Silicon photonics and the data-centric datacenter

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Date: 04/15/2011
“In the last 7 years online data increased 56 times”

Google (2009)
Data-centric computing

• Data grows faster than computation

• Data-centric workloads

• From performance to efficiency

• Scalability
Optical interconnects

State of the art

Distance (m)

Cost pressure

Advantages

- More bits per “wire”
- Less power per bit
- Better signal integrity
Outline

• Architectures

• Devices
  • Waveguides
  • Modulators
  • Detectors
  • Lasers

R. G. Beausoleil “Large-Scale Integrated Photonics for High-Performance Interconnects,” to be published in ACM Transactions on Computational Logic
Architectures
Network-on-Chip link topologies

Point-to-point
- Sun/Oracle, MIT

Switched network
- Cornell

Broadcast bus
- Cornell, Northwestern

Multiple sender single receiver
- HP
Architecture example 1
MIT Local mesh to global switch

- Point-to-point plus passive mesh
- DRAM-centric architecture
- 20W power envelope (network)
- 10x improvement over electrical

Batten 2009
- Multiple-sender single-receiver links
- 1 byte/flop on chip and to memory
- 250W power envelope (compute + network)
- 20x improvement over electrical
Architecture example 3
HP HyperX

• Crossbar used in high-radix switches

• Switch enables high connectivity topology

Optical Data Crossbar
128 channels

input buffer & routing
...... 128 ....

output buffer

Ahn 2009
Technology requirements

- DWDM: bandwidth density
- Silicon photonics: cost and scalability
- Ring resonators: technology of choice
Devices
Low-loss waveguides

**Silicon wire**
- Cladding
- Core
- Substrate
- Loss 1 dB/cm

**Rib waveguide**
- Cladding
- Core
- Substrate
- Loss 0.2 dB/cm

**Slot waveguide**
- Cladding
- Slot
- Substrate
- Loss 6.5 dB/cm

**SWG waveguide**
- Loss 2.1 dB/cm (Bock 2010)
Modulation mechanisms

Carrier injection
- Optical mode
- Cornell, HP

Carrier depletion
- Depletion region
- Sandia, Kotura

Carrier accumulation
- Oxide barrier
- Lightwire

Electro-optic polymer
- EO polymer
- Intel
HP modulators results

10 μm silicon ring resonators

Results

• 45 fJ/bit
• 6 Gbps modulation (with pre-emphasis)
A detectors’ menagerie

Intel Yin2007
Vertical Ge PIN on rib WG BW 31 GHz

CEA-LETI & Paris Vivien2007
Vertical Ge PIN coupled to wire BW 42 GHz

A*STAR Wang2008
Horizontal Ge PIN BW 18 GHz

Lincoln Lab Geis2009
Damaged silicon detector BW 35 GHz
Laser: integrated vs. external

Integrated laser
- The contenders
  - Bonded lasers (UCSB, Intel, Ghent)
  - Germanium laser (MIT)
  - III-V grown on Si (Michigan)
- Pro
  - Less packaging
  - Cheaper
- Cons
  - Thermal issues
  - Fabrication issues

External laser
- The contenders
  - Telecom grade commercial lasers
  - Quantum dot (Innolume)
  - Modulated (UC Davis)
- Pro
  - Power and thermal independent
  - Established technology
- Cons
  - Complexity
  - Cost

Van Campenhout 2008
Zhou 2009
Integrated laser example: HP

• Idea: Hybrid Si/III-V laser with 12.5 Gb/s data rate
  • Wafer bonding + self-aligned process

• Results
  • 2.5 mW output,
  • < 4 mA min threshold
  • 5 GHz BW achieved, 10–12.5 GHz expected

• Future directions
  • Integration
  • Silicon on diamond

Liang 2010

CWDM optical engine

Hybrid microrings

Cost ~ Area ~ 0.015 mm²
Power ~ 2 pJ/bit
External laser example: Innolume

- Idea: quantum dot FP laser
  - MBE grown

- Results
  - 80 Ghz spacing
  - 8 lines
  - >-10dBm per line
  - Low RIN (-110 dB/Hz)

- Future directions
  - Add wavelengths
Open problems and future directions

Work to be done

• Integration
  • How do we put it all together?

• Co-design
  • Drivers and receivers

• Fabrication
  • What happens if we try to build 1000s of devices on a chip?

• Power consumption and thermal

…and most importantly

• Business case

• Solution roadmap

• Supplier ecosystem
Thank you
Bibliography

Review paper
R. G. Beausoleil “Large-Scale Integrated Photonics for High-Performance Interconnects,” to be published in ACM Transactions on Computational Logic

Architecture

Waveguides

Modulators
Bibliography (continued)

Detectors

Laser