Editorial
Introduction to JSTQE Issue on Silicon Photonics

WELCOME to the IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS (JSTQE) Special Issue on **Silicon Photonics**! In the past decade, silicon photonics has rapidly grown from a promising academic field to an industrial reality, with many silicon photonics-based products deployed in the field. The success of this fairly young field, which took its first steps in the 1990s, can be attributed to two unique characteristics of the technology: the scaling down of waveguides, and the scaling up of manufacturing. Silicon, as a semiconductor material, has a high refractive index, and a native oxide with a much lower refractive index. This makes it possible to confine light in submicrometer waveguides with tight bends, which can then be integrated by the thousands on the surface of a small chip. Moreover, these chips can be made using the same techniques used for CMOS electronics manufacturing: this means that the infrastructure and investments from in the electronics industry can be leveraged for the fabrication of silicon photonics. Just like in the field of electronics, we see an ecosystem of fabless research groups and companies emerging around a limited number of commercial and R&D foundries. This requires a minimum level of maturity, and supporting design and packaging technologies.

At the same time, the use of silicon photonics is becoming more diverse. While the initial industrial adoption has been largely driven by the telecom and datacom industry, we now see silicon photonic chips being used in diverse applications, ranging from sensing over signal processing to computing. Especially the field of integrated microwave photonics is gaining traction, with the deployment of 5G and the ever-increasing need for wireless bandwidth that need to be fed through an optical backhaul network. The large-scale integration capabilities of the technology platform make it possible to build ever more complex circuits with a larger number of components. Reliably designing such circuits is not trivial, and design techniques are only just emerging to tackle the challenge of process variability and decreasing compound yield when the circuits become large.

The performance of every photonic circuit depends heavily on the capabilities of the fundamental building blocks. The high index contrast leaves a lot of room for optimized building block designs, which are computationally intensive. Especially fiber-to-chip coupling structures, such as grating couplers, keep on improving from year to year. Smart optimization methods combined with efficient simulation techniques can shorten the development times for these devices.

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Beyond such passive building blocks, photonic circuits need actively actuated elements, such as phase shifters, switches, and high-speed modulators. Traditional solutions in silicon are either power-hungry (heaters) or fairly weak (carriers), so there is an ongoing quest to develop electro-optic actuators that have a low optical loss and low electrical power consumption. Similarly, for detectors there is a push to improve the responsivity, reduce the dark current and increase the speed.

The key missing building block in most silicon photonics platforms is the light source. With its indirect bandgap, silicon is really an abysmal optical gain medium. The past decade has seen a tremendous progress in the integration of III-V semiconductors into a silicon photonics platform, using techniques ranging from flip-chip-based hybrid integration over wafer bonding to direct epitaxy. In the next decade, we expect that on-chip light source integration will become prevalent in most silicon photonics platforms.

This JSTQE Special Issue on Silicon Photonics takes a representative snapshot of the state of the field. The 56 papers, of which 11 invited and 45 contributed papers, cover the entire field from building block design methods to applications of large-scale silicon photonic circuits. The invited papers cover platform technologies such as silicon nitride waveguides of the III-V-on-silicon lasers, design techniques, novel use of waveguides through the use of lateral leakage or MEMS, and several application-oriented discussions on how silicon photonics can scale up to large complex circuits. The many contributed papers cover exciting new results in all of the above topics, and show how much the field has advanced in the past decade. We see exciting new results in the integration of lasers on silicon photonic circuits, novel and more efficient modulators and detectors, and new passive waveguide devices and circuits, including photonic crystal devices that leverage the high refractive index contrast of silicon photonics. Various applications are covered, from optical interconnects over microwave photonics to new computation schemes being accelerated by silicon photonic circuits.

We hope that you consider this Special Issue of JSTQE a significant milestone in the field, and that many of the papers will set the reference and become inspiration for another decade of progress in Silicon Photonics.

ACKNOWLEDGMENT

This issue is the result of the effort and inspiration of many people. First, we would like to express our appreciation to all the authors of the high-quality invited and contributed papers, as well as to the many reviewers who found time in their busy schedules to contribute constructive criticism to make the manuscripts even better. We thank the IEEE publications staff for their general support, and in particular Ms. Chin Tan Lutz for being always-present with technical and editorial assistance and advice. It takes quite some coordination skills to make sure a collection of busy scientists around the world stick to a schedule. Finally, we would like to thank Prof. José Capmany, JSTQE Editor-in-Chief, for his behind-the-scenes coaching and for giving us the opportunity to put together this special issue.

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Wim Bogaerts (Member, IEEE) received the Ph.D. degree in the modeling, design, and fabrication of silicon nanophotonic components from Ghent University, Ghent, Belgium, in 2004. He is a Professor in the Photonics Research Group with Ghent University—imec.

Since 2016, He has been a Full-Time Professor with Ghent University, looking into novel topologies for large-scale programmable photonic circuits, supported by a consolidator grant of the European Research Council.

During this work, he started the first silicon photonics process on imec's 200mm pilot line, which formed the basis of the multi-project-wafer service ePIXfab. In 2014, he cofounded Luceda Photonics, a spin-off company of Ghent University, IMEC, and the University of Brussels. Luceda photonics develops unique software solutions for silicon photonics design, using the IPKISS design framework. His current research focuses on the challenges for large-scale silicon photonics: Design methodologies and controllability of complex photonic circuits. He has a strong interest in telecommunications, information technology, and applied sciences. He is a member of Optical Society and SPIE.

Thomas Van Vaerenbergh received the master's degree in applied physics and the Ph.D. degree in photonics from Ghent University, Ghent, Belgium, in 2010 and 2014, respectively. Since 2014, he has been working with Hewlett Packard Labs, Palo Alto, CA, USA. His main research interests are optical computing, accelerators for combinatorial optimization, and the modeling and design of passive silicon photonic devices such as microring resonators and grating couplers.

Delphine Marris-Morini received the Ph.D. degree in the development of high-speed silicon modulators from Paris Sud University, Orsay, France, in 2004. She is a Professor with Paris-Saclay University, Essonne, France. She is also a Junior Member of the Institut Universitaire de France (IUF), Paris, France. Her research interests at the Center for Nanosciences and Nanotechnologies (CNRS, Paris Saclay University) include silicon photonics in the near-IR and mid-IR wavelength range. She was the recipient of an ERC starting grant (INsPIRE) on Ge-rich photonic integrated chips toward the mid-IR wavelength range for sensing and spectroscopic application. She received the bronze medal from CNRS in 2013.

Jie Sun received the B.S. and M.S. degrees in electronic engineering from Tsinghua University, Beijing, China, in 2005 and 2007, respectively, and the Ph.D. degree in electrical engineering from the Massachusetts Institute of Technology (MIT), Cambridge, MA, USA, in 2013. He was with the MIT Photonic Microsystems Group as a Postdoctoral Researcher from 2013 to 2014. He joined Intel Corporation in 2014 as a Research Scientist in silicon photonics. He recently joined a Silicon Valley startup, LightIC Technologies, to develop silicon photonic products. His research in silicon photonics focuses on addressing challenges in integrated photonic device design and enabling/scaling up electronic-photonic integrated circuits for both communication and sensing applications. His doctoral thesis "Toward accurate and large-scale silicon photonics" has been awarded the Dimitris N. Chorafas Foundation Award. His work has appeared in venues like Discovery News, Technology Review, IEEE Spectrum, Nature, and Science magazines.