inc. (United States) Michael R. Krames, Arkesso, LLC (United States)
- 9 NIR/IR-Emitting LEDs **Changmin Lee**, SLD Laser (United States)
- 10 Light-Based Sensors and Communication Bernd Witzigmann, University Kassel (Germany)
- Novel Substrates and UV/DUV LEDs and their Applications **Masafumi Jo**, RIKEN Center for Brain Science (Japan)
- 12 UV/DUV LEDs and Their Applications **Tetsuya Takeuchi**, Meijo University (Japan)

- 13 Quantum-Dot Based LEDsJuanita N. Kurtin, OSRAM Opto Semiconductors Inc. (United States)
- 14 Wavelength Conversion Materials and Components Marie Anne van de Haar, Seaborough Research B.V. (Netherlands)
- 15 Novel Technologies for LED Design and Fabrication **Je Won Kim**, Namseoul University (Korea, Republic of)