Revolutionizing Computing and communications with Silicon Photonics

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Intel Fellow & GM
Silicon Photonics Solutions Group

ES2 Conference
March 13th 2014
Agenda

• Motivation Industry Trends
• Silicon Photonics why all the buzz?
• 50Gbps Link: Putting it all together
• Scale up and scale out
• Evolution of compute systems
• Making it real
• Summary
A Wealth of Data to Move

**Personal Media**
- Ave. Files on HD 54GB

**Business**
- Retail Customer DB 600 TB

**Medical**
- Clinical Image DB ~1PB

**Social Media**
- HD video forecast 12 EB/yr

**Science**
- Physics (LHC) 300 EB/yr

More than 15B connected devices by 2015

How do you connect all these devices?
What’s Happening with Data

Big Data

- Data growing exponentially
- Faster multi-core CPUs
- Distribute h/w for more efficient compute
- HPC systems growing in size

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**Mega Data Centers**
- Longer reaches needed to connect more systems/servers
- Power envelope key

Utah DC completed in 2013 for NSA (>1M sq. ft.)

QTS Atlanta ~ 1M sq ft
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**More Connectivity**
- Increasing link speeds & lengths
- Copper reaching limits at 25G
- Power, size, reach key
- HPC I/O ~20-25% of system cost

Utah DC completed in 2013 for NSA (>1M sq. ft.)
QTS Atlanta ~ 1M sq ft

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What if we could Eliminate Distance & Bandwidth Constraints Using Optical Links?
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New opportunities to:
- Increase performance
- Reduce system costs
- Reduce thermal density
- Improve energy efficiency
- Enable new form factors-ID

Could Revolutionize future platform architectures
But…. has to be low cost to enable …..
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A Half Century of Innovation

Lasers

1960

First Laser (Ted Maiman)

Today

Countless apps

• Practical usages not known upon invention
• Laser has impacted industries from medicine to manufacturing to entertainment and more
• All long distance communications driven by lasers

Costs limit the use of photonics in and around servers

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A Half Century of Integration

Silicon

1959

First Silicon IC (Noyce and Kilby)

~50 years

Today

Billions of Transistors

• We have gone from 2 transistors to 2 billion

• This “Moore’s Law” scaling has led to transformative technologies
  • Mainframes -> Servers -> PCs -> Laptops -> Handhelds
  • Internet, e-commerce, social media

Silicon manufacturing & integration has made this possible

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Bringing Si Manufacturing to Optical Comms

Si Manufacturing
- High volume, low cost
- Highly integrated
- Scalable

Optical Communications
- Very high bandwidth
- Long distances
- Immunity to electrical noise

OPTICAL ANYWHERE, EVERYWHERE

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Building blocks needed to Siliconize Photonics

1) Light Source
2) Guide Light
3) Modulation
4) Photo-detection
5) Low Cost Assembly
6) Intelligence

First: Innovate to prove silicon is a viable optical material

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The Path to “Siliconizing” Photonics

Lasers

1st Continuous Wave Silicon Raman Laser (Feb. ‘05)

Hybrid Silicon Laser (Sept. ‘06)

Data Encoders

Silicon Modulators
1GHz (Feb ‘04)
10 Gbps (Apr ‘05)
40 Gbps (July ‘07)

Basic Light Routing

Waveguides, multiplexers, demultiplexers, couplers...

Light detectors

40 Gbps PIN Photodetectors (Aug. ‘07)

340 GHz Gain*BW Avalanche Photodetector (Dec ‘08)

Numerous scientific breakthroughs.
Most devices operating greater than 40Gbps
The 50G Integrated Silicon Photonics Link
Transmitting and Receiving Light with Silicon 2010

Integrated Transmitter Chip

Optical Fiber

Integrated Receiver Chip

Transmit Module

Receiver Module

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Single Wavelength Hybrid Silicon Laser

Grating mirrors in silicon, enabling wavelength-specific laser light output

The Device

Optical Spectrum

Line width Measurement

~1000um
~150 um

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Integrated Transmitter Chip

Integrates Hybrid Silicon Lasers With Modulators for data encoding and a Multiplexer to put 4 optical channels onto 1 fiber.

Electrical data in... Up to 12.5 Gbps/channel

50Gbps out on one optical fiber

Parallel channels are key to scaling bandwidths at low costs
Integrated Receiver Chip

Integrates a coupler to receive incoming light with a demultiplexer to split optical signals and Ge-on-Si photodetectors to convert photons to electrons.

50Gbps in on one optical fiber

Receives 4 optical channels at 12.5Gbps and converts to electrical data.

Electrical data out... Up to 12.5 Gbps per channel
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The Path to Tera-scale Data Rates

Today: 12.5 Gbps x 4 = 50Gbps

12.5 Gbps x 8 = 100Gbps

25 Gbps x 4 = 100Gbps

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<th>Width</th>
<th>Rate</th>
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<td>x4</td>
<td>50G</td>
</tr>
<tr>
<td>12.5G</td>
<td>x8</td>
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<tr>
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<td>x25</td>
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Could enable cost-effective high speed I/O for data-intensive applications

Scale UP

Scale OUT

100G..160G

Scale up AND out

Future Terabit+ Links

x16, x32...
What Could You Download in <1 second?

At 50 Gigabit/s

- An HD movie
- 100 hours of digital music
- 1000 High-res photos
- 45 million tweets!
What Could You Download in <1 second?

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At 1 Terabit/s (Future)

- 2-3 seasons of a TV drama in HD
- The contents of a laptop hard drive
- An entire music library: 150+ albums

1 Tbps could download the entire printed collection of the Library of Congress in about 1½ minutes!
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Rack Scale architecture with disaggregated compute, storage, & I/O for flexibility
Allows for rapid deployment in scalable environment
Rack Scale Architecture – Evolution

**Today**

- Physical Aggregation
  - Shared Power
  - Shared Cooling
  - Rack Management

**> 2014**

- Modular Compute Interconnect Integration
  - Modular refresh
  - Transitioning to Photonic Interconnects
  - Local switch silicon

**Future**

- Subsystem Aggregation
  - Pooled compute
  - Pooled storage
  - Pooled memory
  - Shared boot

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Increase Capital Efficiency
Decrease cost/transaction

Increase Agility
Decrease TCO

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What’s needed to enable this vision?

Photonics and cables in around Rack

Links To Spine

Photonic Links to trays and to TOR

Optical Patch Panel

Patch Panel with Connectors

HVM SiPh

SiPh Module and Socket for HVM

Rack

Low cost Cables & Connectors

In rack jumpers

Modular cards with SiPh

Need to enable total solution (Photonics, cables & connectors)
January 2013: OCP physical reference design shown

Mechanical Tray with Atom

Mechanical Tray with Atoms and Xeons

Intel Silicon Photonics

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April 2013: Live demo of 100Gbps at IDF China
September 2013: MXC cable and ClearCurve fiber
Announced with Corning

- Fewer parts – lower cost
- Up to 64 Fibers
  - Up to 4 rows of 16 fibers
  - Recessed Integrated Beam Expander
    better dust immunity
    protection from damage
    Less coupling tolerance
- Tighter bend radius – 7mm vs 38 mm
- More faceplate density

Up to 1.6 terabits of data per cable

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September 2013: Record 300 meters at 25Gbps

- Eye diagram shows little degradation compared to back-to-back
- The total penalty was only ~1 dB after 300m
September 26: ECOC in London: Demonstrated 820m transmission @ 25Gbps

25 Gb/s Transmission over 820m of MMF using a Multimode Launch from an Integrated Silicon Photonics Transceiver

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Abstract We demonstrate 25Gb/s transmission over a record 820m MMF using a multimode launch from an integrated SiPh transceiver through a new fiber optimized for high bandwidth at 1310nm. Error-free performance was achieved with a power penalty of 3.4 dB. Detailed characteristics of the fiber and transceiver are presented along with BER measurements.

Introduction
Interest in using multimode fibers (MMFs) for high data rate short distance communications has increased significantly in recent years due to an increase in the number and size of data centers and enterprise networks, and the limitations of copper at higher line rates. A new standard is being drafted for 4x25 Gb/s 650nm VCSEL transmission over 100m OM4 MMF by the IEEE 802.3cm task force. The 100m maximum reach being considered is significantly shorter than the 550m reach specified for 10Gb/s using a new MMF optimized for the 1310nm window and an integrated SiPh transceiver. This reach is over 8x longer than the 100m reach proposed in 4X25G standards for OM4 fibers at 850nm and addresses the critical need of data centers to maintain or increase their current sizes while increasing the bit rate.

MMF Optimized for 1310nm
The key passive element in this system is a new MMF optimized for high bandwidth and low attenuation around 1310nm. The optimized fiber features...
September 2013: Live Demo of RSA

Intel CPU’s, Switch, MXC & Silicon Photonics

Intel Sr. VP Diane Bryant showing a 128Gbps PCIe Cu cable (left) and a 1.6tbps MXC cable (right)

Intel Sr VP Diane Bryant pointing to SiPh module

Functional rack with:
Atom C2000 CPUs,
Xeon CPUs, MXC cable & connector,
Intel Switch silicon,
Intel Silicon Photonics

All ingredients working well together

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November 6th, 2013: World’s First oPCIe Demo

End User Benefits

- Enables hi-speed, low latency connections for added compute and storage
- Shared pools of compute and storage
- Cooling flexibility and lower cost by distributing hot components further apart

PCI Expansion Box
- 4 Intel® Xeon Phi™ co-processors
- 2 100G Intel® Silicon Photonic modules
- 2 Intel® Optical PCI Express Gasket ICs
- 2 PCI Express switches
- 1 Raid Controller
- 2 SSDs

2 Fujitsu RX200 Servers

- 2 MXC connector with ClearCurve LX fiber
- 2 100G Intel® Silicon Photonic modules
- 2 Intel® Optical PCI Express Gasket ICs
- 2 Intel® Xeon® E5 2600 CPUs
Summary on SiPh

- Silicon Photonic building block strategy allows for b/w scaling from 50Gbps to Terabit/s

Applications in segments from CE to Data Center to HPC

- Could revolutionize system architecture & future platforms designs
- Working with industry to enable this technology
- Look forward to creating the future together
Thank You
Silicon Photonics Participants Swelling

Numerous Silicon Photonics Entrants Across Start-ups, Products, Foundries and Research
Risk Factors

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