

PROCEEDINGS OF SPIE

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

**Klaus P. Streubel
Heonsu Jeon
Li-Wei Tu**
Editors

**27–29 January 2009
San Jose, California, United States**

Sponsored and Published by
SPIE

Cosponsored by
AIXTRON AG (Germany)
OSRAM Opto Semiconductors GmbH (Germany)

Volume 7231

Proceedings of SPIE, 0277-786X, v. 7231

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 XIII*, edited by Klaus P. Streubel, Heonsu Jeon, Li-Wei Tu, Proceedings of SPIE Vol. 7231 (SPIE, Bellingham, WA, 2009) Article CID Number.

ISSN 0277-786X

ISBN 9780819474773

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 © 2009, 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/09/\$18.00.

Printed in the United States of America.

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



SPIDigitalLibrary.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 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

LED DESIGN AND FABRICATION I

- 7231 0A **Color-consistent LED modules for general lighting (Invited Paper)** [7231-09]
C. Hoelen, P. van der Burgt, Philips Lighting (Netherlands); P. Jungwirth, Philips Lighting (Canada); M. Keuper, Philips Lighting (Netherlands); K. Man, Philips Lighting (Canada); C. Mutter, J.-W. ter Weeme, Philips Lighting (Netherlands)
- 7231 0C **Beam-shaping properties of InGaN thin-film micro-cavity light-emitting diodes with photonic crystals** [7231-11]
K. Bergenek, OSRAM Opto Semiconductors GmbH (Germany) and Univ. of St. Andrews (United Kingdom); Ch. Wiesmann, H. Zull, C. Rumbolz, R. Wirth, N. Linder, K. Streubel, OSRAM Opto Semiconductors GmbH (Germany); T. F. Krauss, Univ. of St. Andrews (United Kingdom)
- 7231 0E **Growth of staggered InGaN quantum well light-emitting diodes emitting at 520–525 nm employing graded temperature profile** [7231-13]
H. Zhao, G. Liu, X. Li, R. A. Arif, G. S. Huang, Y.-K. Ee, N. Tansu, Lehigh Univ. (United States)

UV LEDs

- 7231 0G **MOVPE growth for UV-LEDs (Invited Paper)** [7231-15]
A. Knauer, F. Brunner, Ferdinand-Braun-Institut für Höchstfrequenztechnik (Germany); T. Kolbe, Technische Univ. Berlin (Germany); V. Küller, H. Rodriguez, S. Einfeldt, M. Weyers, Ferdinand-Braun-Institut für Höchstfrequenztechnik (Germany); M. Kneissl, Ferdinand-Braun-Institut für Höchstfrequenztechnik (Germany) and Technische Univ. Berlin (Germany)
- 7231 0J **Effect of UV irradiation on the apoptosis and necrosis of Jurkat cells using UV LEDs** [7231-18]
S. A. Inada, H. Amano, I. Akasaki, Meijo Univ. (Japan); A. Morita, K. Kobayashi, Nagoya City Univ. (Japan)
- 7231 0K **Reduced non-thermal roll-over in violet-emitting GaInN wide-well LEDs grown on low-dislocation-density substrates** [7231-56]
M. Maier, T. Passow, M. Kunzer, W. Schirmacher, W. Pletschen, L. Kirste, K. Köhler, J. Wagner, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany)

LED MANUFACTURING

- 7231 0O **Decay of lumen and chromaticity of high-power phosphor-converted white-light-emitting diodes in thermal aging (Invited Paper)** [7231-23]
J.-S. Wang, C.-C. Tsai, M.-H. Chen, National Sun Yat-Sen Univ (Taiwan); Y.-C. Hsu, National Pingtung Univ. of Science and Technology (Taiwan); H.-L. Hu, C.-W. Lee, ITRI (Taiwan); W.-H. Cheng, National Sun Yat-Sen Univ. (Taiwan)

7231 0P **Photoluminescence mapping as a tool to improve LED production (Invited Paper)** [7231-24]
Z. Li, T. Ryan, Nanometrics Inc. (United States)

7231 0Q **High-performance heat sink for solid-state lighting** [7231-25]
J. Vetovec, A. Litt, Aqwest LLC (United States)

LED DESIGN AND FABRICATION II

7231 0U **Enhancement of light extraction efficiency of InGaN quantum well light-emitting diodes with polydimethylsiloxane concave microstructures** [7231-30]
Y.-K. Ee, P. Kumnorkaew, H. Tong, R. A. Arif, J. F. Gilchrist, N. Tansu, Lehigh Univ. (United States)

7231 0V **A 4.26- μ m RCLED and a fast low-power CO₂ sensor** [7231-31]
A. Nelson, A. Kouznetsov, GE Sensing (United States)

7231 0W **Electrical and optical characteristics of green light-emitting diodes grown on bulk GaN substrates** [7231-32]
Y. Yang, X. A. Cao, C. H. Yan, West Virginia Univ. (United States)

PHOSPHORS

7231 0X **Up and down: color conversion for solid-state lighting (Invited Paper)** [7231-33]
P. Hartmann, P. Pachler, Ledon Lighting Jennersdorf GmbH (Austria); E. L. Payrer, TU Graz (Austria); S. Tasch, Ledon Lighting Jennersdorf GmbH (Austria)

7231 11 **Improved predictive modeling of white LEDs with accurate luminescence simulation and practical inputs with TracePro opto-mechanical design software** [7231-37]
C. Tsao, E. R. Freniere, Lambda Research Corp. (United States); L. Smith, Ceres (United States)

NANOSTRUCTURES

7231 12 **Growth and luminescence properties of one-dimensional InN and InGaN nanostructures (Invited Paper)** [7231-38]
L.-C. Chen, A. Ganguly, National Taiwan Univ. (Taiwan); C.-W. Hsu, M.-S. Hu, Institute of Atomic and Molecular Sciences (Taiwan); S.-P. Fu, Y.-F. Chen, National Taiwan Univ. (Taiwan); K.-H. Chen, National Taiwan Univ. (Taiwan) and Institute of Atomic and Molecular Sciences (Taiwan)

NOVEL SUBSTRATES

- 7231 16 **High-quality free-standing GaN thick-films prepared by hydride vapor phase epitaxy using stress reducing techniques (Invited Paper)** [7231-42]
H.-H. Huang, W.-I. Lee, National Chiao Tung Univ. (Taiwan); K.-M. Chen, National Chiao Tung Univ. (Taiwan) and Industrial Technology Research Institute (Taiwan); T.-L. Chu, P.-L. Wu, H.-W. Yu, National Chiao Tung Univ. (Taiwan); P.-C. Liu, C.-L. Chao, T.-W. Chi, J.-D. Tsay, Industrial Technology Research Institute (Taiwan); L.-W. Tu, National Sun Yat-Sen Univ. (Taiwan)
- 7231 18 **GaN-based LEDs grown on 6-inch diameter Si (111) substrates by MOVPE (Invited Paper)** [7231-44]
D. Zhu, C. McAleese, K. K. McLaughlin, M. Häberlen, C. O. Salcianu, E. J. Thrush, M. J. Kappers, W. A. Phillips, Univ. of Cambridge (United Kingdom); P. Lane, D. J. Wallis, T. Martin, M. Astles, QinetiQ (United Kingdom); S. Thomas, A. Pakes, M. Heuken, Aixtron, Ltd. (United Kingdom); C. J. Humphreys, Univ. of Cambridge (United Kingdom)
- 7231 19 **Development of new substrate technologies for GaN LEDs: atomic layer deposition transition layers on silicon and ZnO (Invited Paper)** [7231-45]
W. E. Fenwick, N. Li, M. Jamil, T. Xu, A. Melton, S. Wang, H. Yu, Georgia Institute of Technology (United States); A. Valencia, J. Nause, Cermet, Inc. (United States); C. Summers, I. T. Ferguson, Georgia Institute of Technology (United States)

POSTER SESSION

- 7231 1E **Stray light rejection techniques for LED measurements using CCD based spectrometers** [7231-51]
J. Jablonski, A. Arecchi, J. Jacobs, T. Annicchiarco, SphereOptics, LLC (United States)
- 7231 1F **Simulator for assessing the performance of polychromatic LED light sources** [7231-52]
M. Bürmen, Univ. of Ljubljana (Slovenia); F. Pernuš, B. Likar, Univ. of Ljubljana (Slovenia) and Sensum Computer Vision Systems (Slovenia)
- 7231 1H **Weak-microcavity organic light-emitting diodes with improved light-extraction and wide viewing-angle** [7231-54]
S.-H. Cho, KAIST (Korea, Republic of) and Samsung SDI Co., Ltd. (Korea, Republic of); Y.-H. Lee, KAIST (Korea, Republic of); Y.-W. Song, Y.-C. Kim, J. Lee, J. H. Lee, K. H. Hwang, D.-S. Zang, Samsung SDI Co., Ltd. (Korea, Republic of)

Author Index

Conference Committee

Symposium Chair

James G. Grote, Air Force Research Laboratory (United States)

Symposium Cochair

E. Fred Schubert, Rensselaer Polytechnic Institute (United States)

Program Track Chair

E. Fred Schubert, Rensselaer Polytechnic Institute (United States)

Conference Chairs

Klaus P. Streubel, OSRAM Opto Semiconductors GmbH (Germany)

Heonsu Jeon, Seoul National University (Korea, Republic of)

Conference Cochair

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

Program Committee

Gerd Bacher, Universität Duisburg-Essen (Germany)

Michael Heuken, AIXTRON AG (Germany)

Zhaoran Rena Huang, Rensselaer Polytechnic Institute (United States)

Satoshi Kamiyama, Meijo University (Japan)

Markus Klein, OSRAM Opto Semiconductors GmbH (Germany)

Michael R. Krames, Philips Lumileds Lighting Company (United States)

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)

E. Fred Schubert, Rensselaer Polytechnic Institute (United States)

Jerry A. Simmons, Sandia National Laboratories (United States)

Ross P. Stanley, Centre Suisse d'Electronique et de Microtechnique SA (Switzerland)

Session Chairs

1 LED Applications and SSL

Klaus P. Streubel, OSRAM Opto Semiconductors GmbH (Germany)

- 2 LED Droop
E. Fred Schubert, Rensselaer Polytechnic Institute (United States)
- 3 LED Design and Fabrication I
Kei May Lau, Hong Kong University of Science and Technology (Hong Kong, China)
- 4 UV LEDs
Gerd Bacher, Universität Duisburg-Essen (Germany)
- 5 LED Manufacturing I
Michael Heuken, AIXTRON AG (Germany)
- 6 LED Manufacturing II
Ross P. Stanley, Centre Suisse d'Electronique et de Microtechnique SA (Switzerland)
- 7 LED Design and Fabrication II
Heonsu Jeon, Seoul National University (Korea, Republic of)
- 8 Phosphors
Hans Nikol, Philips Lighting B.V. (Netherlands)
- 9 Nanostructures
Satoshi Kamiyama, Meijo University (Japan)
- 10 Novel Substrates
Li-Wei Tu, National Sun Yat-Sen University (Taiwan)
- 11 Organic LEDs
Heonsu Jeon, Seoul National University (Korea, Republic of)