

# Advance Program

## Optical Networks and Devices for Data Centers

**Monday, 19 July 2010**

**ALL SESSIONS TO BE HELD IN RIVIERA 2**

**9.00 – 9.15**

**OPENING REMARKS**

**9.15 – 10.00**

**Session MD1: PLENARY SESSION**

**Session Chair:** David V. Plant, *McGill University, Montréal, QC, Canada*

**MD1.1 9.15 – 10.00 (Plenary)**

**Analysis of Intra-Node and Inter-Node Fabrics of an Exascale System**, G. Chukkapali, *Oracle, San Diego, CA, USA*

This talk centers around systematic analysis of constraints on two low latency, high speed networks in an exascale system namely, intra-Node fabrics and inter-Node fabrics. Real world examples of an emerging class of exascale applications termed "data intensive computing applications" from scientific computing domains and commercial/enterprise domains will be used. Data from an instrumented and profiled code of a weather forecasting application, a chemistry/biosciences application and a data mining application will be used to derive applications constraints in terms of bandwidth (Bytes/s/FLOPS ratios) and latency constraints to conduct this analysis. A brief outline of system architecture of an exascale system, and future trends of various component evolutions, namely CPU, volatile/non-volatile memory is provided to focus the attention on the fabrics. From the application constraints and component evolutions, fabric constraints are derived in order to architect a well balanced exascale system. Various intra-Node and inter-Node topologies are explored to satisfy these constraints. Other practical constraints such as the "memory wall" and the "power wall" are discussed.

**10.00 – 10.30**

**COFFEE BREAK**

**10.30 - 12.00**

**Session MD2: TUTORIAL**

**Session Chair:** Ashok V. Krishnamoorthy, *Oracle, San Diego, CA, USA*

**MD2.1 10.30 - 11.15 (Tutorial)**

**Optical Switching and Scalability in Datacenters**, A. Leon-Garcia, K. Khavari, H. Rastegarfar and A. Bigdeli, *University of Toronto, Toronto, Canada*

We compare network designs in terms of scale, density, bandwidth, and uniformity of connectivity. We consider all-electronic switching, all-optical switching and hybrid switching with optical WDM interconnection for a datacenter with 10 million microprocessor cores.

**MD2.2 11.15 - 11.30**

**Multi-Plane Optical Interconnection for Energy-Proportional Network Architectures**, O. Liboiron-Ladouceur, *McGill University, Montreal, Canada*, I. Cerutti, P. G. Raponi, N. Andriolli and P. Castoldi, *Scuola Superiore "S. Anna", Pisa, Italy*

This paper considers a multi-plane architecture based on space and wavelength switching for a more energy-efficient and energy-proportional interconnection networks. The power dissipation of the proposed architecture is evaluated with respect to the network utilization, an increasingly important network metric in high performance computing platforms.

**MD2.3 11.30 - 11.45**

**Low Loss Silicon Waveguides for Application of Optical Interconnects**, P. Dong, W. Qian, S. Liao, H. Liang, C.-C. Kung, N.-N. Feng, R. Shafiqi, J. Fong, D. Feng, *Kotura, Monterey Park, CA, USA*, A. V. Krishnamoorthy, *Oracle, San Diego, CA, USA* and M. Asghari, *Kotura, Monterey Park, CA, USA*

We present low loss shallow-ridge silicon waveguides with an average propagation loss of 0.274 dB/cm in the C-band, which can find applications in chip-level optical interconnects.

**MD2.4 11.45 - 12.00**

**Heterogeneous Optical CDMA with Near-Far Mitigation**, M. P. Fok and P. R. Prucnal, *Princeton University, Princeton, NJ, USA*

We demonstrate a heterogeneous-optical-CDMA system with novel detection scheme which enables truly-asynchronous operation and detection. This "wavelength-aware" detection scheme addresses the classic near-far problem and its output is well-suited for classical clock and data recovery.

**12.00 – 13.30****LUNCH BREAK****13.30 - 15.00**

**Session MD3: SILICON PHOTONICS FOR DATA CENTERS**

**Session Chair:** Alberto Leon-Garcia, *University of Toronto, Toronto, ON, Canada*

**MD3.1 13.30 - 14.00 (Invited)**

**Si Photonics and Nanophotonics**, A. Scherer, *California Institute of Technology, Pasadena, CA, USA*

ABSTRACT NOT AVAILABLE

**MD3.2 14.00 - 14.30 (Invited)**

**Designing Energy Efficient Chip-Scale Optical Communication Links from the Bottom Up: A Perspective from First Principles Device Design of Integrated Photonic Devices**, M. A. Popović, *University of Colorado at Boulder, Boulder, CO, USA*

ABSTRACT NOT AVAILABLE

**MD3.3 14.30 - 14.45**

**On the Design of 1xN Multimode Interference Coupler for Photonic Integrated Circuits**, A. Hosseini, D. Kwong and R. T. Chen, *University of Texas at Austin, Austin, TX, USA*

We derive an analytical relation for the maximum number of output channels for high performance (power transmission and uniformity) multimode interference (MMI) based 1xN optical beam splitters. Eigenvalue-expansion based simulation results confirm the analytical relation.

**MD3.4 14.45 - 15.00**

**Broadly Tunable High Speed Silicon Micro-ring Modulator**, P. Dong, R. Shafiqi, S. Liao, H. Liang, C.-C. Kung, W. Qian, D. Feng, *Kotura, Monterey Park, CA, USA*, G. Li, X. Zheng, A. V. Krishnamoorthy, *Oracle, San Diego, CA, USA* and M. Asghari, *Kotura, Monterey Park, CA, USA*

We present a high speed silicon micro-ring modulator with a tunable resonant wavelength enabled by a local heater. With a ~ 46 mW thermal tuning power, the working wavelength can extend to more than 100 nm.

**15.00 – 15.30****COFFEE BREAK****15.30 - 17.00**

**Session MD4: TRANSCIEVERS AND PACKAGING I**

**Session Chair:** Odile Liboiron-Ladouceur, *McGill University, Montreal, QC, Canada*

**MD4.1 15.30 - 16.00 (Invited)**

**Interconnection Technology and Computer Architecture Scaling**, E. P. DeBenedictis, *Sandia National Laboratories, Albuquerque, NM, USA*

ABSTRACT NOT AVAILABLE

**MD4.2 16.00 - 16.30 (Invited)**

**Low Power Silicon Photonic Transceivers**, X. Zheng, J. E. Cunningham, *Oracle, San Diego, CA, USA*, R. Ho, J. K. Lexau, G. Li, *Oracle, Menlo Park, CA, USA*, Y. Luo, H. D. Thacker, J. Yao, *Oracle, San Diego, CA, USA*, F. Liu, D. Patil, P. Amberg, N. Pinckney, *Oracle, Menlo Park, CA, USA*, P. Dong, D. Feng, M. Asghari, *Kotura, Monterey Park, CA, USA*, A. Mekis, T. J. Pinguet, *Luxtera, Inc., Carlsbad, CA, USA*, K. Raj and A. V. Krishnamoorthy, *Oracle, San Diego, CA, USA*

We present ultra low power silicon photonic transceivers, including a 320fJ/bit reverse biased ring modulator integrated with CMOS driver, and a 690fJ/bit record-low power receiver with sensitivity of -18.9dBm at 5Gbps for bit-error-rate of  $10^{-12}$ .

**MD4.3 16.30 - 16.45**

**Burst-Mode Clock and Data Recovery for Optically Interconnected Data Centers**, B. J. Shastri and D. V. Plant, *McGill University, Montréal, QC, Canada*

We propose a novel burst-mode clock/data recovery (BM-CDR) architecture for optical data center applications. Our design is based on a hybrid topology of a CDR (feedback) and clock phase aligner (feed-forward) utilizing multi-phase clocks.

**MD4.4 16.45 - 17.00**

**Wavelength Selective Coupler on Silicon for Applications in Wavelength Division Multiplexing**, D. T. H. Tan, K. Ikeda, S. Zamek, A. Mizrahi, M. P. Nezhad and Y. Fainman, *University of California - San Diego, La Jolla, CA, USA*

An add/drop filter based on coupled vertical gratings is proposed for applications in wavelength division multiplexing on silicon. We demonstrate tailoring of device bandwidth and channel location.

**17.30 – 18.30****Welcome Reception****Tuesday, 20 July 2010****09.00 - 10.00****Session TuD1: DATA CENTER SYSTEMS**

**Session Chair:** George C. Papen, *University of California - San Diego, La Jolla, CA, USA*

**TuD1.1 09.00 - 09.30 (Invited)**

**Optics as a Game Changer in Exascale Datacenters: Beyond Replacing Copper Wires**, E. Schenfeld, *IBM Research, Yorktown Heights, NY, USA*

ABSTRACT NOT AVAILABLE

**TuD1.2 09.30 - 10.00 (Invited)**

**GHz Photonics on a Silicon Chip**, M. Lipson, *Cornell University, Ithaca, NY, USA*

ABSTRACT NOT AVAILABLE

**10.00 – 10.30****COFFEE BREAK****10.30 - 12.00****Session TuD2: OPTOELECTRONICS FOR DATA CENTERS I**

**Session Chair:** Mehdi Asghari, *Kotura, Monterey Park, CA, USA*

**TuD2.1 10.30 - 11.00 (Invited)**

**Efficient Sources for Chip-to-Chip to Box-to-Box Communication within Data Centers**, L. A. Coldren, *University of California - Santa Barbara, Santa Barbara, CA, USA*

Vertical-cavity lasers with strained active regions show increased modulation rates and reliability at lower power dissipation. However, their longer wavelength (980-1100 nm) than the standard 850 nm has inhibited their widespread adoption.

**TuD2.2 11.00 - 11.15**

**2x2 MMI-MZI GaAs-GaAlAs Carrier-Injection Optical Switch**, S. Cao, L. Sun and J. Savoie, *Communications Research Centre, Ottawa, Canada*

We present a 2x2 MMI-MZI GaAs-GaAlAs carrier-injection switch with a low insertion loss, a high on-off extinction ratio, and a very low power consumption. This device has important applications for the future optical Green Internet.

**TuD2.3 11.15 - 11.30**

**Modulation Energy Efficiency of VCSEL and Coupled-Cavity VCSEL**, C. Chen, *McGill University, Montreal, QC, Canada*, K. D. Choquette, *University of Illinois at Urbana-Champaign, Urbana, IL, USA* and D. V. Plant, *McGill University, Montréal, QC, Canada*

We measure the energy per bit (EPB) for the 25-Gb/s implanted holey VCSEL and 12-Gb/s coupled-cavity VCSEL, and discuss the possibilities for the VCSEL to achieve a lower EPB for data center and optical interconnect applications.

**TuD2.4 11.30 - 11.45**

**Si-Ge Surface-normal Asymmetric Fabry-Perot Quantum-confined Stark Effect Electroabsorption Modulator**, E. H. Edwards, R. M. Audet, S. A. Claussen, R. K. Schaevitz, E. Tasyurek, S. Ren, Y. Rong, J. S. Harris, D. A. B. Miller, *Stanford University, Stanford, CA, USA*, O. Dosunmu and M. Unlu, *Boston University, Boston, MA, USA*

The strong electroabsorption modulation possible in Ge/SiGe quantum wells promises efficient, CMOS-compatible integrated optical modulators. Using an asymmetric Fabry-Perot design, we demonstrate the first surface-normal semiconductor modulator structure grown on silicon.

**TuD2.5 11.45 - 12.00**

**An 850 nm Dielectric Guide VCSEL for Data Communication Links**, M. V. R. Murty, *Avago Technologies, San Jose, CA, USA*, K. Chen, *National Changhua University of Education, Changhua, Taiwan, R.O.C.*, C. Chen, S. T. Joyo, T. E. Sale, *Avago Technologies, Singapore*, C. Y. Su, and L. M. Giovane, *Avago Technologies, San Jose, USA*

An 850 nm VCSEL with a lithographically defined aperture and a dielectric index guide has been fabricated with low threshold current and bandwidth for operation at 10 Gb/s and beyond. The device structure and characteristics are described.

**12.00 – 13.30****LUNCH BREAK****13.30 - 15.00****Session TuD3: ENERGY EFFICIENT DATA CENTERS**

**Session Chair:** Eugen Schenfeld, *IBM Research, Yorktown Heights, NY, USA*

**TuD3.1 13.30 - 14.00 (Invited)**

**Survey of Data Center Interconnect Requirements: Now and the Future**, D. C. Lee, *Facebook, Palo Alto, CA, USA*

ABSTRACT NOT AVAILABLE

**TuD3.2 14.00 - 14.30 (Invited)**

**CMOS Photonic Interconnects for Efficient Memory Access**, R. Ram, *Massachusetts Institute of Technology, Cambridge, MA, USA*

ABSTRACT NOT AVAILABLE

**TuD3.3 14.30 - 14.45**

**Monolithic Chip-to-Chip WDM Optical Proximity Coupler Utilizing Echelle Grating Multiplexer/Demultiplexer Integrated with Micro Mirrors Built on SOI Platform**, D. C.-H. Lee, D. Feng, C.-C.Kung, J. Fong, W. Qian, *Kotura, Monterey Park, CA, USA*, X. Zheng, J. E. Cunningham, A. Krishnamoorthy, *Oracle, San Diego, CA, USA* and M. Asghari, *Kotura, Monterey Park, CA, USA*

We report the first monolithically integrated chip-to-chip WDM optical proximity coupler with 4-channel  $\times$  200GHz-spacing multiplexer/demultiplexer (MUX/DEMUX) functionality utilizing an echelle grating, micro reflective mirrors, and waveguide mode transformers on single silicon-on-insulator (SOI) substrate.

**TuD3.4 14.45 - 15.00**

**Highly-Efficient Thermally-Tuned Resonant Filters**, J. E. Cunningham, I. Shubin, X. Zheng, *Oracle, San Diego, CA, USA*, T. Pinguet, A. Mekis, *Luxtera, Carlsbad, CA, USA* and A. Krishnamoorthy, *Oracle, San Diego, CA, USA*

We demonstrate spectral tunability for a microphotonic add-drop filter manufactured as ring resonator in commercial 130 nm SOI CMOS technology. The filters are provisioned with an integrated heater built in CMOS for thermal tuning.

**15.00 – 15.30****COFFEE BREAK****15.30 - 17.00****Session TuD4: OPTOELECTRONICS FOR DATA CENTERS II**

**Session Chair:** Larry A. Coldren, *University of California - Santa Barbara, Santa Barbara, CA, USA*

**TuD4.1 15.30 - 16.00 (Invited)**

**Interconnecting with Silicon**, M. Asghari, *Kotura, Monterey Park, CA, USA*

This talk aims to provide an industrial perspective and overview on the motivation, key challenges and some recent progress in the field of Si Photonics and its applications in optical interconnects.

**TuD4.2 16.00 - 16.15**

**Simple Electroabsorption Model for Silicon-Germanium/Germanium Quantum Well Devices**, R. K. Schaevitz, *Stanford University, Stanford, CA, USA*, J. E. Roth, *Aurion, Santa Barbara, CA, USA*, E. H. Edwards, R. M. Audet, S. A. Claussen, E. Tasyurek, S. Ren, Y. Rong, J. S. Harris and D. A. B. Miller, *Stanford University, Stanford, CA, USA*

We present a simple model for the electroabsorption spectrum of germanium-based quantum wells, which can be used to optimize material design for modulators. The model gives very good agreement with our new experimental data.

**TuD4.3 16.15 - 16.30**

**Demonstration of Rib Waveguide Based 1x12 Multimode Interference Optical Beam Splitter on Silicon-on-Insulator**, D. Kwong, Y. Zhang, A. Hosseini, Y. Liu and R. T. Chen, *University of Texas at Austin, Austin, TX, USA*

We present a compact silicon nanomembrane based 1x12 multimode interference coupler (MMI) fabricated on Silicon On Insulator (SOI) that exhibits low loss and high uniformity at 1550nm wavelength.

**TuD4.4 16.30 - 16.45**

**120-Gb/s 100-m Transmission in a Single Multicore Multimode Fiber Containing Six Cores Interfaced with a Matching VCSEL Array**, B. G. Lee, D. M. Kuchta, F. E. Doany, C. L. Schow, C. Baks, R. A. John, P. K. Pepeljugoski, *IBM Research, Yorktown Heights, NY, USA*, T. F. Taunay, B. Zhu, *OFS Laboratories, Somerset, NJ, USA*, M. F. Yan, *OFS Laboratories, Murray Hill, NJ, USA*, G. E. Oulundsen, D. S. Vaidya, *OFS, Sturbridge, MA, USA*, W. Luo and N.-Y. Li, *Emcore Corp., Albuquerque, NM, USA*

Over 100 Gb/s is carried across a single 100-m strand of multicore multimode fiber. A custom VCSEL array transmits 16.7 to 20 Gb/s/channel into six cores housed within a 125- $\mu$ m cladding. Negligible crosstalk is observed.

**TuD4.5 16.45 - 17.00**

**Spot Size Effects in Asymmetric Fabry-Perot Electroabsorption Modulators**, R. M. Audet, E. H. Edwards, S. A. Claussen, S. Ren, R. K. Schaevitz, E. Tasyurek and D. A. B. Miller, *Stanford University, Stanford, CA, USA*

Simulations of an asymmetric Fabry-Perot modulator reveal degradation of the contrast ratio as the incident spot size is decreased. The minimum practical spot size imposes constraints on the modulator dimensions and hence device capacitance.

**19.00 – 21.00****Panel Discussion****Moderator:**

David Plant, *McGill University, Canada*

**Panel Members:**

Greg Young, *Luxtera, USA*

Mehdi Asghari, *Kotura, USA*

Rajeev Ram, *Massachusetts Institute of Technology, USA*

Daniel Kuchta, *IBM, USA*

## Wednesday, 21 July 2010

**09.00 - 10.00****Session WD1: DEVICE AND SYSTEM DESIGN**

**Session Chair:** Shigeru Nakagawa, *IBM Research, Yamato, Japan*

**WD1.1 09.00 - 09.30 (Invited)**

**Data Center Evolution in the Zettabyte Next Generation Network**, L. Paraschis, *Cisco Systems, Inc., San Jose, CA, USA*

ABSTRACT NOT AVAILABLE

**WD1.2 09.30 - 10.00 (Invited)**

**Light on Board™ Optical IC Packaging**, D. Rolston and R. Varano, *Reflex Photonics, Inc., Montreal, Canada*

The enhancement of ICs with modular optical engines can provide an aggregate bandwidth of up to 2-Tbps. More than 200 optical channels, each operating at greater than 10-Gbps, can be integrated into a standard IC package.

**10.00 – 10.30****COFFEE BREAK****10.30 - 12.00****Session WD2: TRANSCEIVERS AND PACKAGING II**

**Session Chair:** David V. Plant, *McGill University, Montréal, QC, Canada*

**WD2.1 10.30 - 11.00 (Invited)**

**Scalable, Energy Efficient Data Centers**, G. C. Papen, *University of California - San Diego, La Jolla, CA, USA*

We report the initial results of a scalable, energy efficient data center constructed using a hybrid electrical/optical core switch. This approach has the potential to dramatically reduce both the cost and energy per switched bit.

**WD2.2 11.00 - 11.30 (Invited)**

**High-Density, Low-Power Optical Interconnects for Computing Systems**, S. Nakagawa, *IBM Research, Yamato, Japan*

ABSTRACT NOT AVAILABLE

**WD2.3 11.30 - 11.45**

**Block Linear Coherent Detection of Optical Continuous Phase Modulation**, T. F. Detwiler, S. M. Searcy, *Georgia Institute of Technology, Atlanta, GA, USA*, B. Basch, *Verizon, Waltham, MA, USA* and S. E. Ralph, *Georgia Institute of Technology, Atlanta, GA, USA*

Continuous phase modulation (CPM) of optical links is advantageous for avoiding intensity dependent nonlinear phase noise. We present an architecture for all-digital coherent CPM reception covering M-ary full response formats, describing the functions of each module.

**11.45 - 12.00**

**Closing Remarks**

**END OF PROGRAM**