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CONFERENCE 10923

Monday-Wednesday 4-6 February 2019 • Proceedings of SPIE Vol. 10923

Silicon Photonics XIV

Conference Chairs: **Graham T. Reed**, Optoelectronics Research Ctr. (United Kingdom); **Andrew P. Knights**, McMaster Univ. (Canada)

Program Committee: **Martijn J. R. Heck**, Aarhus Univ. (Denmark); **Siegfried Janz**, National Research Council Canada (Canada); **Delphine Marris-Morini**, Ctr. de Nanosciences et de Nanotechnologies (France); **Goran Z. Mashanovich**, Univ. of Southampton (United Kingdom); **Jurgen Michel**, Massachusetts Institute of Technology (USA); **Liam O'Faolain**, Tyndall National Institute (Ireland); **Jason Ching Eng Png**, A*STAR Institute of High Performance Computing (Singapore); **Andrew W. Poon**, Hong Kong Univ. of Science and Technology (Hong Kong, China); **Haisheng Rong**, Intel Corp. (USA); **Dries Van Thourhout**, Univ. Gent (Belgium); **Laurent Vivien**, Ctr. de Nanosciences et de Nanotechnologies (France); **Jeremy Witzens**, RWTH Aachen Univ. (Germany); **Winnie N. Ye**, Carleton Univ. (Canada); **Shui-Qing Yu**, Univ. of Arkansas (USA); **Zhiping Zhou**, Peking Univ. (China); **Aaron J. Zilkie**, Rockley Photonics (USA)

MONDAY 4 FEBRUARY

OPTO PLENARY SESSION 8:00 AM TO 10:05 AM

Welcome and Opening Remarks, Connie J. Chang-Hasnain, Univ. of California, Berkeley (USA); **Graham T. Reed**, Optoelectronics Research Ctr. (United Kingdom)

Hyperscale data center applications of optoelectronics (Plenary Presentation), Katharine Schmidtke, Facebook Inc. (USA)

Two decades of progress for photonic crystals: from the realization of complete 3D crystals to the state of the art for society 5.0 (Plenary Presentation), Susumu Noda, Kyoto Univ. Graduate School of Engineering (Japan)

Deep-learning optics (Plenary Presentation), Aydogan Ozcan, California NanoSystems Institute (USA) and Univ. of California, Los Angeles (USA)

On pages 6-7 for details.

SESSION 1 MON 10:30 AM TO 12:30 PM

Fabrication Technology

Session Chair: **Graham T. Reed**, Optoelectronics Research Ctr. (United Kingdom)

Bulk CMOS photonic/electronic integration (Invited Paper), Vladimir Marko Stojanovic, Univ. of California, Berkeley (USA) [10923-1]

Rapid device prototyping using the CORNERSTONE platform (Invited Paper), Callum G. Littlejohns, Ying Tran, Han Du, Stevan Stanković, Xingzhao Yan, Univ. of Southampton (United Kingdom); Graham J. Sharp, Marc Sorel, Univ. of Glasgow (United Kingdom); Roger Webb, Jonathon England, Univ. of Surrey (United Kingdom); Harold Chong, Frederic Y. Gardes, David J. Thomson, Goran Z. Mashanovich, Graham T. Reed, Univ. of Southampton (United Kingdom) [10923-2]

Alignment-tolerant interfacing of a photonic integrated circuit using backside etched silicon microlenses, Jeroen Missinne, Ctr. for Microsystems Technology (Belgium) and Univ. Gent (Belgium) and IMEC (Belgium); Nuria Teigell Benítez, Univ. Gent (Belgium) and IMEC (Belgium); Nivesh Mangal, IMEC (Belgium); Jing Zhang, Anton Vasiliev, Univ. Gent (Belgium); Joris Van Campenhout, Bradley Snyder, IMEC (Belgium); Gunther Roelkens, Univ. Gent (Belgium); Geert Van Steenberge, Ctr. for Microsystems Technology (Belgium) [10923-3]

High-yield parallel transfer print integration of III-V substrate-illuminated C-band photodiodes on silicon photonic integrated circuits, Grigorij Muliuk, Jing Zhang, Jeroen Goyvaerts, Sulakshna Kumari, Univ. Gent (Belgium); Brian Corbett, Tyndall National Institute (Ireland); Dries Van Thourhout, Gunther Roelkens, Univ. Gent (Belgium) [10923-4]

Challenges and solutions for high-speed integrated silicon photonics, Thomas Y. L. Ang, Ching Eng Png, Soon Thor Lim, Jun Rong Ong, A*STAR Institute of High Performance Computing (Singapore) [10923-5]

Lunch Break Mon 12:30 pm to 2:00 pm

SESSION 2 MON 2:00 PM TO 3:30 PM

Silicon Waveguides I

Session Chair: **Jonathan D. B. Bradley**, McMaster Univ. (Canada)

Engineering sub-wavelength silicon waveguides for sensing applications in the near-infrared and mid-infrared band (Invited Paper), Juan Gonzalo Wangüemert-Pérez, Alejandro Sánchez-Postigo, Abdelfettah Hadij-Elhouati, Univ. de Málaga (Spain); Jonas Leuermann, Ctr. Andaluz de Nanomedicina y Biotecnología (Spain); Carlos Pérez-Armenta, Faysal El Mokhtari Mimun, Daniel Pereira-Martin, José Manuel Luque-González, Alejandro Ortega-Moñux, Robert Halir, Iñigo Molina-Fernández, Univ. de Málaga (Spain); Pavel Cheben, Jens H. Schmid, Dan-Xia Xu, National Research Council Canada (Canada); Jiri Čtyroký, Institute of Photonics and Electronics (Czech Republic); Jordi Soler-Penades, Milos Nedeljkovic, Goran Z. Mashanovich, Optoelectronics Research Ctr. (United Kingdom) [10923-6]

Suspended low-loss germanium waveguides for the mid-infrared, Ahmed Osman, Milos Nedeljkovic, Jordi S. Penades, Yangbo Wu, Zhibo Qu, Ali Z. Khokhar, Goran Z. Mashanovich, Univ. of Southampton (United Kingdom) [10923-7]

Direct thermo-optical tuning of silicon photonic devices, Paul Chevalier, Harvard Univ. (USA); Lara Koehler, Harvard Univ. (USA) and Ecole Polytechnique (France); Euijae Shim, Columbia Univ. (USA); Boris Desiatov, Amirhassan Shams-Ansari, Marco Piccardo, Marko Loncar, Harvard Univ. (USA); Michal Lipson, Alexander Gaeta, Columbia Univ. (USA); Federico Capasso, Harvard Univ. (USA) [10923-8]

Trimming of silicon-on-insulator devices via localised laser annealing, Vera Biryukova, Graham J. Sharp, Charalambos Klitis, Sarah Ruddell, Marc Sorel, Univ. of Glasgow (United Kingdom) [10923-9]

SESSION 3 MON 4:00 PM TO 6:00 PM

Amplified Silicon Photonics

Session Chair: **Andrew P. Knights**, McMaster Univ. (Canada)

On-chip amplifiers and lasers on the Al₂O₃ integrated photonics platform (Invited Paper), Sonia M. García-Blanco, Carlijn I. van Emmerik, Jinfeng Mu, Michiel de Goede, Meindert Dijkstra, Lantian Chang, Univ. Twente (Netherlands) [10923-10]

Antimonide-based optoelectronic devices grown on Si substrates (Invited Paper), Eric Tournié, Laurent Cerutti, Jean-Baptiste Rodriguez, Jean-Philippe Perez, Philippe Christol, Roland Teissier, Alexei N. Baranov, Univ. de Montpellier (France) [10923-11]

Silicon waveguide integrated with a tellurium oxide whispering gallery resonator on chip, Henry C. Frankis, Dawson B. Bonneville, Daniel Su, Jonathan D. B. Bradley, McMaster Univ. (Canada) [10923-12]

1.3µm u-bend traveling wave SOA devices for high efficiency coupling to silicon photonics, Jukka Viheriälä, Heidi Tuorila, Tampere Univ. of Technology (Finland); Matteo Cherchi, Timo Aalto, VTT Technical Research Ctr. of Finland Ltd. (Finland); Mircea Guina, Tampere Univ. of Technology (Finland) [10923-13]

Hydrogen passivation and microstructure fabrication in erbium silicates for optical amplification applications around 1.5 µm, Devika Vipin, Mengbing Huang, SUNY Polytechnic Institute (USA) [10923-14]

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SESSION 9 WED 10:30 AM TO 12:20 PM

Integrated Optical Emission

Session Chair: **Iain F. Crowe**,
The Univ. of Manchester (United Kingdom)

Single-mode lasing in strained Ge microbridges (*Invited Paper*),
Francesco Taro Armand Pilon, Alexey Lyasota, Paul Scherrer Institut
(Switzerland); Vincent Reboud, CEA-LETI (France) and Univ. Grenoble Alpes
(France); Vincent Calvo, Nicolas Pauc, CEA-INAC (France) and Univ. Grenoble
Alpes (France); Julie Widiez, Jean-Michel Hartmann, Alexei Chelnokov, CEA-
LETI (France) and Univ. Grenoble Alpes (France); Jérôme Faist, Institute for
Quantum Electronics, ETH Zurich (Switzerland); Hans Sigg, Paul Scherrer
Institut (Switzerland). [10923-35]

**Distributed feedback lasers integrated on Si substrates for chip-scale
atomic systems**, Kevin Gallacher, Ross W. Millar, Douglas J. Paul, Univ. of
Glasgow (United Kingdom); Gary Ternent, Francesco Mirando,
Kelvin Nanotechnology Ltd. (United Kingdom); Ian Oxtoby, Optocap Ltd.
(United Kingdom); Kai Bongs, Michael Holynski, The Univ. of Birmingham
(United Kingdom); Stefan O. Robbie, M Squared Lasers Ltd. (United
Kingdom). [10923-36]

**Enhanced light emission from a Si optical beam-steering device
consisting of asymmetric photonic crystal waveguide**, Hiroyuki Ito,
Yuma Kusunoki, Daichi Akiyama, Hiroshi Abe, Toshihiko Baba, Yokohama
National Univ. (Japan). [10923-37]

**Photonic crystal laser with an integrated modulator for optical
interconnects**, Praveen Kumar J. Singaravelu, Ganga Chinna Rao Devarapu,
Sharon M. Butler, Cork Institute of Technology (Ireland); Alexandros A. Liles,
Univ. of St. Andrews (United Kingdom); Robert Sheehan, Liam O'Faolain,
Stephen P. Hegarty, Andrei P. Bakoz, Cork Institute of Technology
(Ireland). [10923-38]

BGa(As)P alloys for III-V integration on silicon, Christopher R. Fitch, Univ.
of Surrey (United Kingdom); Peter Ludewig, NASP III/V GmbH (Germany);
Wolfgang Stolz, Philipps-Univ. Marburg (Germany) and NASP III/V GmbH
(Germany); Stephen J. Sweeney, Univ. of Surrey (United Kingdom) . [10923-39]

Lunch/Exhibition BreakWed 12:20 pm to 1:50 pm

SESSION 10 WED 1:50 PM TO 3:30 PM

Device Technology

Session Chair: **Graham T. Reed**,
Optoelectronics Research Ctr. (United Kingdom)

**Generation of O-band PAM-4 signal using a silicon modulator driven
by two binary sequences**, Lucas Deniel, Ctr. de Nanosciences et de
Nanotechnologies (France); Diego Pérez-Galacho, iTEAM Research Institute,
Univ. Politécnic de Valencia (Spain); Mathilde Gay, Fonctions Optiques pour
les Technologies de l'information (France) and Univ. de Rennes 1 (France);
Laurent Bramerie, Univ. de Rennes 1 (France); Oskars Ozolins, RISE Acreo AB
(Sweden); Charles Baudot, Frédéric Boeuf, STMicroelectronics S.A. (France);
Laurent Vivien, Ctr. de Nanosciences et de Nanotechnologies (France);
Christophe Peucheret, Univ. de Rennes 1 (France); Delphine Marris-Morini,
Ctr. de Nanosciences et de Nanotechnologies (France) [10923-40]

**Model and design of silicon photonic carrier-depletion Mach-Zehnder
modulators for 400Gb/s and beyond PAM and QAM applications**,
Jianying Zhou, NeoPhotonics Corp. (USA) [10923-41]

**Tunable and stable hybrid laser design for silicon photonics
applications**, Lorenzo Luigi Columbo, Politecnico di Torino (Italy);
Jock Bovington, Dominic Siriani, Cisco Systems, Inc. (USA);
Fabrizio Forghieri, Cisco Systems, Inc. (Italy); Mariangela Gioannini,
Politecnico di Torino (Italy) [10923-42]

**40-Gbps Si photonic crystal slow-light modulator in the electro-optic
phase matching**, Yosuke Hinakura, Hiroyuki Arai, Toshihiko Baba,
Yokohama National Univ. (Japan) [10923-43]

Modulation linearity analysis of depletion-type Si ring modulator,
Young Kwan Jo, Byung-Min Yu, Yonsei Univ. (Korea, Republic of);
Stefan Lischke, Christian Mai, Lars Zimmermann, IHP (Germany);
Woo-Young Choi, Yonsei Univ. (Korea, Republic of) [10923-44]

WEDNESDAY POSTER SESSION WED 6:00 PM TO 8:00 PM

Conference attendees are invited to attend the OPTO poster session on
Wednesday evening. Come view the posters, enjoy light refreshments, ask
questions, and network with colleagues in your field. Authors of poster papers
will be present to answer questions concerning their papers. Attendees are
required to wear their conference registration badges to the poster sessions.

Poster authors, view poster presentation guidelines and set-up instructions at
<http://spie.org/PWPosterGuidelines>.

**Two-dimensional subwavelength grating-based waveguide-to-fiber
coupler**, Anamika Singh, K.J. Somaiya Institute of Engineering & Information
Technology (India); Ritu Raj Singh, Indian Institute of Technology (Indian
School of Mines), Dhanbad (India) [10923-45]

**Concatenated silicon etalon tunable filter for hyperspectral imaging in
the near infrared**, Hadar Pinhas, Amir Shemer, Omer Wagner, Yossi Danan,
Yafit Flegler, Yonathan Ramon, Meir Danino, Moshe Sinvani, Zeev Zalevsky,
Bar-Ilan Univ. (Israel) [10923-46]

Nested silicon-on-insulator Vernier effect microring resonators,
Mustafa Hammood, Ajay Mistry, Lukas Chrostowski, Nicolas A. F. Jaeger, The
Univ. of British Columbia (Canada) [10923-47]

**Compound period grating coupler for double beam generation and
steering**, Dachuan Wu, Wei Guo, Yasha Yi, Univ. of Michigan (USA) [10923-48]

Parametric analysis of silicon nanowire-based ring resonator,
Ritu Raj Singh, Anumeha Varma, Abhinav Gautam, Rukmani Singh,
Vishnu Priye, Indian Institute of Technology (Indian School of Mines), Dhanbad
(India) [10923-49]

**Optimization of silicon on silica waveguides for mid-infrared
applications at 4.28 μm** , Mina Labib, Diaa Khalil, Michael Gad,
Yasser M. Sabry, Ain Shams Univ. (Egypt) [10923-50]

A novel 350nm CMOS optical receiver based on current assistance,
Sven Boulanger, Maarten Kuijk, Vrije Univ. Brussel (Belgium) [10923-51]

**Low-loss coupling interfaces between InP-based emitters and Si₃N₄
photonic integrated circuits**, Dimitrios Chatzitheocharis, Dimitra Ketzaki,
George Dabos, Konstantinos Vyrsokinos, Ctr. for Interdisciplinary Research
and Innovation, Aristotle Univ. of Thessaloniki (Greece) [10923-52]

**Novel silicon-on-insulator Michelson interferometer for optical filtering
and wavelength demultiplexing applications**, Abdelrahman E. Afifi, The
Univ. of British Columbia (Canada); Raghi Samir El Shamy, Mohamed Badr,
Mohamed El-Rayany, Mohamed A. Swillam, The American Univ. in Cairo
(Egypt) [10923-53]

Optical logical gate using slot waveguide, Mostafa Abdelsalam,
Mohamed A. Swillam, The American Univ. in Cairo (Egypt) [10923-54]

A compact silicon-on-insulator gas sensor, Mohamed El-Rayany,
Raghi Samir El Shamy, Mohamed A. Swillam, The American Univ. in Cairo
(Egypt) [10923-55]

Dynamic tuning of silicon-based nanoantennas, Hosameldin I. Mekawey,
Yehea Ismail, Mohamed A. Swillam, The American Univ. in Cairo
(Egypt) [10923-56]

**Electro-optical modulator using silicon on insulator Michelson
interferometer with electro-optical polymer**, Aya A. Osama, Raghi Samir El
Shamy, The American Univ. in Cairo (Egypt); Abdelrahman E. Afifi, The Univ. of
British Columbia (Canada); Mohamed A. Swillam, The American Univ. in Cairo
(Egypt) [10923-57]

Silicon photonics dual-coupler nested coupled cavities,
Rabab A. Shalaby, Mahmoud A. Selim, George A. Adib, Ain Shams Univ.
(Egypt); Yasser M. Sabry, Ain Shams Univ. (Egypt) and Si-Ware Systems
(Egypt); Michael Gad, Ain Shams Univ. (Egypt); Diaa Khalil, Ain Shams Univ.
(Egypt) and Si-Ware Systems (Egypt) [10923-58]

Gas sensing devices using doped silicon material at mid-infrared region,
Sarah Shafaay, Mohamed A. Swillam, The American Univ. in Cairo
(Egypt) [10923-59]

Modulation linearity analysis of depletion-type Si Ring Modulator

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Christian Mai², Stefan Lischke², Lars Zimmerman² and Woo-Young Choi¹

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ABSTRACT

The depletion-type Si ring modulator (RM) is of great interest among many Si photonic devices for optical interconnect applications because it has a small size, low power consumption, and large modulation bandwidth. Although the major application of the Si RM are digital optical interconnect systems, there is another application of importance, namely microwave photonics in which the modulation linearity is a key performance parameter. We investigate the modulation linearity performance in terms of spurious-free dynamic range (SFDR) of a RM device fabricated by IHP Si PIC foundry. The device has 8- μm radius, 290-nm coupling gap and the nominal peak doping concentration of $7 \times 10^{17} \text{ cm}^{-3}$ for p-region and $3 \times 10^{18} \text{ cm}^{-3}$ for n-region. The measured SFDR is $78.7 \text{ dB} \cdot \text{Hz}^{2/3}$. The major sources of non-linearity of this device are the nonlinear free-carrier plasma dispersion effect in PN junction as well as the nonlinear resonance characteristics. We also perform the numerical simulation of RM SFDR using key device parameters extracted from measurement. The simulation results match well with the measurement results. With this numerical model, we are able to identify the exact cause of RM nonlinearity and come up with suggestions for improving RM linearity.

Keywords: Si ring modulator, modulation linearity, SFDR