

PROCEEDINGS OF SPIE

Silicon Photonics IV

Joel A. Kubby
Graham T. Reed
Editors

26–28 January 2009
San Jose, California, United States

Sponsored and Published by
SPIE

Volume 7220

Proceedings of SPIE, 0277-786X, v. 7220

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 *Silicon Photonics IV*, edited by Joel A. Kubby, Graham T. Reed, Proceedings of SPIE Vol. 7220 (SPIE, Bellingham, WA, 2009) Article CID Number.

ISSN 0277-786X
ISBN 9780819474667

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.

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	<i>Conference Committee</i>
ix	<i>Introduction</i>

SESSION 1 WAVEGUIDES

- 7220 02 **Polarization diversity circuit based on a double-core structure consisting of silicon photonic wire and silicon-oxinitride waveguide (Invited Paper)** [7220-01]
K. Yamada, H. Fukuda, T. Tsuchizawa, T. Watanabe, H. Shinojima, H. Nishi, S. Itabashi, NTT Corp. (Japan)
- 7220 03 **The design of signal processing devices employing SOI MMI couplers** [7220-02]
L. W. Cahill, T. T. Le, La Trobe Univ. (Australia)
- 7220 04 **Optical characteristics of V-groove waveguide structures** [7220-03]
P. Müllner, R. Hainberger, Austrian Research Ctrs. GmbH (Austria)
- 7220 05 **Sub-wavelength grating gradient index mode transformers in high index contrast slab waveguides** [7220-04]
P. J. Bock, Univ. of Ottawa (Canada) and National Research Council Canada (Canada);
P. Cheben, J. H. Schmid, D.-X. Xu, S. Janz, National Research Council Canada (Canada);
T. J. Hall, Univ. of Ottawa (Canada)
- 7220 06 **Free carrier lifetime modification in silicon** [7220-05]
N. M. Wright, D. J. Thomson, K. L. Litvinenko, W. R. Headley, A. J. Smith, Univ. of Surrey (United Kingdom); A. P. Knights, McMaster Univ. (Canada); J. H. B. Deane, F. Y. Gardes,
G. Z. Mashanovich, R. Gwilliam, G. T. Reed, Univ. of Surrey (United Kingdom)

SESSION 2 MODULATORS

- 7220 08 **Hybrid silicon modulators (Invited Paper)** [7220-07]
H.-W. Chen, Y. Kuo, J. E. Bowers, Univ. of California, Santa Barbara (United States)

SESSION 3 INTEGRATION

- 7220 0A **Silicon photonics developments in Europe (Invited Paper)** [7220-09]
J. M. Fedeli, CEA-DRT, LETI (France); J. Marti, Univ. Politécnica de Valencia (Spain); D. Van Thourhout, Ghent Univ. (Belgium); G. Reed, Univ. of Surrey (United Kingdom); T. White, Univ. of St. Andrews (United Kingdom)

- 7220 0B **High speed analog-to-digital conversion with silicon photonics (Invited Paper)** [7220-10]
C. W. Holzwarth, R. Amatya, M. Araghchini, J. Birge, H. Byun, J. Chen, M. Dahlem, N. A. DiLello, F. Gan, J. L. Hoyt, E. P. Ippen, F. X. Kärtner, A. Khilo, J. Kim, M. Kim, A. R. Motamedi, J. S. Orcutt, M. Park, M. Perrott, M. A. Popović, R. J. Ram, H. I. Smith, G. R. Zhou, Massachusetts Institute of Technology (United States); S. J. Spector, T. M. Lyszczarz, M. W. Geis, D. M. Lennon, J. U. Yoon, M. E. Grein, R. T. Schulein, MIT Lincoln Lab. (United States); S. Frolov, A. Hanjani, J. Shmulovich, CyOptics (United States)
- 7220 0C **Universal PIN photodiodes in a 0.35 μ m BiCMOS mixed-signal ASIC technology** [7220-11]
A. Marchlewski, Vienna Univ. of Technology (Austria); G. Meinhardt, I. Jonak-Auer, V. Vescoli, E. Wachmann, austriamicrosystems AG (Austria); K. Schneider-Hornstein, H. Zimmermann, Vienna Univ. of Technology (Austria)
- 7220 0D **Compact silicon-based wavelength-selective photonic integrated devices and the applications (Invited Paper)** [7220-12]
D. Dai, S. He, Zhejiang Univ. (China)

SESSION 4 DETECTORS

- 7220 0F **Ge-on-silicon vertical PIN photodetectors** [7220-14]
J. Osmond, L. Vivien, Institut d'Electronique Fondamentale, Univ. Paris-Sud, CNRS (France); J. Fédéli, CEA-DRT, LETI (France); D. Marris-Morini, P. Crozat, Institut d'Electronique Fondamentale, Univ. Paris-Sud, CNRS (France); J.-F. Damlencourt, CEA-DRT, LETI (France); E. Cassan, J. Mangeney, Institut d'Electronique Fondamentale, Univ. Paris-Sud, CNRS (France); Y. Lecunff, CEA-DRT, LETI (France); S. Laval, Institut d'Electronique Fondamentale, Univ. Paris-Sud, CNRS (France)
- 7220 0H **Solid state photomultipliers and Geiger photodiodes with integrated readout and signal processing** [7220-16]
C. J. Stapels, E. B. Johnson, S. Mukhopadhyay, P. S. Lindsay, E. C. Chapman, J. F. Christian, RMD, Inc. (United States)

SESSION 5 LAB ON A CHIP I

- 7220 0K **Reconfigurable optofluidic silicon-based photonic crystal components** [7220-19]
C. Karnutsch, U. Bog, C. L. C. Smith, S. Tomljenovic-Hanic, C. Grillet, C. Monat, The Univ. of Sydney (Australia); L. O'Faolain, T. White, T. F. Krauss, Univ. of St. Andrews (United Kingdom); R. McPhedran, B. J. Eggleton, The Univ. of Sydney (Australia)
- 7220 0L **Biosensing microsystem platforms based on the integration of Si Mach-Zehnder interferometer, microfluidics and grating couplers (Invited Paper)** [7220-20]
L. M. Lechuga, Research Ctr. on Nanoscience and Nanotechnology (CIN2) (Spain); K. Zinoviev, Instituto de Microelectrónica de Barcelona (Spain); L. Fernández, J. Elizalde, IKERLAN S. Coop (Spain); O. E. Hidalgo, Research Ctr. on Nanoscience and Nanotechnology (CIN2) (Spain); C. Dominguez, Instituto de Microelectrónica de Barcelona (Spain)

- 7220 0N **A robust silicon photonic platform for multiparameter biological analysis (Invited Paper)** [7220-22]
R. C. Bailey, A. L. Washburn, A. J. Qavi, Univ. of Illinois at Urbana-Champaign (United States);
M. Iqbal, M. Gleeson, F. Tybor, L. C. Gunn, Genalyte, Inc. (United States)

SESSION 6 LAB ON A CHIP II

- 7220 0O **Biosensors in silicon on insulator (Invited Paper)** [7220-23]
P. Bienstman, K. De Vos, T. Claes, P. Debackere, R. Baets, J. Girones, E. Schacht, Ghent Univ.
(Belgium)
- 7220 0P **Micro-nano photonic biosensors scalable at the wafer level (Invited Paper)** [7220-24]
M. Holgado, R. Casquel, M.-F. Lagunas, Univ. Politécnica de Madrid (Spain)

SESSION 7 SILICON PHOTONICS

- 7220 0S **Self-assembled InGaAs/GaAs quantum dot microtube coherent light sources on GaAs and silicon (Invited Paper)** [7220-27]
Z. Mi, S. Vicknesh, F. Li, McGill Univ. (Canada); P. Bhattacharya, Univ. of Michigan (United States)

SESSION 8 RESONATORS AND INTERCONNECTS

- 7220 0U **Physical layer design of nanoscale silicon photonic interconnection networks (Invited Paper)** [7220-29]
K. Bergman, Columbia Univ. (United States)
- 7220 0V **The integration of silicon photonics and VLSI electronics for computing systems intra-connect (Invited Paper)** [7220-30]
A. V. Krishnamoorthy, R. Ho, X. Zheng, H. Schwetman, J. Lexau, P. Koka, G. Li, I. Shubin, J. E. Cunningham, Sun Microsystems, Inc. (United States)
- 7220 0W **Complete optical isolation created by indirect interband photonic transitions** [7220-31]
Z. Yu, S. Fan, Stanford Univ. (United States)
- 7220 0Y **Identifying resonance frequency deviations for high order nano-wire ring resonator filters based on a coupling strength variation** [7220-33]
S. Park, Electronics and Telecommunications Research Institute (Korea, Republic of);
K.-J. Kim, Electronics and Telecommunications Research Institute (Korea, Republic of) and
Korea Advanced Institute of Science and Technology (Korea, Republic of); D.-J. Kim, G.
Kim, Electronics and Telecommunications Research Institute (Korea, Republic of)

SESSION 9 RESONATORS AND WAVEGUIDE DEVICES

- 7220 11 **Fabrication and tailoring of silicon photonic devices via focused ion beam** [7220-36]
S. Howe, W. R. Headley, D. C. Cox, G. Z. Mashanovich, D. J. Thomson, G. T. Reed, Univ. of
Surrey (United Kingdom)

POSTER SESSION

- 7220 14 **On-chip silicon photonic wavelength control of laser source** [7220-40]
X. Wang, T. Liu, Florida International Univ. (United States); V. R. Almeida, Instituto de Estudos Avançados (Brazil) and Instituto Tecnológico de Aeronáutica (Brazil); R. R. Panepucci, Florida International Univ. (United States)

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

Yakov Sidorin, Bromberg Sunstein LLP (United States)

Conference Chairs

Joel A. Kubby, University of California, Santa Cruz (United States)

Graham T. Reed, University of Surrey (United Kingdom)

Program Committee

Laurence W. Cahill, La Trobe University (Australia)

Philippe M. Fauchet, University of Rochester (United States)

L. Cary Gunn, Genalyte, Inc. (United States)

Siegfried Janz, National Research Council Canada (Canada)

Andrew P. Knights, McMaster University (Canada)

Laura M. Lechuga, Research Center on Nanoscience and
Nanotechnology (CIN2) (Spain)

Sebania Libertino, Istituto per la Microelettronica e Microsistemi (Italy)

Mario J. Paniccia, Intel Corporation (United States)

Andrew W. Poon, Hong Kong University of Science and Technology
(Hong Kong China)

Dan-Xia Xu, National Research Council Canada (Canada)

Session Chairs

1 Waveguides

Graham T. Reed, University of Surrey (United Kingdom)

2 Modulators

Philippe M. Fauchet, University of Rochester (United States)

3 Integration

Graham T. Reed, University of Surrey (United Kingdom)

- 4 Detectors
Paul E. Jessop, McMaster University (Canada)
- 5 Lab on a Chip I
Laurence W. Cahill, La Trobe University (Australia)
- 6 Lab on a Chip II
Laura M. Lechuga, Research Center on Nanoscience and
Nanotechnology (CIN2) (Spain)
- 7 Silicon Photonics
Mario J. Paniccia, Intel Corporation (United States)
- 8 Resonators and Interconnects
Graham T. Reed, University of Surrey (United Kingdom)
- 9 Resonators and Waveguide Devices
Joel A. Kubby, University of California, Santa Cruz (United States)
- 10 Emitters
Joel A. Kubby, University of California, Santa Cruz (United States)

Introduction

Silicon has a legendary history as the material of choice for microelectronic integration, but has not been the material of choice for optoelectronic integration. That is now beginning to change with the introduction of monolithic and hybrid silicon photonics. Silicon photonic devices have been demonstrated with the capability to emit, modulate, guide and detect light and can be combined with microelectronics to form electronic and photonic integrated circuits. Silicon photonic devices such as high-speed (40 GSa/s) analog to digital converters are now being fabricated in commercial CMOS foundries, enabling these devices to leverage the \$500 billion fabrication infrastructure for integrated circuits. The previous barrier of silicon's indirect bandgap has been overcome through the integration of germanium and III-V materials to form novel in-plane silicon lasers and high-speed (16 GHz) modulators. The cascaded Raman effect and nano-engineering of crystalline silicon and silicon-rich nitride films have also been used to obtain light from silicon and an electrically pumped silicon laser is on the horizon.

The decrease in waveguide bend radius made possible in silicon due to its high-index contrast, together with increased levels of optical and microelectronic integration, may lead to a new formulation of Moore's Law for silicon photonics. We are now seeing the convergence of communications and computing directly on-chip with the advent of optical interconnects, driven by the need for smaller and less expensive components that can leverage the infrastructure for CMOS manufacturing. In addition to on-chip communications and signal processing, silicon photonics is also being used to form laboratories on a chip with integrated micro-fluidics for low-cost, label-free biosensing. The past year has been an exciting time for silicon photonics! We hope you will enjoy the papers detailing these advancements that are included in this conference proceeding.

Joel A. Kubby
Graham T. Reed

