PSC2018
Limassol, Cyprus

Photonics in Switching and Computing

19 - 21 September, 2018

Workshop 1:
"Optical Data Center Interconnects – Applications, technologies and components"

organized by H2020 DIMENSION project (www.dimension-h2020.eu, grant 688003)

Objectives:

- To highlight emerging applications, technologies and components for datacenter interconnects

Chairman:

- Ronny Henker, Technische Universität Dresden

Duration:

- ~4 h in total (including break); 17 min talks (incl. 2 min discussion)

Speakers:

- Niels Neumann, TU Dresden, "Energy Efficiency Comparison of Optical and Electrical Interconnects for High-Performance Computing and Datacenters"
- Jean-Pierre Locquet, KU Leuven, "Photonic Reservoir Computing"
- J.J.G.M. (Jos) van der Tol, TU/e "Hybrid integration of photonics and electronics using wafer scale polymeric bonding techniques"
- Hesham Taha, Teramount Ltd., "Scalable photonic packaging"
- S. Lischke, IHP, "Monolithic photonic BiCMOS technology: Enabler for high-speed transceiver applications"
- Pascal Stark, IBM Research Zurich, "Novel III-V and Electro-Optic Components Co-Integrated with Silicon Photonics"
- Benjamin Wohlfeil, ADVA Optical Networking, "Photonic integrated circuits for data center interconnects"
- Alexandru Giuglea, TU Dresden "Comparison of Segmented and Traveling-Wave Electro-Optical Transmitters Based on Silicon Photonics Mach-Zehnder Modulators"
- Xiao Liu, TU/e "A DC to 40 GHz Linear Driver for Optical Communication and Wafer-to-Wafer Bonding"
- N. Ledentsov Jr., VI-Systems, "Future of high-speed VCSEL-based interconnects applying high order modulation formats"
- Theoni Alexoudi, Aristotle University of Thessaloniki, "Mid-board Transceiver and Routing technologies for chip-to-chip optical interconnection"

Schedule

9:00 AM	9:05 AM	Welcome and Workshop Introduction
9:05 AM	9:22 AM	Niels Neumann, TU Dresden *Energy Efficiency Comparison of Optical and Electrical Interconnects for High-Performance Computing and Datacenters*
9:22 AM	9:39 AM	Jean-Pierre Locquet, KU Leuven *Photonic Reservoir Computing*
9:39 AM	9:56 AM	J.J.G.M. (Jos) van der Tol, TU/e *Hybrid integration of photonics and electronics using wafer scale polymeric bonding techniques*
9:56 AM	10:13 AM	Hesham Taha, Teramount Ltd. *Scalable photonic packaging*
10:13 AM	10:30 AM	S. Lischke, IHP Microelectronics *Monolithic photonic BiCMOS technology: Enabler for high-speed transceiver applications*
10:30 AM	11:00 AM	Coffee Break
11:00 AM	11:17 AM	Pascal Stark, IBM Research Zurich *Novel III-V and Electro-Optic Components Co-Integrated with Silicon Photonics*
11:17 AM	11:34 AM	Benjamin Wohlfeil, ADVA Optical Networking *Photonic integrated circuits for data center interconnects*
11:34 AM	11:51 AM	Alexandru Giuglea, TU Dresden *Comparison of Segmented and Traveling-Wave Electro-Optical Transmitters Based on Silicon Photonics Mach-Zehnder Modulators*
11:51 AM	12:08 PM	Xiao Liu, TU/e *A DC to 40 GHz Linear Driver for Optical Communication and Wafer-to-Wafer Bonding*
12:08 PM	12:25 PM	N. Ledentsov Jr., VI-Systems *Future of high-speed VCSEL-based interconnects applying high order modulation formats*
12:25 PM	12:42 PM	Theoni Alexoudi, Aristotle University of Thessaloniki *Mid-board Transceiver and Routing technologies for chip-to-chip optical interconnection*
12:42 PM	1:45 PM	Lunch

Energy Efficiency Comparison of Optical and Electrical Interconnects for High-Performance Computing and Datacenters

Niels Neumann, Dirk Plettemeier

TU Dresden, Chair for RF and Photonics Engineering

Abstract: For very short distances, interconnects are realized today as electrical interface. For longer ranges, optical interfaces are in operation. In between, both solutions are implemented. However, with increasing data rates, optical interconnects are used for shorter and shorter links. Energy efficiency is an important parameter for the choice of the interconnect technology. Already in state-of-the-art systems, interconnect power reaches 20% of the total chip power consumption. This contribution studies the energy efficiency of electrical and optical interconnects in a generalized way (i.e. independent from actual realizations) in order to identify common principles and bottlenecks. This way, the transmission length where optical systems become more power efficient than their electrical counterparts can be found depending on component power consumption.

Speaker bio: Niels Neumann was born in Germany in 1980. He received the Dipl.-Ing. and Dr.-Ing. degrees in Electrical Engineering from TU Dresden in 2005 and 2010, respectively. He currently leads the microwave photonics group at the Chair for RF and Photonics Engineering at the Faculty of Electrical and Computer Engineering of TU Dresden. His research interests include microwave photonics, fiber-to-the-antenna, millimeterwave and THz systems, optical antennas as well as electromagnetic modeling and characterization of electro-optical structures.

Photonic Reservoir Computing

Jean-Pierre Locquet

KU Leuven

Abstract: New computing paradigms are required to feed the next revolution in Information Technology. Machines need to be invented that can learn, but also handle vast amount of data. In order to achieve this goal and still reduce the energy footprint of Information and Communication Technology, fundamental hardware innovations must be done. A physical implementation natively supporting new computing methods is required. Most of the time, CMOS is used to emulate e.g. neuronal behavior, and is intrinsically limited in power efficiency and speed.

Reservoir computing (RC) is one of the concepts that has proven its efficiency to perform tasks where traditional approaches fail. It is also one of the rare concepts of an efficient hardware realization of cognitive computing into a specific, silicon-based technology. Small RC systems have been demonstrated using optical fibers and bulk components. In 2014, optical RC networks based integrated photonic circuits were demonstrated.

The PHRESCO project aims to bring photonic reservoir computing to the next level of maturity. A new RC chip is being co-designed, including innovative electronic and photonic component that will enable major breakthrough in the field. The aim is to: i) scale optical RC systems up to 60 nodes ii) build an all-optical chip based on the unique electro-optical properties of new materials iii) Implement new learning algorithms to exploit the capabilities of the RC chip.

Speaker bio: Jean-Pierre Locquet was born in Belgium in 1960. He obtained a Master in Physics in 1983 and a PhD in Physics in 1989 from the University of Leuven in Belgium. He was with IBM Research Zurich Research where he worked on precisely defined thin films of new materials for future computer chips. In 2007 he joint KU Leuven as full professor for advanced solid state physics at the Faculty of Science. He chaired the Leuven Nanoscience and Nanotechnology Research Centre and the division of Solid State Physics and Magnetism. The research of Jean-Pierre Locquet focuses on the physics and material science of thin films and devices of complex materials. This includes materials which display a dielectric, magnetic, ferroelectric, superconducting and/or semiconducting behavior for use in storage, memory and logic devices.

Hybrid integration of photonics and electronics using wafer scale polymeric bonding techniques

J.J.G.M. (Jos) van der Tol

Technische Universiteit Eindhoven

Abstract: Bottlenecks are appearing in the transmission of data that threaten the very existence of the famous Moore's law. Therefore new solutions are pursued, merging micro-electronics and micro-photonics. The European project WIPE is doing just that: well-developed electronic circuits and photonic integrated chips are hybrid integrated in one package, using a polymer based bonding technique. Through the bonding layer electrical connections are made. Thus photonic and electronic devices merge to become one new device, which implies a co-design in both domains. This offers ample opportunities to optimize functionality, speed and energy consumption of the photonic/electronic combined devices.

Speaker bio: Jos (dr. J.J.G.M.) van der Tol received his Ph.D. degree (physics) from Leiden University in the Netherlands, after which he joined KPN Research, also in the Netherlands, and worked on integrated optical components. This covered waveguide modelling, design and fabrication of lithium niobate devices and guided wave components on InP. Since 1999 he works at the TU/e on opto-electronic integration, polarization, membranes and photonic crystals. Currently he is also the project leader of the European project WIPE, which develops a wafer scale heterogeneous integration of photonics and electronics.

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Scalable photonic packaging

Hesham Taha, Abraham Israel, Faivush Ulfan, Leonid Pascar

Teramount Ltd., Hi-Tech village 4/5, Jerusalem 9139102, Israel

Abstract: Photonics packaging is one of the main challenges today for optical connectivity to become pervasive in datacom and telecom applications. Furthermore, it sets major obstacles when scaling to wide-band applications with multiple port number and 2.5D optical-electrical interposers. The PhotonicPlug technology enables scalable packaging of any optical element, including single-mode fibers and laser modules, to photonic channels through passive alignment protocols by means of standard flip-chip equipment. PhotonicPlug technology uses wafer level processes for accurate alignment of its "self-aligning" optical elements for achieving 80 times improvement of assembly tolerances compared to typical active alignment packaging equipment. These advances take photonic packaging into the manufacturing space of CMOS flows and thus support high-yield, low cost and high volume manufacturing. In this talk, we will present the PhotonicPlug technology and its compatibility for wide band 400/800G modules and co-packaged optics applications.

Speaker bio: Hesham Taha is CEO and co-founder of Teramount Ltd. and a Ph.D in Applied Physics from the Hebrew University of Jerusalem. Hesham lead dozens of academic and industrial projects in the fields of nanoscience and technology, optical microscope, near-field optics and silicon photonics.

Teramount addresses wide-band optical connectivity with unique and patented PhotonicPlug technology. It technology enables scalable photonic packaging fully aligned with industrial high volume lines. The technology has been successfully demonstrated with photonic products of leading industrial vendors.

Monolithic photonic BiCMOS technology: Enabler for high-speed transceiver applications

S. Lischke, C. Mai, L. Zimmermann

IHP Microelectronics

Abstract: Photonic-electronic integration is a key technology to master data traffic growth and therefore an enabler of future network technologies. For some time now, a novel silicon-based photonic-electronic integration technology, photonic BiCMOS, is under development at IHP. Photonic BiCMOS is a planar technology co-integrating monolithically on a single substrate high-speed RF frontend electronics with high-speed photonic devices such as broadband germanium detectors, modulators, and SOI nano-waveguide integrated optics. High RF capability of this electronic photonic integrated circuit (ePIC) technology is enabled by SiGe heterojunction bipolar transistors (HBTs), which are integrated with 0.25µm CMOS. This talk reviews the integration approach deployed in the photonic BiCMOS and discusses performance issues for both, electronic and photonic devices. Measures to overcome detrimental integration effects will be discussed. Examples of transmitter and receiver demonstrators are presented to indicate the potential for monolithically integrated high-speed transceivers at 1550 nm.

Speaker bio: Stefan Lischke received the B.Sc. and M.Sc. degrees in Physics with specialization in Semiconductor Technology from the Technical University Brandenburg, Cottbus in 2005 and 2007, respectively. He is currently a Researcher in the Silicon Photonics group within the Technology department of IHP, Frankfurt (Oder), Germany. He received the Ph.D. degree in physics from Technical University Berlin in 2017. His current work is focused on Germanium photo detectors and the integration of photonic devices into IHP’s photonic BiCMOS process.

Novel III-V and Electro-Optic Components Co-Integrated with Silicon Photonics

Pascal Stark*, Yannick Baumgartner*, Marc Seifried*, Charles Caer*, Roger Dangel*, Felix Eltes*, Mattia Halter*, †, Folkert Horst*, Antonio La Porta*, Norbert Meier*, Daniele Caimi*, Daniel Jubin*, Jonas Weiss*, Heinz Siegwart*, Jean Fompeyrine*, Lukas Czornomaz*, Stefan Abel*, Bert J. Offrein*

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Abstract: Today's silicon (Si) photonic circuits can be cost-effectively fabricated in standard CMOS processing lines. However, the current technology is limited to components made from silicon due to the lack of other functional optical materials, such as III-V materials for on-chip light sources and Pockels materials for high-speed modulators. We will discuss the fabrication of a novel generation of silicon photonic circuits employing advanced photonic materials.

In the first part of our discussion, we will report on the monolithic integration of ultra-thin active optical devices embedded in silicon photonic circuits. The integration is compatible to the back-end-of-the-line of standard CMOS fabrication processes. In the second part, we will present how such a III-V on Si platform can be extended with additional photonic layers such as barium titanate (BTO), a material with very large Pockels coefficients. We will present our integration scheme, where light can be transferred from silicon waveguides to the other, co-integrated photonic waveguide layers. The discussion will be focused on simulation and experimental results on a novel three-layer coupling scheme between a hybrid electro-optic BTO/Si layer, a passive Si waveguide layer, and an active III-V layer. Optical power transfer losses as low as 0.5 dB could be measured between the Si and the BTO structures.

The co-integration of multiple functional layers on a standard silicon photonics platform enables novel integrated components and new applications for CMOS-integrated photonics beyond high-speed communication, such as advanced sensing devices in support of the Internet of Things and novel neuromorphic computing systems.

Acknowledgment: This Project has received funding from the European Commission under grant agreement no. H2020-ICT-2015-688003 (DIMENSION), H2020-ICT-2015-688579 (PHRESCO), H2020-ICT-2015- 688544 (L3MATRIX) and H2020-ICT-2015- 688172 (ICT-STREAMS).

Speaker bio: Pascal joined IBM Research – Zurich as a PhD student in January 2018. He is a member of the Neuromorphic Devices & System group in the Science & Technology department. Pascal's research focus is on physics for AI, specifically he is working on photonic neuromorphic architectures. Before joining IBM Pascal received a Master of Science degree in Electrical Engineering after studying at ETH Zurich.

Photonic integrated circuits for data center interconnects

Benjamin Wohlfeil, Gilda Raoof Mehrpoor, Annika Dochhan, Danish Rafique, Michael Eiselt and Jörg-Peter Elbers

ADVA Optical Networking

Abstract: Next generation optical transceivers for data center interconnects are expected to feature bandwidths in excess of 400Gb/s, while exhibiting a smaller footprint, lower power consumption and lower cost per Gb/s compared to current generation 100Gb/s transceivers. To this end, new technologies such as photonic hetero integration are explored within research and industry and standardization efforts are made to ensure cross compatibility between vendors and ultimately to reduce costs. New packaging concepts such as optical BGAs (OpBGA) are needed to increase RF bandwidth between DSP and optical engine and use of standard SMT assembly methods as known from the electronics industry allows for a high degree of automation, eliminating the need for time consuming manual assembly processes. Similarly, automated wafer scale testing of electronic-photonic integrated circuits (EPIC) is a critical part in reducing manufacturing time and thus will lead to reduced DCI costs.

Speaker bio: Dr. Benjamin Wohlfeil is currently Manager in the Advanced Technology group at ADVA Optical Networking and is involved in the photonic integration activities of ADVA. He received his Dipl.-Ing. degree in computer science from Technische Universität Berlin in 2008 and the Dr.-Ing. Degree in electrical engineering also from Technische Universität Berlin in 2015. From 2014 to 2015 he worked as a post-doc in the group Computational Nano-optics at the Konrad-Zuse-Center for applied mathematics. Benjamin has authored more than a dozen papers and is inventor of several patents. He is an active contributor to OIF and COBO standardization groups regarding coherent optical transceivers and is involved in several national and international research projects.

Comparison of Segmented and Traveling-Wave Electro-Optical Transmitters Based on Silicon Photonics Mach-Zehnder Modulators

Alexandru Giuglea*, Guido Belfiore*, Mahdi Khafaji*, Ronny Henker*, Despoina Petousi°, Georg Winzer°, Lars Zimmermann°, Frank Ellinger*

*Technische Universität Dresden, Chair of Circuit Design and Network Theory

°IHP Microelectronics

Abstract: This paper presents a brief study of the two most commonly used topologies – segmented and traveling-wave – in realizing monolithically integrated electro-optical transmitters consisting of Si-photonics Mach-Zehnder modulators and their corresponding electrical drivers. To this end, two transmitters designed in the aforementioned topologies are presented and compared with regard to the achievable data rate, extinction ratio of the optical output signal, DC power consumption and chip area. The electrical drivers were realized in a 250 nm SiGe BiCMOS electronic-photonic integrated technology.

Speaker bio: Alexandru Giuglea received the Dipl.-Ing. degree in electrical engineering from Technische Universität Dresden in 2016. Since then he has been working at the Chair of Circuit Design and Network Theory at Technische Universität Dresden under the supervision of Prof. Frank Ellinger. His main research field is the design of integrated circuits for broadband optical communications, with focus on electrical drivers for monolithically integrated Mach-Zehnder modulators.

A DC to 40 GHz Linear Driver for Optical Communication and Wafer-to-Wafer Bonding

Xiao Liu

Technische Universiteit Eindhoven

Abstract: Single-chip photonic-electronic integrated circuits will outperform discrete electronic-optical systems in terms of performance, physical size and ease of assembly. Wafer scale packaging of InP wafers onto Si integrated circuits is one promising solution. By using the polymer adhesive bonding technique, Silicon Electronic Integrated Circuits (EICs) bond to the InP Photonic Integrated circuits (PICs) on the wafer scale. Small through polymer vias (TPVs) connect EICs to the PICs which reduces the parasitic and improves the maximum date rate.

For the wafer scale packaging, a low-power high-efficiency linear driver in a 0.25-µm SiGe: C BiCMOS technology is implemented, which features a small-signal gain of 18 dB and a 3-dB bandwidth of 40 GHz and delivers a maximum output amplitude of 4 Vpp to a 100 Ω differential load. Time-domain electrical measurements using NRZ and PAM4 are performed, yield a symbol rate of 50 Gbps NRZ and 25 Gbaud PAM4 respectively and are limited by the used signal generator.

Speaker bio: Xiao Liu received the B.Sc. degree from Shandong University, China, in 2013, and the M.Sc. degree from Eindhoven University of Technology, the Netherlands, in 2015. Since 2015, he started to pursue his Ph.D. degree in Integrated Circuits (IC) group, Eindhoven University of Technology. He is now working in project Photronics and his main research topics are high-speed optical transceiver design and broadband amplifier design. Xiao Liu was the recipient of the ALSP scholarship during his M.Sc. study in Eindhoven University of Technology during 2013-2015.

Future of high-speed VCSEL-based interconnects applying high order modulation formats

N. Ledentsov Jr., M. Agustin, V. A. Shchukin, V. P. Kalosha, J.-R. Kropp, N. N. Ledentsov

VI Systems GmbH

Abstract: The number of mobile devices and connections grew to 8.4 billion in 2017 and is expected to grow further as the autonomous driving and the internet of things continue to emerge. 1 In view of this growth, the speed and energy efficiency of data processing and data storage becomes very important in modern datacenters.

Multimode Vertical Cavity Surface Emitting Lasers (MM VCSELs) is a well-established solution for short distance communication through Multi-Mode Fiber (MMF). Such systems have low cost, small footprint, high energy efficiency, stability and speed, but their transmission distance is limited to ~100 meters at 25 Gb/s by far due to the chromatic dispersion. Contrary to multimode VCSELs, Single-mode VCSELs (SM VCSELs) allow data transmission over much longer MMF distances because the effect of chromatic dispersion can be drastically suppressed. Recent successes in development of single-mode VCSELs open an opportunity to apply them for data transmission over km-long MMF distances at very high rates, in applications where previously only 1.3 - 1.5 µm edge-emitting lasers coupled into Single-Mode Fiber (SMF) were used.

We review state of the art VCSEL technology and state of the art high order modulation formats in context of transmission speed and transmission distance. As example Discrete Multi-Tone (DMT) modulation enables bit rates of 160 Gb/s per single VCSEL. 2 Finally, we discuss method to achieve bit rates of 200 Gb/s and above per single MMF with Shortwave Wavelength Division Multiplexing (SWDM) of 850 nm, 880 nm, 910 nm and 940 nm lasers operating in non-return-to-zero (NRZ) and pulse-amplitude modulation (PAM) formats as well as space division multiplexing techniques. Combination of these technologies paves the way towards Tb/s data transmission over single multimode fiber in the coming years.

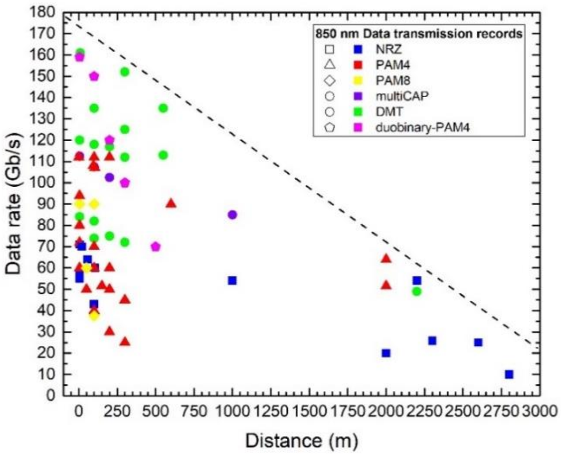

Figure 1. Analysis of publications on data transmission through multi-mode fiber with 850 nm VCSELs

1 Cisco Visual Networking Index (VNI) Global Mobile Data Traffic Forecast 2017

2 C. Kottke, C. Caspar, V. Jungnickel, R. Freund, M. Agustin, and N. Ledentsov, "High Speed 160 Gb/s DMT VCSEL Transmission Using Pre–equalization", in Optical Fiber Communication Conference, OSA Technical Digest (online) (Optical Society of America, 2017), paper W4I.7 (2017).

Speaker bio: Nikolay Ledentsov, Jr. received his B.Sc. degree from the Technical University of Berlin in 2012 (thesis: “Photoluminescence spectroscopy on (In)AlGaN quantum wells for efficient ultraviolet light emitting diodes”) and M.Sc. degree in 2014 (thesis: "Growth and characterization of light emitters based on semipolar InGaN quantum wells: Optical polarization of QWs grown on (20-2-1) and (20-21) GaN with MOVPE"). As an engineer at VI Systems GmbH he is responsible for the research & development of VCSELs for high speed optical links and sensors.

ICT-STREAMS project: Mid-board Transceiver and Routing technologies for chip-to-chip optical interconnection

Theoni Alexoudi, Stelios Pitris, Miltos Moralis-Pegios, Charoula Mitsolidou, Nikos Terzenidis and Nikos Pleros

Department of Informatics and Center for Interdisciplinary Research and Innovation, Aristotle University of Thessaloniki, 57001, Greece

Abstract: Multi-socket server boards have emerged as a solution in order to increase the on-board processing power density as well as further flatten the data center networks. Scaling however the number of processors per board is currently challenging the electronic technology infrastructure, as it requires high bandwidth interconnects and high throughput switches with increased number of ports that are currently unavailable. On-board optical interconnection holds the credential to efficiently satisfy the bandwidth needs, but their use has been limited to parallel links without offering any smart routing functionality. Within this context, cyclic wavelength routing appears to fit the datacom for rack-to-rack and board-to-board communication and appears to be a promising solution for on-board routing platform. ICT-STREAMS is a European project that aims to develop the necessary Silicon Photonics transceiver and routing technologies towards a new, power efficient, WDM-based, Tb/s, optical on-board interconnection paradigm that enables multiple high bandwidth and point-to-point direct links on the board level. STREAMS will develop a distributed routing system based on a passive Si-Pho AWGR routing element to provide simultaneous direct any-to-any communication towards flattening data centers and facilitating east-west communication. In this communication, we present the ICT-STREAMS on-board wavelength routing architecture for multiple chip-to-chip interconnections and report on the recent advances of ICT-STREAMS platform key-enabling technologies.

Speaker bio: Theoni Alexoudi currently works as a post-doctoral researcher at PhosNeT laboratory in the Department of Informatics of Aristotle University of Thessaloniki in Greece and is the lead researcher in ICT-STREAMS project. Her research interests include WDM technologies towards enabling novel all-optical high performance and energy-efficient computing system architectures. Dr. Alexoudi is a member of IEEE society and has published more than 30 scientific papers.