

PROCEEDINGS OF SPIE

Silicon Photonics and Photonic Integrated Circuits IV

**Laurent Vivien
Seppo Honkanen
Lorenzo Pavesi
Stefano Pelli**
Editors

**14–17 April 2014
Brussels, Belgium**

Sponsored by
SPIE

Cosponsored by
B-PHOT—Brussels Photonics Team (Belgium)
FWO—Fonds Wetenschappelijk Onderzoek (Belgium)
Brussels-Capital Region (Belgium)
Ville de Bruxelles (Belgium)

Cooperating Organisations
CBO-BCO (Belgium)
European Laser Institute
Photonics 21 (Germany)
EOS—European Optical Society (Germany)

Published by
SPIE

Volume 9133

Proceedings of SPIE 0277-786X, V. 9133

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

Silicon Photonics and Photonic Integrated Circuits IV, edited by Laurent Vivien, Seppo Honkanen,
Lorenzo Pavesi, Stefano Pelli, Proc. of SPIE Vol. 9133, · © 2014 SPIE
CCC code: 0277-786X/14/\$18 · doi: 10.1117/12.2070011

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 *Silicon Photonics and Photonic Integrated Circuits IV*, edited by Laurent Vivien, Seppo Honkanen, Lorenzo Pavesi, Stefano Pelli, Proceedings of SPIE Vol. 9133 (SPIE, Bellingham, WA, 2014) Article CID Number.

ISSN: 0277-786X

ISBN: 9781628410815

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 © 2014, 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/14/\$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 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

- ix *Conference Committee*
- xi *Introduction*

SESSION 1 HYBRID PHOTONICS

- 9133 02 **Hybrid III-V/silicon lasers (Invited Paper)** [9133-2]
P. Kaspar, C. Jany, A. Le Liepvre, A. Accard, M. Lamponi, D. Make, G. Levaufre, N. Girard, F. Lelarge, A. Shen, P. Charbonnier, F. Mallecot, G.-H. Duan, J. -L. Gentner, III-V Lab, Thales Research and Technology, CEA-LETI (France); J.-M. Fedeli, S. Olivier, A. Descos, B. Ben Bakir, S. Messaoudene, D. Bordel, S. Malhouitre, C. Kopp, S. Menezo, CEA-LETI (France)

SESSION 2 LIGHT EMISSION AND AMPLIFICATION I

- 9133 07 **New strategies to improve Eu light emission in Si-based matrices** [9133-7]
G. Franzò, MATIS IMM CNR (Italy); G. Bellocchi, MATIS IMM CNR (Italy) and Univ. degli Studi di Catania (Italy); S. Boninelli, M. Miritello, F. Iacona, MATIS IMM CNR (Italy)
- 9133 08 **Erbium-doped spiral amplifiers with 20 dB gain on a silicon chip** [9133-9]
S. A. Vázquez-Córdova, E. H. Bernhardt, K. Wörhoff, S. M. García-Blanco, M. Pollnau, Univ. Twente (Netherlands)
- 9133 09 **On the photoluminescence of as-deposited Tb-doped silicon oxides and oxynitrides fabricated by ECR-PECVD (Best Student Paper Award)** [9133-10]
J. M. Ramírez, Univ. de Barcelona (Spain); J. Wojcik, McMaster Univ. (Canada); Y. Berencén, Univ. de Barcelona (Spain); P. Mascher, McMaster Univ. (Canada); B. Garrido, Univ. de Barcelona (Spain)

SESSION 3 RECEIVERS

- 9133 0D **Design, integration, and testing of a compact FBG interrogator, based on an AWG spectrometer** [9133-14]
A. Trita, Univ. Gent (Belgium); G. Vickers, Optocap Ltd. (United Kingdom); I. Mayordomo, Fraunhofer-Institut für Integrierte Schaltungen (Germany); D. van Thourhout, Univ. Gent (Belgium); J. Vermeiren, Xenics NV (Belgium)
- 9133 0E **Fully CMOS compatible photonics integrated on silicon substrates** [9133-15]
Z. Li, H. Xu, Institute of Semiconductors (China); X. Xiao, Wuhan Research Institute of Posts and Telecommunications (China); A. Nemkova, Y. Yu, J. Yu, Institute of Semiconductors (China)

SESSION 4 LIGHT COUPLING

- 9133 0F **Packaging challenges for integrated silicon photonic circuits (Invited Paper)** [9133-16]
N. Pavarelli, J. S. Lee, P. A. O'Brien, Tyndall National Institute, Univ. College Cork (Ireland)
- 9133 0G **Active polarization independent coupling to silicon photonics circuit** [9133-17]
J. N. Caspers, Univ. of Toronto (Canada); Y. Wang, L. Chrostowski, The Univ. of British Columbia (Canada); M. Mojahedi, Univ. of Toronto (Canada)
- 9133 0I **Adiabatic optical bus for long-range coupling between silicon photonic waveguides** [9133-19]
A. P. Hope, T. G. Nguyen, A. D. Greentree, A. Mitchell, RMIT Univ. (Australia)

SESSION 5 NONLINEAR OPTICS

- 9133 0L **Quasi-phase-matched four-wave-mixing of optical pulses in periodically modulated silicon photonic wires** [9133-23]
S. Lavdas, Univ. College London (United Kingdom); J. B. Driscoll, R. R. Grote, R. M. Osgood Jr., Columbia Univ. (United States); N. C. Panoiu, Univ. College London (United Kingdom)
- 9133 0M **Nonlinear response of SiGe waveguides in the mid-infrared** [9133-24]
L. Carletti, Ecole Centrale de Lyon (France); P. Ma, B. Luther-Davies, The Australian National Univ. (Australia); D. Hudson, The Univ. of Sydney (Australia); C. Monat, Ecole Centrale de Lyon (France); S. Madden, The Australian National Univ. (Australia); D. J. Moss, RMIT Univ. (Australia); M. Brun, S. Ortiz, S. Nicoletti, CEA-LETI (France); C. Grillet, Ecole Centrale de Lyon (France)

SESSION 6 MODULATION AND SWITCHING

- 9133 0P **A silicon Mach Zehnder comb switch for low power operation in on-chip optical data communications** [9133-27]
L. Sánchez, A. Brimont, S. Lechago, A. Griol, P. Sanchis, Univ. Politècnica de Valencia (Spain)
- 9133 0Q **Ge quantum-well waveguide modulator at 1.3 μ m** [9133-28]
M.-S. Rouifed, D. Marris-Morini, P. Chaisakul, Institut d'Electronique Fondamentale, CNRS-Univ. Paris Sud 11 (France); J. Frigerio, G. Isella, D. Chrastina, Politecnico di Milano (Italy); S. Edmond, X. Le Roux, J.-R. Coudevylle, D. Bouville, L. Vivien, Institut d'Electronique Fondamentale, CNRS-Univ. Paris Sud 11 (France)

SESSION 7 INTEGRATION

- 9133 0R **High-density silicon optical interposer for inter-chip interconnects (Invited Paper)** [9133-30]
T. Nakamura, Y. Urino, Institute for Photonics–Electronics Convergence System Technology (Japan) and Photonics Electronics Technology Research Association (Japan); Y. Arakawa, Institute for Photonics–Electronics Convergence System Technology (Japan) and The Univ. of Tokyo (Japan)

- 9133 0T **Microring based ratio-metric wavelength monitor on silicon** [9133-32]
A. Shen, B. Yang, T. Hu, T. Dai, Zhejiang Univ. (China); C. Qiu, Huawei Technologies Co. Ltd., (China); Y. Li, Y. Hao, X. Jiang, J. Yang, Zhejiang Univ. (China)
- 9133 0U **Fabrication of high-density pitch adapters by laser ablation** [9133-33]
F. Rey-García, Univ. de Santiago de Compostela (Spain) and Univ. of Zaragoza (Spain); C. Bao-Varela, E. Pérez, Univ. de Santiago de Compostela (Spain); P. Rodríguez, Univ. de Santiago de Compostela (Spain) and Univ. of Manchester (United Kingdom); A. Gallas, Univ. de Santiago de Compostela (Spain); G. F. de la Fuente, Univ. of Zaragoza (Spain)
- 9133 0V **An inter- and intra-chip optical interconnect using a hybrid plasmonic leaky-wave nano-antenna** [9133-34]
V. Ebrahimi, L. Yousefi, M. Mohammad-Tahri, Univ. of Tehran (Iran, Islamic Republic of)

SESSION 8 PHOTONIC STRUCTURES I

- 9133 0Y **A novel wavelength multiplexer/demultiplexer based on side-port multimode interference coupler** [9133-37]
S. Wei, Beijing Univ. of Posts and Telecommunications (China) and Institute of Semiconductors (China); W. Jian, Beijing Univ. of Posts and Telecommunications (China); L. Zhao, Institute of Semiconductors (China); J. Qiu, Z. Yin, Beijing Univ. of Posts and Telecommunications (China); R. Hui, The Univ. of Kansas (United States)

SESSION 9 SIMULATED DEVICES AND CIRCUITS

- 9133 10 **A complete design flow for silicon photonics** [9133-39]
J. Pond, Lumerical Solutions, Inc. (Canada); C. Cone, Mentor Graphics Corp. (United States); L. Chrostowski, The Univ. of British Columbia (Canada); J. Klein, Lumerical Solutions, Inc. (Canada); J. Flueckiger, The Univ. of British Columbia (Canada); A. Liu, D. McGuire, X. Wang, Lumerical Solutions, Inc. (Canada)
- 9133 11 **How the new optoelectronic design automation industry is taking advantage of preexisting EDA standards** [9133-40]
K. A. Nesmith, S. Carver, Silicon Integration Initiative, Inc. (United States)
- 9133 12 **Modeling of PN interleaved phase shifters for high speed silicon modulators** [9133-41]
D. Perez-Galacho, D. Marris-Morini, E. Cassan, L. Vivien, Institut d'Electronique Fondamentale, CNRS-Univ. Paris Sud 11 (France)
- 9133 13 **Analysis of a polarization-independent nonlinear cross-slot waveguide with Fourier Modal Method (FMM)** [9133-42]
S. Paul, J. Tervo, S. Honakanen, Univ. of Eastern Finland (Finland)

SESSION 10 PHOTONIC STRUCTURES II

- 9133 14 **Coupling light to whispering gallery mode resonators (Invited Paper)** [9133-44]
D. Farnesi, G. C. Righini, Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi (Italy) and Istituto di Fisica Applicata Nello Carrara, CNR (Italy); A. Barucci, S. Berneschi, F. Chiavaioli, F. Cosi, S. Pelli, S. Soria, C. Trono, Istituto di Fisica Applicata Nello Carrara, CNR (Italy); D. Ristic, Institut Ruder Bošković (Croatia); M. Ferrari, CSMFO Lab., CNR, Istituto di Fotonica e Nanotecnologie (Italy); G. Nunzi Conti, Istituto di Fisica Applicata Nello Carrara, CNR (Italy)
- 9133 15 **Efficient lasing in Nd:GdVO₄ depressed cladding waveguides produced by femtosecond laser writing** [9133-45]
H. Liu, Shandong Univ. (China); J. R. Vázquez de Aldana, Univ. de Salamanca (Spain); F. Chen, Shandong Univ. (China)
- 9133 16 **Three port optical circulators with ring resonators** [9133-46]
D. Jalas, A. Yu. Petrov, M. Eich, Technische Univ. Hamburg-Harburg (Germany)
- 9133 17 **Suspended photonic waveguide arrays for submicrometer alignment** [9133-47]
T.-J. Peters, M. Tichem, U. Staufer, Technische Univ. Delft (Netherlands)

SESSION 11 III-V LASER ON SI

- 9133 19 **Wavelength tuning speed in semiconductor ring lasers using on-chip filtered optical feedback** [9133-49]
G. Verschaffelt, M. Khoder, R. M. Nguimdo, Vrije Univ. Brussel (Belgium); X. Leijtens, J. Bolk, Technische Univ. Eindhoven (Netherlands); J. Danckaert, Vrije Univ. Brussel (Belgium)
- 9133 1A **Misalignment tolerant couplers for hybrid integration of semiconductor lasers with silicon photonics parallel transmitters** [9133-50]
S. Romero-García, B. Marzban, S. Sharif Azadeh, F. Merget, B. Shen, J. Witzens, RWTH Aachen (Germany)
- 9133 1B **Towards a low noise class-A hybrid III-V/silicon laser** [9133-51]
N. Girard, G. Baili, P. Nouchi, D. Dolfi, Thales Research & Technology (France); A. Le Liepvre, A. Accard, P. Kaspar, D. Make, P. Charbonnier, F. Mallecot, M. Faugeron, F. Van Dijk, G.-H. Duan, III-V Lab, Thales Research and Technology, CEA-LETI (France); S. Olivier, S. Malhouitre, C. Kopp, CEA-LETI (France)

SESSION 12 LIGHT EMISSION AND AMPLIFICATION II

- 9133 1C **Electrical and electroluminescence properties of silicon nanocrystals/SiO₂ superlattices** [9133-8]
J. López-Vidrier, Y. Berencén, B. Mundet, S. Hernández, Univ. de Barcelona (Spain); S. Gutsch, D. Hiller, Albert-Ludwigs-Univ. Freiburg (Germany); P. Löper, Fraunhofer-Institut für Solare Energiesysteme (Germany) and Ecole Polytechnique Fédérale de Lausanne (Switzerland); M. Schnabel, S. Janz, Fraunhofer-Institut für Solare Energiesysteme (Germany); M. Zacharias, Albert-Ludwigs-Univ. Freiburg (Germany); B. Garrido, Univ. de Barcelona (Spain)

- 9133 1D **High-frequency sub-wavelength IR thermal source** [9133-53]
F. Ottonello Briano, KTH Royal Institute of Technology (Sweden); P. Renoux, Univ. of Iceland (Iceland); F. Forsberg, H. Sohlström, KTH Royal Institute of Technology (Sweden); S. Ingvarsson, Univ. of Iceland (Iceland); G. Stemme, K. B. Gylfason, KTH Royal Institute of Technology (Sweden)

SESSION 13 PHOTONICS IN VISIBLE RANGE

- 9133 1F **Characterization of PECVD silicon nitride photonic components at 532 and 900 nm wavelength** [9133-55]
P. Neutens, IMEC (Belgium) and Katholieke Univ. Leuven (Belgium); A. Subramanian, Univ. Gent (Belgium); M. Ul Hasan, C. Chen, R. Jansen, T. Claes, X. Rottenberg, B. Du Bois, K. Leyssens, P. Helin, S. Severi, IMEC (Belgium); A. Dhakal, F. Peyskens, Univ. Gent (Belgium); L. Lagae, IMEC (Belgium) and Katholieke Univ. Leuven (Belgium); P. Deshpande, IMEC (Belgium); R. Baets, Univ. Gent (Belgium); P. Van Dorpe, IMEC (Belgium) and Katholieke Univ. Leuven (Belgium)
- 9133 1G **Polymer and composite polymer slot waveguides** [9133-56]
M. Hiltunen, VTT Technical Research Ctr. of Finland (Finland); W. S. Fegadolli, California Institute of Technology (United States); H. L. R. Lira, Instituto de Estudos Avançados (Brazil); P. Vahimaa, Univ. of Eastern Finland (Finland); J. Hiltunen, S. Aikio, VTT Technical Research Ctr. of Finland (Finland); V. R. Almeida, Instituto Tecnológico de Aeronáutica (Brazil); P. Karioja, VTT Technical Research Ctr. of Finland (Finland)

POSTER SESSION

- 9133 1H **Large-scale characterization of silicon nitride-based evanescent couplers at 532nm wavelength** [9133-20]
T. Claes, R. Jansen, P. Neutens, B. Du Bois, P. Helin, S. Severi, P. Van Dorpe, P. Deshpande, X. Rottenberg, IMEC (Belgium)
- 9133 1I **Influence of waveguide structure on Y-branch splitting ratio** [9133-43]
C. Burtcher, D. Seyringer, Vorarlberg Univ. of Applied Sciences (Austria)
- 9133 1K **Optical power distributions through fractal routing** [9133-57]
R. Jansen, T. Claes, P. Neutens, B. Du Bois, P. Helin, S. Severi, P. Van Dorpe, P. Deshpande, X. Rottenberg, IMEC (Belgium)
- 9133 1M **Efficient split-step time-domain modeling for multi-ring waveguide all pass and add/drop filters** [9133-59]
Y. Chung, Kwangwoon Univ. (Korea, Republic of)

Author Index

Conference Committee

Symposium Chairs

Francis Berghmans, Vrije Universiteit Brussel (Belgium)
Ronan Burgess, European Commission (Belgium)
Jürgen Popp, Institut für Photonische Technologien e.V. (Germany)
Peter Hartmann, SCHOTT AG (Germany)

Honorary Symposium Chair

Hugo Thienpont, Vrije Universiteit Brussel (Belgium)

Conference Chairs

Laurent Vivien, Institut d'Électronique Fondamentale (France)
Seppo Honkanen, University of Eastern Finland (Finland)
Lorenzo Pavesi, Università degli Studi di Trento (Italy)
Stefano Pelli, Istituto di Fisica Applicata Nello Carrara (Italy)

Conference Programme Committee

Vilson R. Almeida, Instituto de Estudos Avançados (Brazil)
Frédéric Boeuf, STMicroelectronics (France)
Eric Cassan, Institut d'Électronique Fondamentale (France)
Guang-Hua Duan, III-V Laboratoire (France)
Xudong Fan, University of Michigan (United States)
Jean-Marc Fédéli, CEA-LETI (France)
Maurizio Ferrari, Istituto di Fotonica e Nanotecnologie (Italy)
Gong-Ru Lin, National Taiwan University (Taiwan)
Andrew W. Poon, The Hong Kong University of Science and
Technology (Hong Kong, China)
Graham T. Reed, University of Southampton (United Kingdom)
Giancarlo C. Righini, Museo Storica della Fisica e Center Studi e
Ricerche Enrico Fermi (Italy)
Gunther Roelkens, Universiteit Gent (Belgium)
Jung Hun Shin, KAIST (Korea, Republic of)
Tsung-Yang Liow, A*STAR Institute of Microelectronics (Singapore)
Dan-Xia Xu, National Research Council Canada (Canada)
Koji Yamada, Nippon Telegraph and Telephone Corporation (Japan)
Jinzhong Yu, Institute of Semiconductors (China)

Session Chairs

- 1 Hybrid Photonics
Laurent Vivien, Institut d'Électronique Fondamentale (France)
- 2 Light Emission and Amplification I
Stefano Pelli, Istituto di Fisica Applicata Nello Carrara (Italy)
- 3 Receivers
Antti Säynätjoki, Aalto University (Finland)
- 4 Light Coupling
Zhiyong Li, Institute of Semiconductors (China)
- 5 Nonlinear Optics
Stefano Pelli, Istituto di Fisica Applicata Nello Carrara (Italy)
- 6 Modulation and Switching
Takahiro Nakamura, Photonics Electronics Technology Research Association (Japan)
- 7 Integration
Jens H. Schmid, National Research Council Canada (Canada)
- 8 Photonic Structures I
Gualtiero Nunzi Conti, Istituto di Fisica Applicata Nello Carrara (Italy)
- 9 Simulated Devices and Circuits
Eric Cassan, Institut d'Électronique Fondamentale (France)
- 10 Photonic Structures
Stefano Pelli, Istituto di Fisica Applicata Nello Carrara (Italy)
- 11 III-V Laser on Si
Marco Lamponi, Huawei Technologies Company, Ltd. (Belgium)
- 12 Light Emission and Amplification II
Antti Säynätjoki, Aalto University (Finland)
- 13 Photonics in Visible Range
Laurent Vivien, Institut d'Électronique Fondamentale (France)

Introduction

This Proceedings book contains the papers presented at the 4th edition of the “*Silicon Photonics and Photonic Integrated Circuits*” Conference of Photonics Europe 2014. The conference focused on integrated photonics devices based on silicon as well as on other optical materials (e.g. glass, crystals, polymers...). The aim was to present new trends in research, technology and applications.

More than 50 papers were presented, either oral or poster, which covered a whole range of subjects. The quality of the presentations was excellent, which is also reflected in the papers published in this book.

As in the previous edition, the conference has confirmed how silicon technologies are getting pervasive in diverse application fields, from the domains of telecommunications/interconnects to sensing and light emission. The conference has in fact understandably given a particular focus to light amplification and emission devoting two sessions to this topic.

Light coupling and integration are in many ways two very strictly connected issues affecting the viability and efficiency of devices. The conference therefore devoted several sessions to these topics, which included presentations about very diverse optical structures and material systems.

A special session with invited papers devoted to Hybrid Photonics was organized to highlight how novel devices can take advantage from combining the properties of different material systems to obtain better performances and new functionalities.

All sessions were very well attended and actively enlivened by many questions and comments posed by the participants, testifying the interest risen by the quality of the presentations offered by the speakers.

We were delighted to assign the Best Student Paper Award offered by SPIE for this conference to Joan Manel Ramirez, Univ. de Barcelona, Spain, for the paper, *On the photoluminescence of as-deposited Tb-doped silicon oxides and oxynitrides fabricated by ECR-PECVD*.

We would like to thank the members of the Programme Committee and the authors for helping us organizing this high-level conference and SPIE for the smooth organization of the whole symposium.

Vivien Laurent
Seppo Honkanen
Lorenzo Pavesi
Stefano Pelli