

PROCEEDINGS OF SPIE

Silicon Photonics X

Graham T. Reed
Michael R. Watts
Editors

9–12 February 2015
San Francisco, California, United States

Sponsored and Published by
SPIE

Volume 9367

Proceedings of SPIE 0277-786X, V. 9367

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

Silicon Photonics X, edited by Graham T. Reed, Michael R. Watts, Proc. of SPIE Vol. 9367,
936701 · © 2015 SPIE · CCC code: 0277-786X/15/\$18 · doi: 10.1117/12.2190472

Proc. of SPIE Vol. 9367 936701-1

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 X*, edited by Graham T. Reed, Michael R. Watts, Proceedings of SPIE Vol. 9367 (SPIE, Bellingham, WA, 2015) Article CID Number.

ISSN: 0277-786X

ISBN: 9781628414578

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 © 2015, 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/15/\$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. Papers are published as they are submitted and meet publication criteria. A unique 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.

Contents

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

SESSION 1 WAVEGUIDE-BASED DEVICES I

- 9367 04 **Fabrication error tolerant SOI WDM device using bidirectional angled multimode interferometers** [9367-2]
- 9367 05 **Improved performance of a silicon arrayed waveguide grating by reduction of higher order mode generation near the boundary of a star coupler** [9367-3]
- 9367 06 **Architectures for evanescent frequency tuning of microring resonators in micro-opto-electro-mechanical SOI platforms** [9367-4]

SESSION 2 WAVEGUIDE-BASED DEVICES II

- 9367 07 **Feedback and control in integrated optics enabled by contactless integrated photonic probe (Invited Paper)** [9367-5]
- 9367 08 **Suspended silicon slotted microring resonators with ultra-high optical quality** [9367-6]
- 9367 0A **Low-loss delay lines with small footprint on a micron-scale SOI platform** [9367-8]
- 9367 0B **Total internal reflection mirrors with ultra-low losses in 3 μm thick SOI waveguides** [9367-9]

SESSION 3 MODULATORS I

- 9367 0C **Design and characterisation of high-speed monolithic silicon modulators for digital coherent communication (Invited Paper)** [9367-10]
- 9367 0D **Power-efficient carrier-depletion SOI Mach-Zehnder modulators for 4x25Gbit/s operation in the O-band** [9367-11]
- 9367 0E **Strain tuning of germanium bandgap by selective epitaxial growth for electro-absorption modulators** [9367-12]
- 9367 0F **Accurate modelling and simulation of silicon optical modulators in QPSK** [9367-13]
- 9367 0G **Silicon photonics cloud (SiCloud)** [9367-15]

SESSION 4 SLOW-LIGHT MODULATORS I

- 9367 0I **Modulation efficiency enhancement of an optical phase modulator using one dimensional photonic crystal structures** [9367-17]
- 9367 0K **25 Gb/s photoreceiver based on vertical-illumination type Ge-on-Si photodetector and CMOS amplifier circuit for optical interconnects** [9367-19]
- 9367 0L **A hybrid photonic-electronic switching architecture for next generation datacenters (Invited Paper)** [9367-20]

SESSION 5 SLOW-LIGHT MODULATORS II

- 9367 0M **Monolithic silicon photonics in a sub-100nm SOI CMOS microprocessor foundry: progress from devices to systems (Invited Paper)** [9367-21]
- 9367 0N **Photonic-electronic integration with polysilicon photonics in bulk CMOS (Invited Paper)** [9367-22]
- 9367 0O **Interferometric microscopy of silicon photonic devices** [9367-23]
- 9367 0P **Hybrid silicon mode-locked laser with improved RF power by impedance matching** [9367-24]

SESSION 6 MIR SILICON PHOTONICS AND GESN DEVICES

- 9367 0Q **Group IV mid-infrared photonics (Invited Paper)** [9367-25]
- 9367 0R **Si based GeSn light emitter: mid-infrared devices in Si photonics (Invited Paper)** [9367-26]
- 9367 0S **Temperature-dependent study of Si-based GeSn photoconductors** [9367-27]
- 9367 0T **Integrated photonic crystal waveguides on silicon-on-sapphire for chemical sensing in mid-infrared** [9367-28]

SESSION 7 PICS FOR OPTICAL INTERCONNECTS: JOINT SESSION WITH CONFERENCES 9367 AND 9368

- 9367 0V **Imec iSiPP25G silicon photonics: a robust CMOS-based photonics technology platform** [9367-35]
- 9367 0W **Mode-converting coupler for silicon-on-sapphire devices** [9367-36]
- 9367 0X **Topology-optimized silicon photonic wire mode (de)multiplexer** [9367-37]
- 9367 0Y **25 Gbps silicon photonics multi-mode fiber link with highly alignment tolerant vertically illuminated germanium photodiode** [9367-38]

9367 0Z **Silicon-based tunable optical delay lines and switches for next generation optical telecommunications (Invited Paper)** [9367-39]

SESSION 8 DEVICE COUPLING APPROACHES FOR SILICON PHOTONICS CHIPS: JOINT SESSION WITH CONFERENCES 9367 AND 9368

9367 10 **Si-wire grating couplers for integrated optical transceivers based on single-mode fiber connection** [9367-40]

9367 11 **Low back-reflection CMOS-compatible grating coupler for perfectly vertical coupling** [9367-41]

9367 12 **Mode conversion based on the acousto-optical interaction in photonic-phononic waveguide** [9367-42]

SESSION 9 WAVEGUIDE-BASED DEVICES III

9367 13 **Comparison of different types of MMI-resonators fabricated on a micron-scale SOI platform** [9367-43]

9367 14 **Structural and optical properties of 200nm germanium-on-insulator (GeOI) substrates for silicon photonics applications** [9367-44]

9367 15 **Silicon photonics athermal Mach-Zehnder interferometer with wide thermal and spectral operating range** [9367-45]

9367 16 **Bending behavior of a flexible single crystal nanomembrane photonic crystal cavity** [9367-46]

9367 17 **Compact 4×4 1250GHz silicon arrayed waveguide grating router for optical interconnects** [9367-47]

SESSION 10 LAB-ON-A-CHIP, OPTOFLUIDICS, AND SENSING

9367 18 **Silicon-PDMS optofluidic integration (Invited Paper)** [9367-30]

9367 1B **4H-SiC detectors for ultraviolet light monitoring** [9367-33]

SESSION 11 LIGHT EMISSION AND DETECTION

9367 1E **Photoluminescence quenching effect by Si cap in n⁺ Ge on Si** [9367-49]

9367 1F **Comparison of large photovoltaic power plants with conventional ones and prospects for photovoltaic plants use in Israel** [9367-50]

9367 1G **GeSn waveguide structures for efficient light detection and emission** [9367-51]

9367 1H **Comparison of EL emitted by LEDs on Si substrates containing Ge and Ge/GeSn MQW as active layers** [9367-52]

9367 1I **Ultra-low-cost near-infrared photodetectors on silicon** [9367-53]

POSTER SESSION

9367 1J **High-quality slot waveguide ring resonator based on atomic layer deposition** [9367-54]

9367 1K **Toward new design-rule-check of silicon photonics for automated layout physical verifications** [9367-55]

9367 1L **Induced strain in silicon waveguides and couplers** [9367-56]

9367 1O **Solar cell enhancement using metallic nanoparticles embedded in titanium dioxide** [9367-59]

9367 1P **Strained germanium-tin multiple quantum well microdisk resonators towards a light source on silicon** [9367-60]

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.

Aalto, Timo, 0A, 0B, 13
Absil, Philippe P., 0V
Ackert, J. J., 0Q
Al-Kabi, S., 0R
Allen, Kenneth W., 1O
Alloatti, Luca, 0M
Alonso-Ramos, C., 0Q
Annoni, Andrea, 07
Arguirov, T., 1H
Arimoto, Hideo, 0Y
Atabaki, Amir, 0M
Atar, Fatih B., 1I
Autere, A., 1J
Badalà, P., 1B
Balboni, R., 1L
Baudot, Charles, 0D
Ben Bakir, Badhise, 0D
Bernier, Eric, 0L
Bernini, Romeo, 18
Blampey, Benjamin, 0D
Boeuf, Frédéric, 0D
Bolognini, G., 1L
Bowers, John, 0P
Burnett, Max A., 1O
Calvo, Vincent, 14
Carbone, B., 1B
Carminati, Marco, 07
Carmona, Christopher, 0G
Chakravarty, Swapnajit, 0T
Chan, Andrew C., 0G
Chang, Guo-En, 1G
Chantre, Alain, 0D
Cheben, P., 0Q
Chelnokov, Alexei, 14
Chen, Guanting, 17
Chen, Guodong, 12
Chen, Hongtao, 0V
Chen, Jianping, 0Z
Chen, Ray T., 0T, 16
Chen, Robert, 1P
Chen, Shao-Wei, 1G
Chen, Yu-Hsin, 0M
Cherchi, Matteo, 0A, 0B, 13
Chi, Hankyu, 0K
Ciccarella, Pietro, 07
Coffa, S., 1B
Corticelli, F., 1L
Dabos, G., 11
Dahlem, Marcus S., 06
De Coster, Jeroen, 0V
De Heyn, Peter, 0V
DePrenger, Michael J., 0O
Derickson, Dennis, 0P
DeVore, Peter T. S., 0G
Ding, Yunhong, 0X
Drissi, Youssef, 0V
Du, Wei, 0R, 0S
Duprez, Hélène, 0D
Elesin, Yuriy, 0X
El Shamy, Raghi S., 1K
Faist, Jérôme, 14
Färm, E., 1J
Feng, Danqi, 12
Ferrari, Giorgio, 07
Ferraro, Mike S., 0O
Ferri, M., 1L
Ferrotti, Thomas, 0D
Fiddy, Michael A., 1O
Fleet, Erin, 0O
Fowler, David, 14
Frandsen, Lars H., 0X
Frellsen, Louise F., 0X
Fu, H. Y., 0L
Gao, Ya, 12
Gardes, Frederic Y., 04, 0Q
Gassenq, Alban, 14
Geiger, Richard, 14
Geng, Dongyu, 0L
Georgas, Michael, 0M
Ghetmiri, Seyed Amir, 0R, 0S
Goetz, Peter G., 0O
Goi, Kazuhiro, 0C
Goodwill, Dominic, 0L
Graves, Alan, 0L
Grillanda, Stefano, 07
Guilloy, Kevin, 14
Gupta, Suyog, 1P
Hammouda, Sherif, 1K
Harduin, Julie, 0D
Harjanne, Mikko, 0A, 0B, 13
Harris, James S., 1P
Hartmann, Jean Michel, 14
Hassan, Karim, 0D
He, Jianjun, 17
Healy, N., 0Q
Honkanen, S., 1J
Hosseini, Seyedreza, 0I
Hu, Youfang, 04

Huang, Yi-Chiau, 1P
 Huang, Yu-Hui, 1G
 Huo, Yijie, 1P
 Ismail, Mohamed, 1K
 Jacobs, E. W., 0W
 Jalali, Bahram, 0G
 Jamshidi, Kambiz, 0I
 Jang, Ki-Seok, 0K
 Jeong, Deog-Kyoon, 0K
 Jeong, Gyu-Seob, 0K
 Jeong, Seok-Hwan, 10
 Jiang, Wei C., 08
 Jiang, Yunshan, 0G
 Joo, Jiho, 05, 0K
 Kamins, Theodore I., 1P
 Kapulainen, Markku, 0A, 0B, 13
 Karvonen, L., 1J
 Kasper, E., 1H
 Kemell, M., 1J
 Khanna, Amit, 0V
 Khokhar, Ali Z., 04, 0Q
 Kiaei, Mohammad, 0L
 Kim, Gyungock, 05, 0K
 Kim, In Gyoo, 0K
 Kim, Sanghoon, 0K
 Kim, Sun Ae, 0K
 Kim, Yihwan, 1P
 Kittler, M., 1H
 Knights, A. P., 0Q
 Kostecki, K., 1H
 Kumar, Rajesh, 0M
 Kwack, Myung-Joon, 05
 Kwong, Dim-Lee, 0C
 Lang, Tingting, 17
 Lepage, Guy, 0V
 Leskelä, M., 1J
 Leu, Jonathan, 0M
 Li, Baohua, 0R, 0S
 Li, Shuaibing, 0L
 Li, Zuxiang, 0Z
 Lim, Soon Thor, 0C, 0F
 Lin, Qiang, 08
 Lin, You-Long, 1G
 Liow, Tsung-Yang, 0C, 1J
 Littlejohns, C. J., 0Q
 Lo, Guo-Qiang, 0C, 1J
 Lu, Liangjun, 0Z
 Luan, N. M., 0E
 Lynch, Michael, 0G
 Ma, Huixiao, 0L
 Madkour, Kareem, 1K
 Mahon, Rita, 0O
 Mancarella, F., 1L
 Margetis, Joe, 0R, 0S
 Marini, D., 1L
 Mashanovich, Goran Z., 04, 0Q
 Mashiko, Yasuhiro, 0C
 Matsuoka, Yasunobu, 0Y
 Mazzillo, M., 1B
 Medres, B., 1F
 Mehrvar, Hamid, 0L
 Melloni, Andrea, 07
 Menezes, Sylvie, 0D
 Milesi, Frédéric, 0D
 Mitchell, Colin J., 04, 0Q
 Miyatake, Taira, 0G
 Mizuno, Y., 0E
 Molina-Fernandez, I., 0Q
 Montanari, G. B., 1L
 Morichetti, Francesco, 07
 Morito, Ken, 10
 Mosleh, Aboozar, 0R, 0S
 Moss, Benjamin, 0M
 Muniam, Kuhan, 0G
 Myko, André, 0D
 Nammari, Kareem, 0M
 Naseem, Hameed A., 0R, 0S
 Nazirzadeh, M. Amin, 1I
 Nazzari, A., 0R
 Nedeljkovic, M., 0Q
 Nomoto, Etsuko, 0Y
 Notaros, Jelena, 0M
 Oda, Katsuya, 0Y
 Oehme, M., 1H
 Offord, B. W., 0W
 Ogawa, Kensuke, 0C, 0F
 Oh, Jin Hyuk, 0K
 Oka, Akira, 0C
 Okumura, Tadashi, 0Y
 Okyay, Ali K., 1I
 Orcutt, Jason S., 0M
 Ortega-Moñux, A., 0Q
 Osvaldo Dias, Guilherme, 14
 Owen, M., 0W
 Pan, H., 1E
 Pantouvaki, Marianna, 0V
 Park, Doe, 0O
 Park, Hyundai, 05
 Park, Jaegyoo, 05
 Passaro, V. M. N., 0Q
 Pauc, Nicolas, 14
 Pavanello, Fabio, 0M
 Peacock, A. C., 0Q
 Persichetti, Gianluca, 18
 Peserico, Nicola, 07
 Pham, Thach, 0S
 Pleros, N., 1I
 Png, Ching Eng, 0C, 0F
 Popović, Miloš A., 0M
 Pregerman, L., 1F
 Pruessner, Marcel, 0O
 Rabinovich, William S., 0O
 Ram, Rajeev J., 0M, 0N
 Reboud, Vincent, 14
 Reed, Graham T., 04
 Reynolds, S., 0Q
 Rifala, M., 1J
 Rousseau, M., 1J
 Rowe, D. J., 0Q
 Russo, A., 1B

Sagawa, Misuzu, 0Y
 Sampietro, Marco, 07
 Sanchez, Errol, 1P
 Sanmartin, M., 1L
 Saraswat, Krishna C., 1P
 Sarro, Pasqualina M., 18
 Säynätjoki, A., 1J
 Schulze, J., 1H
 Schwartz, B., 1H
 Sciancalepore, Corrado, 0D
 Sciuto, A., 1B
 Sekiguchi, Shigeaki, 10
 Shainline, Jeffrey M., 0M
 Shang, Colleen K., 1P
 Shen, L., 0Q
 Shimabukuro, R., 0W
 Shoman, Hossam, 06
 Sigg, Hans, 14
 Sigmund, Ole, 0X
 Slonim, M., 1F
 Sobu, Yohei, 10
 Soler Penades, J., 0Q
 Soref, Richard A., 0R, 0S
 Srinivasan, Sudharsanan, 0P
 Stanković, Stevan, 04, 0Q
 Stojanović, Vladimir, 0M
 Subbaraman, Harish, 16
 Sun, Chen, 0M
 Sun, Greg, 0R, 0S
 Sun, Junqiang, 12
 Sun, Min Jie, 0C, 0F
 Sun, Z., 1J
 Swillam, Mohamed A., 1K
 Takahashi, R., 1E
 Takemoto, Takashi, 0Y
 Takinai, K., 1E
 Tanaka, Shigehisa, 0Y
 Tanaka, Yu, 10
 Testa, Genni, 18
 Thomson, David J., 04, 0Q
 Tolle, John, 0R, 0S
 Tossoun, Bassem, 0P
 Troia, B., 0Q
 Tsiokos, D., 11
 Tu, Xiaoguang, 0C, 1J
 Turgut, B. Berkan, 1I
 Van Campenhout, Joris, 0V
 Van Thourhout, Dries, 0V
 Vehmas, Tapani, 0A, 0B, 13
 Verheyen, Peter, 0V
 Viegas, Jaime, 15
 Vyrsoinos, Konstantinos, 0A
 Wada, K., 0E, 1E
 Wade, Mark T., 0M
 Wakayama, Yuki, 0Y
 Wang, Dawei, 0L
 Wang, Y., 0Q
 Wang, Yan, 0L
 Wanguemert-Perez, G., 0Q
 Widiez, Julie, 14
 Wilkinson, J. S., 0Q
 Xie, Heng, 12
 Xie, Jingya, 0Z
 Xing, Peng, 15
 Xiong, Huang, 12
 Xu, Xiaochuan, 0T, 16
 Yako, M., 0E
 Yang, Xiaoling, 0L
 Ylinen, Sami, 0A, 0B, 13
 Yu, Shui-Qing, 0R, 0S
 Yvind, Kresten, 0X
 Zabel, T., 14
 Zhang, Ruiwen, 12
 Zhou, Linjie, 0Z
 Zhou, Y., 0R
 Zlatanovic, S., 0W
 Zou, Jun, 17
 Zou, Yi, 0T

Conference Committee

Symposium Chairs

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

Symposium Co-chairs

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

Program Track Chair

Yakov Sidorin, Quarles & Brady LLP (United States)

Conference Chairs

Graham T. Reed, University of Southampton (United Kingdom)
Michael R. Watts, Massachusetts Institute of Technology
(United States)

Conference Program Committee

Laurence W. Cahill, La Trobe University (Australia)
Philippe M. Fauchet, Vanderbilt University (United States)
L. Cary Gunn, Genalyte, Inc. (United States)
Siegfried Janz, National Research Council Canada (Canada)
Andrew P. Knights, McMaster University (Canada)
Joel Kubby, University of California, Santa Cruz (United States)
Laura Maria Lechuga, CIN2 (Spain)
Sebania Libertino, Istituto per la Microelettronica e Microsistemi (Italy)
Goran Z. Mashanovich, University of Southampton (United Kingdom)
Ching Eng Jason Png, A*STAR Institute of High Performance
Computing (Singapore)
Andrew W. Poon, Hong Kong University of Science and Technology
(Hong Kong, China)
Haisheng Rong, Intel Corporation (United States)
Holger Schmidt, University of California, Santa Cruz (United States)
Dan-Xia Xu, National Research Council Canada (Canada)
Zhiping Zhou, Peking University (China)

Session Chairs

- 1 Waveguide-based Devices I
Goran Z. Mashanovich, University of Southampton (United Kingdom))
- 2 Waveguide-based Devices II
Graham T. Reed, University of Southampton (United Kingdom)
- 3 Modulators I
Miloš Popović, University of Colorado at Boulder (United States)
- 4 Slow-Light Modulators I
Andrew P. Knights, McMaster University (Canada)
- 5 Slow-Light Modulators II
Graham T. Reed, University of Southampton (United Kingdom)
- 6 MIR Silicon Photonics and GeSn Devices
Graham T. Reed, University of Southampton (United Kingdom)
Goran Z. Mashanovich, University of Southampton (United Kingdom)
- 7 PICs for Optical Interconnects: Joint Session with Conferences 9367 and 9368
Henning Schröder, Fraunhofer-Institut für Zuverlässigkeit und Mikrointegration (Germany)
Graham T. Reed, University of Southampton (United Kingdom)
- 8 Device Coupling Approaches for Silicon Photonics Chips: Joint Session with Conferences 9367 and 9368
Graham T. Reed, University of Southampton (United Kingdom)
Henning Schröder, Fraunhofer-Institut für Zuverlässigkeit und Mikrointegration (Germany)
- 9 Waveguide-based Devices III
Graham T. Reed, University of Southampton (United Kingdom)
- 10 Lab-on-a-Chip, Optofluidics, and Sensing
Eng Huat Khoo, A*STAR Institute of High Performance Computing (Singapore)
- 11 Light Emission and Detection
Michael R. Watts, Massachusetts Institute of Technology (United States)