

PROCEEDINGS OF SPIE

Silicon Photonics XV

Graham T. Reed

Andrew P. Knights

Editors

3–6 February 2020

San Francisco, California, United States

Sponsored and Published by

SPIE

Volume 11285

Proceedings of SPIE 0277-786X, V. 11285

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

Silicon Photonics XV, edited by Graham T. Reed, Andrew P. Knights, Proc. of SPIE Vol. 11285,
1128501 · © 2020 SPIE · CCC code: 0277-786X/20/\$21 · doi: 10.1117/12.2570190

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 SPIEDigitalLibrary.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 *Silicon Photonics XV*, edited by Graham T. Reed, Andrew P. Knights, Proceedings of SPIE Vol. 11285 (SPIE, Bellingham, WA, 2020) Seven-digit Article CID Number.

ISSN: 0277-786X

ISSN: 1996-756X (electronic)

ISBN: 9781510633339

ISBN: 9781510633346 (electronic)

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 © 2020, 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/20/\$18.00.

Printed in the United States of America.

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



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 seven-digit CID article numbering system structured as follows:

- The first five 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

xii	Authors
ix	Conference Committee

PHOTONIC INTEGRATION

- 11285 03 **MORPHIC: programmable photonic circuits enabled by silicon photonic MEMS (Invited Paper)** [11285-1]
- 11285 04 **Epitaxial integration of high-performance quantum-dot lasers on silicon (Invited Paper)** [11285-2]
- 11285 06 **Multi-chip heterogeneously integrated array of active three-terminal transistor lasers and passive photonic structures for electronic-photonic integration on silicon** [11285-4]
- 11285 07 **Amorphous silicon waveguide escalator: monolithic integration of active components on 3 μm SOI platform** [11285-5]

OPTICAL COMMUNICATIONS I

- 11285 0A **Fabrication tolerant high-speed SiP ring modulators and optical add-drop multiplexers for WDM applications** [11285-8]
- 11285 0B **Advanced Si photonics platform for high-speed and energy-efficient optical transceivers for datacom** [11285-9]

OPTICAL COMMUNICATIONS II

- 11285 0C **Power-efficient lumped-element meandered silicon Mach-Zehnder modulators** [11285-10]
- 11285 0D **Strain induced Pockels effect in silicon for electro-optic modulation** [11285-11]
- 11285 0F **16×16 silicon photonic AWGR for dense wavelength division multiplexing (DWDM) O-band interconnects** [11285-13]
- 11285 0G **Flat-top interleavers based on single MMIs** [11285-14]
- 11285 0H **Ultrafast self-induced oscillation in a nonlinear subwavelength grating metamaterial ring resonator** [11285-15]

SILICON PHOTONICS ENABLED LIDAR

- 11285 0J **An overview of silicon photonics for LiDAR (Invited Paper)** [11285-17]
- 11285 0K **Integrated optical phased arrays: LiDAR, augmented reality, and beyond (Invited Paper)** [11285-18]

WAVEGUIDES

- 11285 0P **Suspended subwavelength grating waveguides on SOI for ultra-broadband operation** [11285-23]
- 11285 0Q **Photonic crystal and quasi photonic crystal Ge-on-Si lenses for the combination of QCL array outputs** [11285-24]
- 11285 0R **Optical reflection from a free carrier-induced front in a slow light waveguide** [11285-25]

GE/SI INTEGRATION

- 11285 0V **Monolithic integration of up to 40 GHz Ge photodetectors in 3 μ m SOI** [11285-29]

MANUFACTURING TECHNOLOGY

- 11285 0Y **Hot-wire CVD hydrogenated amorphous silicon for multi-layer photonic applications (Invited Paper)** [11285-32]
- 11285 10 **Experimental phase-error extraction and modelling in silicon photonic arrayed waveguide gratings** [11285-34]
- 11285 12 **Electrical annealing for Ge ion-implanted directional couplers** [11285-36]

OPTICAL DETECTION AND SENSING I

- 11285 13 **Micro PA detector: pushing the limits of mid IR photoacoustic spectroscopy integrated on silicon (Invited Paper)** [11285-37]
- 11285 15 **High speed integrated waveguide lateral Si/Ge/Si photodiodes with optimized transit time** [11285-39]
- 11285 16 **Heterodyne detection for the measurement of electro-optical frequency combs generated with a silicon Mach-Zehnder modulator** [11285-40]

EMERGING APPLICATIONS II

- 11285 1A **Reconfigurable photonic integrated circuits (RPICs) based on functional materials for integrated optical communication applications [11285-44]**
- 11285 1C **The effect of two-photon absorption on the dynamic range of integrated microwave photonics links [11285-46]**

OPTICAL DETECTION AND SENSING II

- 11285 1G **Investigations into group IV photonic waveguides with a wide working optical bandwidth [11285-49]**

OPTICAL COMMUNICATIONS III

- 11285 1J **Fast thermo-optic optimization of high-order SOI microring optical filters by method of gradient descent [11285-53]**

POSTER SESSION

- 11285 1K **Design of silicon photonics based accelerometer for displacement sensing applications [11285-54]**
- 11285 1L **Low voltage 12 GHz silicon optical electro-absorption modulator (EAM) using a Schottky diode for optical interconnectors in the C-band [11285-55]**
- 11285 1O **Model-based guard ring structure guideline for the enhancement of silicon-based single-photon avalanche diode characteristics [11285-58]**
- 11285 1P **A compact structure for realizing electromagnetically induced transparency in a microring resonator [11285-59]**
- 11285 1R **A widely tunable twin-fano resonator for wavelength monitor [11285-61]**
- 11285 1T **Absorptivity enhancement of black silicon using electroless Cu plating [11285-63]**
- 11285 1U **Laterally asymmetrical photonic crystal waveguide as a compact TM-pass polarization filter for C-band operation [11285-64]**

Authors

Numbers in the index correspond to the last two digits of the seven-digit citation identifier (CID) article numbering system used in Proceedings of SPIE. The first five 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, 07, 0G, 0V | Edinger, Pierre, 03 |
| Abasahl, Banafsheh, 03 | Eich, Manfred, 0R |
| Abautret, Johan, 0Q | Elsayed, Ahmed A., 1T |
| Alexoudi, T., 0F | Errando-Herranz, Carlos, 03 |
| Alonso-Ramos, Carlos, 0D | Faneca, Joaquin, 1A |
| Baiocco, Christopher, 0K | Fiers, Martin, 10 |
| Baldycheva, Anna, 1A | Fotiadis, K., 0F |
| Barbier, Margaux, 16 | Fowler, Daivid, 0B |
| Bass, Jake, 1C | Gaafar, Mahmoud A., 0R |
| Baudot, Charles, 16 | Gao, Feng, 0V |
| Benedikovic, Daniel, 0D | Garcia Porcel, Marco, 03 |
| Bera, Arijit, 07 | Gardes, Frederic Y., 1A |
| Berciano, Mathias, 0D | Gay, Mathilde, 16 |
| Bernabé, Stéphane, 0B, 15 | Glière, A., 13 |
| Berthelot, A., 13 | Gossard, Arthur C., 04 |
| Bhargava, Pavan, 0K | Grillot, Frederic, 04 |
| Boeuf, Frédéric, 16 | Grosse, P., 15 |
| Bogaerts, Wim, 03, 10 | Guais, Maxime, 0Q |
| Bourouina, Tarik, 1T | Guilhabert, Benoit, 1G |
| Bowers, John E., 04 | Guo, Xiaoqing, 1R |
| Bramerie, Laurent, 16 | Gupta, S., 0J |
| Brea, Brandon, 1C | Gylfason, Kristinn B., 03 |
| Brision, Stéphane, 0B, 15 | Harjanne, Mikko, 0G |
| Byrd, Matthew J., 0K | Heimala, Päivi, 07, 0V |
| Cao, Wei, 1G | Herrick, Robert W., 04 |
| Carlson, John A., 06 | Huang, Heming, 04 |
| Carras, Mathieu, 0Q | Hussain, A., 1P |
| Cassan, Eric, 0D | Hussein, Magdy, 1T |
| Chae, Youngcheol, 1O | Jalas, Dirk, 0R |
| Chen, Bei, 1R | Jeong, Uiseok, 1L |
| Chen, Ray T., 0H | Jezzini, Moises, 03 |
| Chen, Xia, 12 | Jung, Daehwan, 04 |
| Cheng, Yue, 0H | Kapulainen, Markku, 0G, 0V |
| Cherchi, Matteo, 07, 0G | Kennedy, M. J., 04 |
| Chong, Harold M. H., 0Y | Khaled, Ahmed, 1T |
| Chung, Chi-jui, 0H | Khalil, Diaa, 1T |
| Coutard, J. G., 13 | Khan, Umar, 03, 10 |
| Crobat, Paul, 0D | Khokhar, Ali Z., 1G |
| Dai, Tingge, 1R | Kiang, Kian Shen, 1G |
| Dallesasse, John M., 06 | Kim, Jinsik, 1L |
| De Heyn, P., 0F | Kim, Kwangwoong, 1L |
| Delrosso, Giovanni, 0V | Kim, Taehwan, 0K |
| Deniel, Lucas, 0D, 16 | Koshkinbayeva, A., 1K |
| Dominguez Bucio, Thalia, 1A | Krauss, Thomas F., 0R |
| Doylend, J. K., 0J | Lafforgue, Christian, 0D |
| Du, Wei, 1C | Le Roux, Xavier, 0D |
| Duan, Jianan, 04 | Lee, Kyungwoon, 1L |
| Dumont, Mario, 04 | Lhermet, H., 13 |
| Dyer, Thomas, 0K | Li, Juntao, 0R |

- Li, Nanxi, 0K
 Li, Ting, 0P
 Liu, Songtao, 04
 Magden, Emir Salih, 0K
 Maisons, Grégory, 0Q
 Malhouitre, Stéphane, 0B
 Malik, F., 1P
 Mang, Thomas, 0B
 Marcaud, Guillaume, 0D
 Marris-Morini, Delphine, 0D, 0Q, 16
 Marty, Frédéric, 1T
 Mashanovich, Goran Z., 1G
 Maximus, A. R., 1K
 Merget, Florian, 0A, 0C
 Michinobu, Tsuyoshi, 0H
 Milosevic, Milan M., 12
 Mitsolidou, C., 0F
 Mittal, Vinita, 0Y
 Moralis-Pegios, M., 0F
 Moscoso-Mártir, A., 0C
 Müller, Juliana, 0A
 Nedeljkovic, Milos, 1G
 Nefzaoui, Elyes, 1T
 Ngo, Huynh, 1J
 Niklaus, Frank, 03
 Nojić, Jovana, 0A, 0C
 Norman, Justin C., 04
 Notaros, Jelena, 0K
 Notaros, Milica, 0K
 O'Brien, Peter, 03
 O'Faolain, Liam, 0R
 Olivier, Sérgolène, 0B
 Oo, Swe Z., 0Y
 Pan, Zeyu, 0H
 Park, Byungchoul, 1O
 Park, Hyo-Hoon, 1K
 Park, Jung Ho, 1L
 Peacock, Anna C., 0Y
 Pérez-Galacho, Diego, 16
 Petra, Rafidah, 0Y
 Petrov, Alexander Yu., 0R
 Peucheret, Christophe, 16
 Pitris, S., 0F
 Pleros, N., 0F
 Poulton, Christopher V., 0K
 Prakash, Chandra, 1U
 Qadir, M. Favad, 1P
 Quack, Niels, 03
 Raval, Manan, 0K
 Reed, Graham T., 0Y, 12
 Ren, Yang, 1J
 Ribaud, Karen, 0B
 Ribeiro, Antonio, 03
 Ruiz-Caridad, Alicia, 0D
 Sabry, Yasser M., 1T
 Saito, Shinichi, 12
 Sattari, Hamed, 03
 Saurav, Kumar, 03
 Scherer, B., 13
 Sciancalepore, Corrado, 0B
 Selridge, Jennifer G., 04
 Sen, Mrinal, 1U
 Shang, Chen, 04
 Sharif Azadeh, Saeed, 0A, 0C
 Shin, Dongseok, 1O
 Soref, Richard, 1C
 Stirling, Callum J., 1G
 Stojanovic, Vladimir, 0K
 Strahl, T., 13
 Strain, Michael J., 1G
 Su, Zhan, 0K
 Sun, Fei, 0G, 0V
 Szelag, Bertrand, 0B, 15
 Tahir, W., 1P
 Takabayashi, Alain Yuji, 03
 Talli, Giuseppe, 03
 Tappura, Kirsi, 07
 Tarazona, Antulio, 0Y
 Teulle, A., 13
 Timurdogan, Erman, 0K
 Tran, Huong, 1C
 Ukaegbu, I. A., 1K
 Vakanin, Vladyslav, 0D
 Van Campenhout, J., 0F
 Van, Vien, 1J
 Vehmas, Tapani, 0V
 Verdot, T., 13
 Verheyen, Peter, 03
 Virot, L., 15
 Vivien, Laurent, 0D, 16
 Wan, Yating, 04
 Wang, Xiaojing, 03
 Wang, Yaguo, 0H
 Wang, Yang, 0H
 Wang, Yuehai, 1R
 Watts, Michael R., 0K
 Weckenmann, Erwan, 16
 Wilmar, Quentin, 0B, 15
 Witzens, Jeremy, 0A, 0C
 Xing, Yufei, 10
 Xu, Xiaochuan, 0H
 Yan, Xingzhao, 12
 Yang, Jianyi, 1R
 Yu, Hui, 1R
 Yu, Shui-Qing, 1C
 Yu, Xingshi, 12
 Yun, Ilgu, 1O
 Zakwan, M., 1P
 Zand, Iman, 03
 Zegmout, H., 15
 Zhang, Zeyu, 04
 Zhou, Peiji, 0P
 Zimmerling, Tyler J., 1J
 Zou, Yi, 0P

Conference Committee

Symposium Chairs

Sailing He, KTH Royal Institute of Technology (Sweden) and Zhejiang University (China)
Yasuhiro Koike, Keio University (Japan)

Symposium Co-chairs

Connie J. Chang-Hasnain, University of California, Berkeley (United States)
Graham T. Reed, Optoelectronics Research Centre, University of Southampton (United Kingdom)

Program Track Chairs

Yakov Sidorin, Quarles & Brady LLP (United States)
Jean-Emmanuel Broquin, IMEP-LAHC (France)

Conference Chairs

Graham T. Reed, Optoelectronics Research Centre (United Kingdom)
Andrew P. Knights, McMaster University (Canada)

Conference Program Committee

Martijn J. R. Heck, Aarhus University (Denmark)
Siegfried Janz, National Research Council Canada (Canada)
Delphine Marris-Morini, Centre de Nanosciences et de Nanotechnologies (France)
Goran Z. Mashanovich, University of Southampton (United Kingdom)
Jurgen Michel, Massachusetts Institute of Technology (United States)
Liam O'Faolain, Tyndall National Institute (Ireland)
Jason Ching Eng 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)
Dries Van Thourhout, University Gent (Belgium)
Laurent Vivien, Centre de Nanosciences et de Nanotechnologies (France)
Jeremy Witzens, RWTH Aachen University (Germany)
Winnie N. Ye, Carleton University (Canada)
Shui-Qing Yu, University of Arkansas (United States)

Zhiping Zhou, Peking University (China)
Aaron J. Zilkie, Rockley Photonics (United States)

Session Chairs

- 1 Photonic Integration
Andrew P. Knights, McMaster University (Canada)
- 2 Optical Communications I
Graham T. Reed, Optoelectronics Research Centre (United Kingdom)
- 3 Optical Communications II
Iain F. Crowe, The University of Manchester (United Kingdom)
- 4 Silicon Photonics Enabled LIDAR
Andrew P. Knights, McMaster University (Canada)
- 5 Waveguides
Dan-Xia Xu, National Research Council Canada (Canada)
- 6 Ge/Si Integration
Dylan F. Logan, RANOVUS, Inc. (Canada)
- 7 Manufacturing Technology
Iain F. Crowe, The University of Manchester (United Kingdom)
- 8 Optical Detection and Sensing I
Jens H. Schmid, National Research Council Canada (Canada)
- 9 Emerging Applications I
Andrew P. Knights, McMaster University (Canada)
- 10 Emerging Applications II
Jonathan K. Doylend, Intel Corporation (United States)
- 11 Optical Detection and Sensing II
Graham T. Reed, Optoelectronics Research Centre (United Kingdom)
- 12 Optical Communications III
Graham T. Reed, Optoelectronics Research Centre (United Kingdom)