PROCEEDINGS OF SPIE

Light-Emitting Diodes: Materials, Devices, and Applications for Solid State Lighting XVI

Klaus P. Streubel Heonsu Jeon Li-Wei Tu Norbert Linder Editors

24–26 January 2012 San Francisco, California, United States

Sponsored by SPIE

Cosponsored by OSRAM GmbH (Germany)

Published by SPIE

Volume 8278

Proceedings of SPIE, 0277-786X, v. 8278

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

The papers included 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. The papers published in these proceedings 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 this book:

Author(s), "Title of Paper," in Light-Emitting Diodes: Materials, Devices, and Applications for Solid State Lighting XVI, edited by Klaus P. Streubel, Heonsu Jeon, Li-Wei Tu, Norbert Linder, Proceedings of SPIE Vol. 8278 (SPIE, Bellingham, WA, 2012) Article CID Number.

ISSN 0277-786X ISBN 9780819489210

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 © 2012, 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/12/\$18.00.

Printed in the United States of America.

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



SPIEDigitalLibrary.org

Paper Numbering: Proceedings of SPIE follow an e-First publication model, with papers published first online and then in print and on CD-ROM. Papers are published as they are submitted and meet publication criteria. A unique, consistent, permanent citation identifier (CID) number is assigned to each article at the time of the first 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, print, and electronic versions of the publication. SPIE uses a six-digit CID article numbering system in which:

- The first four 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. The complete citation is used on the first page, and an abbreviated version on subsequent pages. Numbers in the index correspond to the last two digits of the six-digit CID number.

Contents

vii Conference Committee

SOLID STATE LIGHTING AND HUMAN LIFE

- Spectral design flexibility of LED brings better life (Invited Paper) [8278-01]
 H. Ou, D. Corell, Y. Ou, P. B. Poulsen, C. Dam-Hansen, P.-M. Petersen, Technical Univ. of Denmark (Denmark)
- 8278 03 Blue enhanced light sources: opportunities and risks [8278-02] D. Lang, OSRAM AG (Germany)
- 8278 04 Smart dimming circuit used in solid state lightings suitable for skygazer [8278-03] K. Sakai, Kochi Univ. of Technology (Japan)
- Secondary optical design for safety light curtains [8278-04]
 Y.-H. Hsu, Y.-Y. Chen, A. J.-W. Whang, National Taiwan Univ. of Science and Technology (Taiwan)

SOLID STATE LIGHTING AND PHOSPHORS

- 8278 0D **Multispectral mixing scheme for smart LED-based lighting system** [8278-12] S.-B. Chiang, M.-C. Chien, C.-H. Tien, National Chiao Tung Univ. (Taiwan)
- 8278 0E Infrared excited Yb:Er: Y2O2S phosphors with intense emission for lighting applications (Green Photonics Award) [8278-13]
 G. A. Kumar, M. Pokhrel, D. K. Sardar, The Univ. of Texas at San Antonio (United States)

INTERNAL QUANTUM EFFICIENCY AND DROOP EFFECT IN LEDS I

8278 0J Effect of dislocation density on efficiency curves in InGaN/GaN multiple quantum well light-emitting diodes [8278-18]
 Y. Harada, T. Hikosaka, S. Kimura, M. Sugai, H. Nago, K. Tachibana, N. Sugiyama, S. Nunoue, Toshiba Corp. (Japan)

UV LEDS

Beep UV-LEDs with high IQE based on AlGaN alloys with strong band structure potential fluctuations (Invited Paper) [8278-20]
 T. D. Moustakas, Y. Liao, C. Kao, C. Thomidis, A. Bhattacharyya, D. Bhattarai, A. Moldawer, Boston Univ. (United States)

8278 0N Toward blue emission in ZnO based LED [8278-22] B. Viana, LCMCP, Ecole Nationale Supérieure de Chimie de Paris (France); T. Pauporté, O. Lupan, T. Le Bahers, I. Ciofini, LECIME, Ecole Nationale Supérieure de Chimie de Paris (France)

NOVEL TECHNIQUES AND STRUCTURES FOR LEDS

- Ban-based microcavity polariton light emitting diodes (Invited Paper) [8278-23]
 T.-C. Lu, Y.-Y. Lai, S.-W. Huang, J.-R. Chen, Y.-C. Wu, S.-C. Lin, S.-C. Wang, National Chiao Tung Univ. (Taiwan); Y. Yamamoto, Stanford Univ. (United States)
- 8278 0Q Optical mode pattern study of GaN LEDs with and without top nano-gratings [8278-25]
 G. Chavoor, D. Cattarusa, X. Jin, California Polytechnic State Univ., San Luis Obispo (United States); X.-X. Fu, X.-N. Kang, B. Zhang, G.-Y. Zhang, Peking Univ. (China)
- 8278 0S Power enhancement of 380 nm UV-LED with hexagonal pyramid structures by AIN sacrificial layer [8278-27]
 T.-C. Hung, P.-M. Tu, S.-H. Huang, C.-P. Shen, C. Hsu, Advanced Optoelectronic Technology, Inc. (Taiwan)

LED FABRICATION AND PROPERTIES I

- 8278 0W Innovative methodology for testing the reliability of LED based systems [8278-32] N. Trivellin, LightCube LED Design Ctr. (Italy); M. Meneghini, M. Dal Lago, G. Meneghesso, E. Zanoni, Univ. of Padova (Italy)
- Study on GaN epilayer transferring to Cu substrate from sapphire substrate using Ga₂O₃ sacrificial layer [8278-50]
 R. H. Horng, National Chung Hsing Univ. (Taiwan); D. S. Wuu, National Chung Hsing Univ. (Taiwan) and Da-Yeh Univ. (Taiwan); S. L. Ou, H. H. Hsueh, National Chung Hsing Univ. (Taiwan)

NANOPHOTONICS FOR PHOSPHORS

Power conversion and luminous efficiency performance of nanophosphor quantum dots on color-conversion LEDs for high-quality general lighting [8278-35]
 T. Erdem, S. Nizamoglu, Bilkent Univ. (Turkey); H. V. Demir, Bilkent Univ. (Turkey) and Nanyang Technological Univ. (Singapore)

NANOSTRUCTURES FOR LEDS

8278 15 Electrically driven nanoarrow array green LED [8278-39]
 J.-R. Chang, S.-P. Chang, Y.-C. Chen, K.-P. Sou, National Chiao Tung Univ. (Taiwan);
 Y.-J. Cheng, National Chiao Tung Univ. (Taiwan) and Research Ctr. for Applied Sciences (Taiwan); H.-C. Kuo, C.-Y. Chang, National Chiao Tung Univ. (Taiwan)

8278 16 Top-down fabrication of GaN-based nanorod LEDs and lasers [8278-40]
 G. T. Wang, Q. Li, J. Wierer, J. Figiel, J. B. Wright, T. S. Luk, I. Brener, Sandia National Labs. (United States)

INTERNAL QUANTUM EFFICIENCY AND DROOP EFFECT IN LEDS II

- Simulation of light-emitting diodes for new physics understanding and device design (Invited Paper) [8278-43]
 K. A. Bulashevich, O. V. Khokhlev, I. Yu. Evstratov, S. Yu. Karpov, STR Group-Soft Impact Ltd. (Russian Federation)
- 8278 1A Low efficiency droop of InGaN/GaN blue LEDs with super-lattice active structure [8278-44] S.-P. Chang, K.-P. Sou, J.-R. Chang, National Chiao Tung Univ. (Taiwan); Y.-J. Cheng, National Chiao Tung Univ. (Taiwan) and Research Ctr. for Applied Sciences (Taiwan); Y.-J. Li, Y.-C. Chen, H.-C. Kuo, K.-Y. Hsu, C.-Y. Chang, National Chiao Tung Univ. (Taiwan)
- 8278 1B Investigation of efficiency droop for UV LED with N-type AIGaN layer [8278-45] P.-M. Tu, Advanced Optoelectronic Technology, Inc. (Taiwan); J.-R. Chang, National Chiao Tung Univ. (Taiwan); S.-C. Huang, S.-K. Yang, Y. Lin, T.-C. Hung, C.-P. Hsu, Advanced Optoelectronic Technology, Inc. (Taiwan); C.-Y. Chang, National Chiao Tung Univ. (Taiwan)

LED FABRICATION AND PROPERTIES II

8278 1E GaN-based LEDs with air voids prepared by laser scribing and chemical etching (Invited Paper) [8278-48]

S. J. Chang, National Cheng Kung Univ. (Taiwan)

POSTER SESSION

- 8278 1H Spectroscopic study and white-light simulation using praseodymium-doped fluorogermanate glass as single phosphor for white LEDs [8278-52]
 A. S. Gouveia-Neto, N. P. S. M. Rios, L. A. Bueno, Univ. Federal Rural de Pernambuco (Brazil)
- 8278 11 Characterization of four-color multi-package white light-emitting diodes combined with various green monochromatic phosphor-converted light-emitting diodes [8278-53] J. H. Oh, K. N. Lee, Y. R. Do, Kookmin Univ. (Korea, Republic of)
- 8278 1J Effects of 2D SiO₂ and SiN_x photonic crystal on extracted light from Y₃Al₅O₁₂:Ce³⁺ ceramic plate phosphor [8278-54]
 H. K. Park, J. R. Oh, Y. R. Do, Kookmin Univ. (Korea, Republic of)
- Museum lighting for golden artifacts with low correlated color temperature, high color uniformity, and high color rendering index, using diffusing color mixing of red, cyan, and white-light-emitting diodes [8278-58]
 A. Thorseth, D. D. Corell, P. B. Poulsen, S. S. Hansen, C. Dam-Hansen, Technical Univ. of Denmark (Denmark)

- 8278 10 Optimization of light quality from color mixing light-emitting diode systems for general lighting [8278-59] A. Thorseth, Technical Univ. of Denmark (Denmark)
- 8278 1P Light emitting diode in stationary transportation applications: wavelength response to varying temperature [8278-60] G. Schirripa Spagnolo, D. Papalillo, A. Martocchia, Univ. degli Studi di Roma Tre (Italy)
- 8278 1S Study of efficiency-droop mechanism in vertical red light-emitting diodes using electrical-to-optical impulse responses [8278-63] J.-W. Shi, National Central Univ. (Taiwan) and Univ. of California, Santa Barbara (United States); F.-M. Kuo, C.-W. Lin, W. Chen, National Central Univ. (Taiwan); M. L. Lee, Southern Taiwan Univ. of Technology (Taiwan); L.-J. Yan, J.-K. Sheu, National Cheng-Kung Univ. (Taiwan)
- 8278 1T Suppression of efficiency-droop effect of InGaN-based LEDs by using localized high indium quantum wells [8278-65]

Y.-C. Yao, Y.-C. Chen, Y.-J. Lee, National Taiwan Normal Univ. (Taiwan)

Author Index

Conference Committee

Symposium Chair

Klaus P. Streubel, OSRAM GmbH (Germany)

Symposium Cochairs

David L. Andrews, University of East Anglia Norwich (United Kingdom) **Liang-Chy Chien**, Kent State University (United States)

Program Track Chair

Klaus P. Streubel, OSRAM GmbH (Germany)

Conference Chairs

Klaus P. Streubel, OSRAM GmbH (Germany) Heonsu Jeon, Seoul National University (Korea, Republic of) Li-Wei Tu, National Sun Yat-Sen University (Taiwan)

Conference Cochair

Norbert Linder, OSRAM Opto Semiconductors GmbH (Germany)

Program Committee

Gerd Bacher, Universität Duisburg-Essen (Germany) Shoou-Jinn Chang, National Cheng Kung University (Taiwan) Mitch M. C. Chou, National Sun Yat-Sen University (Taiwan) Michael Heuken, AIXTRON SE (Germany) Satoshi Kamiyama, Meijo University (Japan) Jong Kyu Kim, Pohang University of Science and Technology (Korea, Republic of) Markus Klein, OSRAM Opto Semiconductors GmbH (Germany) Michael R. Krames, Soraa, Inc. (United States) Hao-Chung Kuo, National Chiao Tung University (Taiwan) Kei May Lau, Hong Kong University of Science and Technology (Hong Kong, China) Kurt J. Linden, Spire Corporation (United States) Hans Nikol, Philips Lighting B.V. (Netherlands) Joongseo Park, LG Electronics Inc. (Korea, Republic of) E. Fred Schubert, Rensselaer Polytechnic Institute (United States) Ross P. Stanley, Centre Suisse d'Electronique et de Microtechnique SA (Switzerland)

Session Chairs

1	Solid State Lighting and Human Life Klaus P. Streubel , OSRAM GmbH (Germany)
2	Novel Substrates for LED Growth Michael Heuken, AIXTRON SE (Germany)
3	Solid State Lighting and Phosphors Li-Wei Tu , National Sun Yat-Sen University (Taiwan)
4	Internal Quantum Efficiency and Droop Effect in LEDs I E. Fred Schubert, Rensselaer Polytechnic Institute (United States)
5	UV LEDs Gerd Bacher, Universität Duisburg-Essen (Germany)
6	Novel Techniques and Structures for LEDs Dong-Sing Wuu , National Sun Yat-Sen University (Taiwan)
7	LED Fabrication and Properties I Ross P. Stanley , Centre Suisse d'Electronique et de Microtechnique SA (Switzerland)
8	Nanophotonics for Phosphors Satoshi Kamiyama , Meijo University (Japan)
9	Nanostructures for LEDs Kurt J. Linden , Spire Corporation (United States)
10	Internal Quantum Efficiency and Droop Effect in LEDs II Michael R. Krames, Soraa, Inc. (United States)
11	LED Fabrication and Properties II Jong Kyu Kim, Pohang University of Science and Technology (Korea, Republic of)