PROCEEDINGS OF SPIE

Gallium Nitride Materials and Devices VI

Jen-Inn Chyi
Yasushi Nanishi
Hadis Morkoç
Joachim Piprek
Euijoon Yoon
Editors

24–27 January 2011
San Francisco, California, United States

Sponsored and Published by
SPIE

Volume 7939

Proceedings of SPIE, 0277-786X, v. 7939

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 *Gallium Nitride Materials and Devices VI*, edited by Jen-Inn Chyi, Yasushi Nanishi, Hadis Morkoç, Joachim Piprek, Euijoon Yoon, Proceedings of SPIE Vol. 7939 (SPIE, Bellingham, WA, 2011) Article CID Number.

ISSN 0277-786X
ISBN 9780819484765

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

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

POSTER SESSION

Conference Committee

Symposium Chair

Liang-Chy Chien, Kent State University (United States)

Symposium Cochairs

E. Fred Schubert, Rensselaer Polytechnic Institute (United States)
Klaus P. Streubel, OSRAM GmbH (Germany)

Program Track Chair

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

Conference Chairs

Jen-Inn Chyi, National Central University (Taiwan)
Yasushi Nanishi, Ritsumeikan University (Japan)
Hadis Morkoç, Virginia Commonwealth University (United States)
Joachim Piprek, NUSOD Institute LLC (United States)
Euijoon Yoon, Seoul National University (Korea, Republic of)

Program Committee

Hiroshi Amano, Meijo University (Japan)
Jong-Hyeob Baek, Korea Photonics Technology Institute (Korea, Republic of)
Alison A. Baski, Virginia Commonwealth University (United States)
Shoou-Jinn Chang, National Cheng Kung University (Taiwan)
Li-Chyong Chen, National Taiwan University (Taiwan)
Hiroshi Fujioka, The University of Tokyo (Japan)
Nicolas Grandjean, Ecole Polytechnique Fédérale de Lausanne (Switzerland)
Detlef Hommel, Universität Bremen (Germany)
Yoichi Kawakami, Kyoto University (Japan)
Michael Kneissl, Technische Universität Berlin (Germany)
Hao-Chung Kuo, National Chiao Tung University (Taiwan)
Narihiko Maeda, NTT Photonics Laboratory (Japan)
Hideto Miyake, Mie University (Japan)
Yong-Tae Moon, LG Electronics Inc. (Korea, Republic of)
Takashi Mukai, Nichia Corporation (Japan)
Ok-Hyun Nam, Korea Polytechnic University (Korea, Republic of)
Ulrich T. Schwarz, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany)

Tae-Yeon Seong, Korea University (Korea, Republic of)
Jong-In Shim, Hanyang University (Korea, Republic of)
Kenji Shiojima, University of Fukui (Japan)
Cheolsoo Sone, Samsung Electro-Mechanics (Korea, Republic of)
Chih-Chung Yang, National Taiwan University (Taiwan)

Session Chairs

Growth I
Hadis Morkoç, Virginia Commonwealth University (United States)

GaN Doping
Yasushi Nanishi, Ritsumeikan University (Japan)

FET I
Euijoon Yoon, Seoul National University (Korea, Republic of)

FET II
Joachim Piprek, NUSOD Institute LLC (United States)

Advanced Techniques I
Jen-Inn Chyi, National Central University (Taiwan)

Advanced Techniques II
Akira Uedono, University of Tsukuba (Japan)

Advanced Techniques III
Bernard Gil, Universitité Montpellier 2 (France)

Lasers
Jen-Inn Chyi, National Central University (Taiwan)

Novel Devices
Enrico Zanoni, Università degli Studi di Padova (Italy)

LEDs I
Sergey Y. Karpov, STR Group-Soft Impact Limited (Russian Federation)

LEDs II
Shangir Gwo, National Tsing Hua University (Taiwan)

LEDs III
Christopher L. Chua, Palo Alto Research Center, Inc. (United States)

LEDs IV
Hadis Morkoç, Virginia Commonwealth University (United States)

Introduction

GaN based electronic and optoelectronic devices continue to develop rapidly as reflected by the advances reported at the meeting. Today, the GaN based light emitters adorn the automobiles, traffic lights, moving signs, outdoor displays, handheld electronics, and background lighting in many consumer electronics including flat panel televisions. All LED outdoor lighting applications are already in full swing. Indoor lighting with LEDs seems to be catching up as high efficiency warm-white lamps, some voltage compatible with existing fixtures, have been demonstrated by increasing number of vendors. Efficiency retention or the loss of it at high injection levels has received a great deal of attention due to the enormous impact of efficiency on indoor lighting by LEDs. To the end, non polar and semi-polar orientations of GaN and InGaN in the context of growth and investigations of optical processes are under intensive studies. Models accounting for leakage, including that due hot electrons, and remedies therefore are being developed. Due to cost pressures, using Si substrates for GaN epitaxy with clever patterning and strain balancing, to avoid cracking upon cooling from growth temperatures, is being implemented. Semi-polar LEDs on Si substrates have also been demonstrated. New LED approaches, such as alternating-current (AC) LEDs and high-voltage (HV) LEDs, have shown their potential in addressing the cost and reliability issues.

The research on GaN-based power electronic devices, including FETs and diodes, has drawn increasing attentions lately, especially from the industry sector as the deployments of energy efficient power supplies and converter for all electric and hybrid vehicles are highly sought after. To compete with its Si counterpart in this realm, novel device structures and process technologies for GaN-based devices are emerging. High-breakdown normally-off devices with low on-resistance, low off-leakage current, fast recovery time, high temperature operation, and high conversion efficiency are rigorously pursued. Monolithic integration of GaN power transistors and Schottky diodes for inverters have been demonstrated.

The SPIE symposium on GaN Materials and Devices is annually organized to disseminate the latest results and provide an opportunity for researchers from around the world to engage in far reaching and probing discussions. Many world renowned invited speakers from Asia, Europe and USA set the stage with wide ranging formal discussions. Not to be underestimated is the fact that the meeting served the purpose of getting experts and newcomers, particularly graduate students who turned out in large numbers, together for friendship and informal discussions of issues relevant to GaN and related materials and devices, and also to develop collaborations. Such exchanges will undoubtedly play an invaluable role in propelling the field forward in general and in particular addressing pivotal issues such as determination and improvement of internal quantum efficiency

and external quantum efficiency of LEDs as well as realizing the full potential of GaN power devices for energy efficiency products.

Jen-Inn Chyi
Hadis Morkoç
Yasushi Nanishi
Joachim Piprek
Euijoon Yoon