

PROCEEDINGS OF SPIE

Physics, Simulation, and Photonic Engineering of Photovoltaic Devices V

**Alexandre Freundlich
Laurent Lombez
Masakazu Sugiyama**
Editors

**15–17 February 2016
San Francisco, California, United States**

Sponsored and Published by
SPIE

Volume 9743

Proceedings of SPIE 0277-786X, V. 9743

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

Physics, Simulation, and Photonic Engineering of Photovoltaic Devices V, edited by Alexandre Freundlich,
Laurent Lombez, Masakazu Sugiyama, Proc. of SPIE Vol. 9743, 974301 · © 2016 SPIE
CCC code: 0277-786X/16/\$18 · doi: 10.1117/12.2240348

Proc. of SPIE Vol. 9743 974301-1

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 SPIDigitalLibrary.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 *Physics, Simulation, and Photonic Engineering of Photovoltaic Devices V*, edited by Alexandre Freundlich, Laurent Lombez, Masakazu Sugiyama, Proceedings of SPIE Vol. 9743 (SPIE, Bellingham, WA, 2016) Six-digit Article CID Number.

ISSN: 0277-786X
ISSN: 1996-756X (electronic)
ISBN: 9781628419788

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 © 2016, 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/16/\$18.00.

Printed in the United States of America.

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

SPIE. DIGITAL LIBRARY
SPIDigitalLibrary.org

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 six-digit CID article numbering system structured as follows:

- 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.

Contents

vii	<i>Authors</i>
ix	<i>Conference Committee</i>

SESSION 1 EMERGING TOPICS IN DESIGN AND CHARACTERIZATION OF PHOTOVOLTAIC DEVICES

- 9743 04 **Advances with vertical epitaxial heterostructure architecture (VEHSA) phototransducers for optical to electrical power conversion efficiencies exceeding 50 percent (Invited Paper) [9743-3]**

SESSION 2 ADVANCES IN SIMULATION OF PHOTOVOLTAIC DEVICES

- 9743 05 **Energy and entropy currents for nanoscaled optoelectronics (Invited Paper) [9743-4]**
- 9743 06 **Numerical modeling of photon recycling and luminescence coupling in non-ideal multijunction solar cell [9743-5]**
- 9743 08 **Development of numerical modeling program for organic/inorganic hybrid solar cells by including tail/Interfacial states models [9743-7]**

SESSION 3 ADVANCES IN CHARACTERIZATION OF PHOTOVOLTAIC DEVICES

- 9743 0C **Local transport properties investigation by correlating hyperspectral and confocal luminescence images [9743-11]**
- 9743 0D **Calibration standards and measurement accuracy of absolute electroluminescence and internal properties in multi-junction and arrayed solar cells [9743-12]**
- 9743 0F **A novel measurement method of luminescence coupling in multijunction solar cells based on small signal method [9743-50]**

SESSION 4 ADVANCES IN LIGHT MANAGEMENT AND SPECTRAL SHAPING OF PHOTOVOLTAIC DEVICES

- 9743 0G **Computational optimization and solution-processing of thick and efficient luminescent down-shifting layers for photovoltaics [9743-14]**
- 9743 0J **Rapid 2D incoherent mirror fabrication by laser interference lithography and wet etching for III-V MQW solar cells [9743-17]**
- 9743 0K **Silicon solar cell using optimized intermediate reflector layer [9743-18]**

9743 0L **Design and fabrication of a micro CPV system based on Cu(In,Ga)Se₂ microcells array**
[9743-19]

SESSION 5 PEROVSKITES AND HYBRID PHOTOVOLTAIC DEVICES

9743 0M **Carrier scattering processes and low energy phonon spectroscopy in hybrid perovskites crystals (Invited Paper)** [9743-20]

9743 0N **Dielectric properties of hybrid perovskites and drift-diffusion modeling of perovskite cells**
[9743-21]

9743 0O **Design optimization of thin-film/wafer-based tandem junction solar cells using analytical modeling** [9743-22]

SESSION 6 HOT CARRIER SOLAR CELLS

9743 0R **Hot-carrier solar cell NEGF-based simulations** [9743-25]

9743 0S **Third generation hot carrier solar cells: paths towards innovative energy contacts structures**
[9743-26]

SESSION 7 ADVANCES IN III-V PHOTOVOLTAIC MATERIALS AND DEVICES

9743 0U **Characterization and modeling of radiation damages via internal radiative efficiency in multi-junction solar cells** [9743-28]

9743 0W **Performance impact of luminescent coupling on monolithic 12-junction phototransducers for 12 V photonic power systems** [9743-30]

9743 0Y **Enhanced photocarrier extraction mechanisms in ultra-thin photovoltaic GaAs n/p junctions** [9743-32]

9743 10 **1.7eV Al_{0.2}Ga_{0.8}As solar cells epitaxially grown on silicon by SSMBE using a superlattice and dislocation filters** [9743-34]

SESSION 8 ADVANCES IN QUANTUM WELL AND SUPERLATTICE-ENHANCED PHOTOVOLTAIC DEVICES

9743 11 **Quantum wells for high-efficiency photovoltaics (Invited Paper)** [9743-35]

9743 12 **Observation of mini-band formation in the ground and high-energy electronic states of super-lattice solar cells** [9743-36]

9743 13 **Carrier dynamics in QW and bulk bismide and epitaxial lift off GaAs-In(AI)GaP double heterostructures grown by MOVPE for multi-junction solar cells** [9743-37]

9743 15 **Effective drift mobility approximation in multiple quantum-well solar cell** [9743-39]

- 9743 16 **Quasi-Fermi level splitting evaluation based on electroluminescence analysis in multiple quantum-well solar cells for investigating cell performance under concentrated light** [9743-40]

SESSION 9 INTERMEDIATE BAND SOLAR CELLS

- 9743 17 **Carrier dynamics in type-II quantum dots for wide-bandgap intermediate-band solar cells (Invited Paper)** [9743-41]
- 9743 18 **Design optimization for two-step photon absorption in quantum dot solar cells by using infrared photocurrent spectroscopy** [9743-42]

SESSION 10 PHOTOVOLTAICS MODELING: JOINT SESSION WITH CONFERENCES 9742 AND 9743

- 9743 1B **Simulation study of GaAsP/Si tandem cells including the impact of threading dislocations on the luminescent coupling between the cells** [9743-45]

POSTER SESSION

- 9743 1D **Asymmetric angular-selective thermal emission** [9743-47]
- 9743 1E **Competitive hybridization in quantum dot-based nanodevices** [9743-48]
- 9743 1F **The behavior of series resistance of a p-n junction: the diode and the solar cell cases** [9743-49]
- 9743 1G **Metal/metal-oxide nanocoatings on black silicon nanograss for enhanced solar absorption and photochemical activity** [9743-51]
- 9743 1H **Organic photovoltaic with various plasmonic nanostructures using titanium nitride** [9743-52]
- 9743 1I **Numerical analysis of the supercontinuum spectrum generation in a couple of photonic crystal fibers with different structure by using the RK4IP method** [9743-53]
- 9743 1J **Nanostructure-based enhancement of performance in thin-film photovoltaic devices** [9743-54]

Authors

Numbers in the index correspond to the last two digits of the six-digit citation identifier (CID) article numbering system used in Proceedings of SPIE. The first four 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.

A. K., Jagdish, 1J
Aimez, Vincent, 04, 0Y
Akiyama, Hidefumi, 0D, 0U
Alonso-Álvarez, Diego, 11
Arès, Richard, 04, 0Y
Bajcsy, M., 04
Ban, D., 04
Batentschuk, Miroslaw, 0G
Beck, A., 0N
Beltako, Katawoura, 05, 1E
Benamara, Mourad, 10
Bermel, Peter, 1D
Bescond, Marc, 0R
Bilir, Taner, 0F
Bourges, Philippe, 0M
Bouzazi, Boussairi, 04, 0Y
Brabec, Christoph J., 0G
Bueno, Poliana H., 1F
Carvalho, André, 1F
Cavassilas, Nicolas, 0R, 1E
Chahal, Sanmeet, 0W
Chen, Shaoqiang, 0D, 0U
Chen, Siming, 10
Chen, Yusi, 06
Cordier, Stéphane, 0M
Cornet, C., 0N
Costa, Diogo F., 1F
Crépieux, Adeline, 05
Dahal, Pabitra, 1G
Davidson, Lauren, 0O
Delamarre, Amaury, 16
Dhaka, Shailja, 1D
Durand, Olivier, 0M, 0N
Egelhaaf, Hans-Joachim, 0G
Eick, Alexander, 1F
Ekins-Daukes, Nicholas, 11
Elamurugu, Elangovan, 1G
El-Hajje, G., 0C
Estudillo-Ayala, J. M., 11
Even, Jacky, 0M, 0N
Fafard, Simon, 04, 0W, 0Y
Filoteo-Razo, J. D., 11
Flores, Raquel, 1G
Forberich, Karen, 0G
Forghani, Kamran, 13
Freundlich, Alex, 0J
Fukuyama, Atsuhiko, 12
Gan, Qiaoqiang, 1H
Gibelli, Francois, 0S
Guan, Yingxin, 13
Guillemoles, Jean-François, 0C, 0L, 0S, 16
Harder, Nils-Peter, 10, 1B
Harris, James S., 06, 0F
Hegde, Gopalakrishna, 1J
Hernández-García, J. C., 11
Hinzer, Karin, 04, 0W
Ho, Kuan-Ying, 08
Huang, Y., 0N
Huo, Yijie, 06, 0F
Ikari, Tetsuo, 12
Imaizumi, Mitsuru, 0D, 0U
Inoue, Tomoyuki, 15, 16
Ishigaki, Masanori, 0W
Jaouad, Abdelatif, 04, 0Y
Jauregui-Vazquez, D., 11
Jehl Li Kao, Zacharie, 0S
Jia, Jieyang, 06, 0F
Jiang, Qi, 10
Joie, Thibault, 0R
Jouiad, Mustapha, 1G
Julian, Anatole, 0S
Jutteau, Sebastien, 0L
Kanemitsu, Yoshihiko, 0D, 0U
Katan, Claudine, 0M, 0N
Kepenekian, M., 0N
Khalifa, Ahmed E., 0K
Kick, Christopher, 0G
Kim, Changsu, 0D, 0U
Kim, Honghyuk, 13
Kim, Kangho, 13
Kita, Takashi, 15
Kubota, Hidehiro, 0D
Kuech, Thomas F., 13
LaLumondiere, Stephen, 13
Lauterio-Cruz, J. P., 11
Lee, Jaejin, 13
Letoublon, Antoine, 0M
Lingley, Zachary, 13
Liu, Huiyun, 10, 1B
Liu, Yi, 06, 0F
Lombes, Laurent, 0C, 0L, 16
Lu, I-Hsin, 08
Luke, Sibimol, 1J
Lyu, Zheng, 06, 0F
Magdi, Sara, 1H
Maidaniuk, Yurii, 10
Masson, Denis P., 04, 0W, 0Y
Matsuochi, Kouki, 12

Mawst, Luke J., 13
Mazur, Yuriy I., 10
Miao, Yu, 06, 0F
Michelini, Fabienne Velia, 05, 0R, 1E
Mochizuki, Toshimitsu, 0D, 0U
Monteiro, Davies W. L., 1F
Moss, Steven C., 13
Nakamura, Tetsuya, 0D, 0U
Nakamura, Tsubasa, 12
Nakano, Yoshiaki, 12, 15, 16
Oberbeck, Lars, 10, 1B
Okada, Y., 18
Onno, Arthur, 10, 1B
Ory, D., 0C
Osvet, Andres, 0G
Paire, Myriam, 0L, 16
Paofai, Serge, 0M
Pedesseau, L., 0N
Peterson, Mark, 13
Pottiez, O., 1I
Proulx, Francine, 04, 0Y
Rajput, Nitul, 1G
Ramamurthy, Praveen C., 1J
Rojas-Laguna, R., 1I
Rolland, A., 0N
Roy Mahapatra, D., 1J
Sakr, Enas, 1D
Salamo, Gregory J., 10
Samano-Aguilar, L. F., 1I
Sapori, D., 0N
Shoji, Y., 18
Sin, Yongkun, 13
Solodovnyk, Anastasiia, 0G
Stern, Edda, 0G
Sugaya, Takeyoshi, 17
Sugiyama, Masakazu, 12, 15, 16
Swillam, Mohamed A., 0K, 1H
Tamaki, R., 18
Tang, Mingchu, 10
Tatavarti, Rao, 13
Tayagaki, Takeshi, 17
Toor, Fatima, 0O
Toprasertpong, Kasidit, 12, 15, 16
Usuki, Takanori, 12
Valdivia, Christopher E., 04, 0W
Viegas, Jaime, 1G
Wang, S., 0N
Wang, Wei, 0J
Watanabe, Kentaroh, 15, 16
Wilkins, Matthew, 04, 0W
Wu, Jiang, 10
Wu, Yuh-Renn, 08
York, Mark C. A., 04, 0Y
Yoshita, Masahiro, 0D, 0U
Yuan, Mengyang, 06, 0F
Zhu, Lin, 0D, 0U

Conference Committee

Symposium Chairs

Jean-Emmanuel Broquin, IMEP-LAHC (France)
Shibin Jiang, AdValue Photonics, Inc. (United States)

Symposium Co-chairs

David L. Andrews, University of East Anglia (United Kingdom)
Alexei L. Glebov, OptiGrate Corporation (United States)

Program Track Chair

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

Conference Chairs

Alexandre Freundlich, University of Houston (United States)
Laurent Lombez, Institut de Recherche et Développement sur
l'Energie Photovoltaïque (France)
Masakazu Sugiyama, The University of Tokyo (Japan)

Conference Program Committee

Kylie R. Catchpole, The Australian National University (Australia)
Gavin Conibeer, The University of New South Wales (Australia)
Olivier Durand, Institut National des Sciences Appliquées de Rennes
(France)
Nicholas J. Ekins-Daukes, Imperial College London (United Kingdom)
Jean-François Guillemoles, Institut de Recherche et Développement
sur l'Energie Photovoltaïque (France) and Next PV (Japan)
Karin Hinzer, University of Ottawa (Canada)
Louise C. Hirst, United States Naval Research Laboratory
(United States)
Seth M. Hubbard, Rochester Institute of Technology (United States)
Marek Osiński, The University of New Mexico (United States)
Robert J. Walters, United States Naval Research Laboratory
(United States)
David M. Wilt, Air Force Research Laboratory (United States)
Peichen Yu, National Chiao Tung University (Taiwan)

Session Chairs

- 1 Emerging Topics in Design and Characterization of Photovoltaic Devices
Alexandre Freundlich, University of Houston (United States)
Laurent Lombez, Institut de Recherche et Développement sur l'Energie Photovoltaïque (France)
- 2 Advances in Simulation of Photovoltaic Devices
Gavin Conibeer, The University of New South Wales (Australia)
Jacky Even, Institut National des Sciences Appliquées de Rennes (France)
- 3 Advances in Characterization of Photovoltaic Devices
Mariana Bertoni, Arizona State University (United States)
Laurent Lombez, Institut de Recherche et Développement sur l'Energie Photovoltaïque (France)
- 4 Advances in Light Management and Spectral Shaping of Photovoltaic Devices
Karin Hinzer, University of Ottawa (Canada)
- 5 Perovskites and Hybrid Photovoltaic Devices
Masakazu Soguiyama, University of Tokyo (Japan)
Angus A. Rockett, University of Illinois at Urbana-Champaign (United States)
- 6 Hot Carrier Solar Cells
Andre Cattoni, LPN - CNRS (France)
- 7 Advances in III-V Photovoltaic Materials and Devices
Masakazu Sugiyama, The University of Tokyo (Japan)
Marina Leite, University of Maryland (United States)
- 8 Advances in Quantum Well and Superlattice-Enhanced Photovoltaic Devices
Seth M. Hubbard, Rochester Institute of Technology (United States)
Simon Fafard, Azastra Opto Inc. (Canada)
- 9 Intermediate Band Solar Cells
Masakazu Sugiyama, The University of Tokyo (Japan)
Laurent Lombez, Institut de Recherche et Développement sur l'Energie Photovoltaïque (France)
- 10 Photovoltaics Modeling: Joint Session with Conferences 9742 and 9743
Bernd Witzigmann, Universität Kassel (Germany)