Silicon Photonics Transceivers for Hyper-Scale Datacenters: Deployment and Roadmap

Peter De Dobbelaere
Luxtera Inc.

09/19/2016
Luxtera Company Introduction

- Founded in 2001, Luxtera has the world’s only Silicon Photonics platform proven in volume transceiver production, in continuous production since 2008 with ~1Mu deployed.
- Fundamental IP position with 180+ WW Patent filings including 122 issued US Patents.
- After 1H’16 market delay, strengthening demand for Luxtera’s 100G products
- Continuing R&D Investment: Roadmap supports 5 year hyper-growth cycle of 25/50/100/400G SMF transceivers leading to broad scale SoC integration.

- $100B+ Shift in technology spend to the Cloud changed the market. Cloud Operators require reliable & cost-effective 100G Single Mode Optics at high volume scale
- Major Cloud Operators, System OEMs, Semiconductor companies have placed their bet on Luxtera
- Scaling production of new 100G Optics products which lead the market on price/performance and availability

- Roadmap: Pluggable optics, embedded modules at 100Gb, 400Gb, and 1Tb+, ultimately leading to SoC/ASIC integration
Luxtera’s technology leverages strongly from Si IC industry:
- Wafer manufacturing in commercial fabs
- Design methodologies & design automation
- Wafer level testing, built-in self-test
- Wafer Level assembly, low-cost packaging

Luxtera’s technology enables highest level of integration:
- Increased functionality & density
- Dense interconnect with electronic ICs
- Simplification of packaging and test

Luxtera’s Silicon Photonics Technology Platform & Milestones:

Luxtera’s Silicon Photonics Milestones:
- 2006: First WDM (4x10 Gbps) silicon photonics transceiver:
  - 4x10 Gbps NRZ, duplex
  - Monolithic integration of photonics & electronics
  - Integrated controls for modulator and wavelength mux/demux
- 2009: First commercial PSM4 silicon photonics transceiver:
  - 4x10 Gbps NRZ, 4x14 Gbps NRZ, low cost PSM solution
  - Monolithic integration of photonics and electronics
  - Single micro-packaged CW LD light source
  - Volume: > 1 Million units shipped (2016)
  - Reliable: > 10 billion failure free operating hours
- 2011: First 100 Gbps silicon photonics transceiver:
  - 4x25 Gbps NRZ
  - Monolithic integration of photonics and electronics
  - Single micro-packaged CW LD light source
- 2014: First 200 Gbps silicon photonics transceiver:
  - 8x25 Gbps NRZ
  - Hybrid integration of photonics and electronics
  - Single micro-packaged CW LD light source
- 2015: First 100G-PSM4 silicon photonics transceiver:
  - 4x25 Gbps NRZ
  - Hybrid integration of photonics and electronics
  - Single micro-packaged CW LD light source
Integration Photonics & Electronics

Monolithic Integration
- Single chip solution
- Lower parasitics between photonics and electronics
- More complex wafer fabrication process
- Less area efficient
- **Moving to advanced nodes is complicated & very expensive**

Hybrid Integration
- Multi chip solution
- Higher parasitics between photonic and electronics
- Photonics & electronics fabrication processes decoupled
- Efficient use of area: photonics doesn’t take area on (expensive) advanced e-node
- **Flexible electronic node selection (CMOS, BiCMOS,..), enabling integration with 3rd party IP**

Monolithic SiP IC
Electronics + Photonics

[Image of monolithic SiP IC with micro-bumps connection]

Electronic IC
Photonic IC
**Light Source, Test & Assembly**

**Light Source**
- Silicon Laser Micro Package:
  - Base wafer: silicon micro bench
  - Lid wafer: cavity with mirror
  - Hermeticity obtained by solder seal
- Features:
  - Use mature InP laser diode technology (multiple suppliers)
  - Include an isolator in the system
  - Use efficient optical coupling scheme
  - Wafer level assembly, packaging and test
  - Use established wafer level burn-in method

**Optical Test**
- Fully automated optical test of wafers on industrial platform (TEL): 200 mm & 300 mm
- Outstanding test gage: 0.1 dB for IL test

**Chip-to-chip & Optical Assembly**
- Fully automated assembly
- Chip-to-chip bonding by Cu Pi technology
- High throughput single mode connection by active alignment
PSM4 4x28 Gbps Chipset in QSFP28 Module

Electronic IC:
- 28 nm technology (TSMC N28HPM)
- MZI drivers & TIAs + controls
- E-interfaces w/ bypassable CDR & programmable signal conditioning (CTLE)
- BIST (electrical high-speed loopback)
- Laser diode driver
- Digital core with MCU
- 2-wire communication

Photonic IC:
- Mach-Zehnder high-speed modulators
- Ge high-speed photodetectors
- Ge monitor photodetectors for control and monitoring
- BIST (optical high-speed loopback)
- Photonics assembly features

Application: QSFP28 Modules plugged in switch front panel
Chipset mounted on PCBA:
- Si Photonics IC (1310 nm)
- Electronic IC (TSMC 28 nm)
- Single light source (1310 nm)

Wire bonding for electrical connections:
- High-speed differential pairs
- Power & ground
- Low-speed communication
Cloud Computing increases rapidly and takes market share of Enterprise Computing

Web/Cloud:
- Computing is the business: Datacenter = “Computing Factory”
- ~50% of servers in 2018 (E)
- Small number of large-scale web/cloud service providers

Enterprise:
- Computing supports the business
- Thousands of companies with 100-1,000s of servers
- Hundreds of companies with 1,000-10,000s of servers
Optical interconnect technology:
• In the rack: will likely stay electrical for now
• TOR-LEAF: Can be AOC (technology independent)
• L > 20 m: Single-Mode Fiber

Single mode fiber:
• Fiber infrastructure can be reused when data rate scales up
• Fiber cost lower, optical connector cost higher
High-Speed Interconnect: Two Bottlenecks

- **Data streams limited at 2 bottlenecks:**
  - ASIC: number of electrical I/Os limited by packaging constraints
  - Shelf: front plate density limited by size of optical modules

- **How to resolve?**
  - **Increase bit/baud rate:**
    10 Gbps -> 25 Gbps -> 56 Gbps
  - Use **embedded optics** (e.g. COBO MSA initiative)
    - Transceivers internal to shelf (instead of z-pluggable modules on face plate)
    - High density optical connectors at face plate
  - Longer term: **Integrate high density optical I/O with ASIC** allowing higher density (MCM or photonic interposer)
## High-Speed Interconnect: High port count, high data rate, low power

<table>
<thead>
<tr>
<th>CONTEMPORARY – Today</th>
<th>EMERGING – 2016/17</th>
<th>Next – 2018+</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="QSFP28 Module" /></td>
<td><img src="image" alt="200 Gbps Mid-Board Optics Module" /></td>
<td><img src="image" alt="ASIC with photonic I/O on interposer" /></td>
</tr>
</tbody>
</table>

### CONTEMPORARY – Today
- QSFP28 Module
- Switch ASIC
- Re-timer
- Optical Module
- PCBA

### EMERGING – 2016/17
- Switch ASIC
- Embedded optical module
- Fiber
- PCBA

### Next – 2018+
- Switch ASIC w/ photonics
- Fiber
- PCBA
Data Rate Scaling

Data Rates Keep Increasing

Data Rate Scaling vectors

Scaling Trade-Offs

- Cost
- Power dissipation
- Link budget margin
- Further Scalability

SMF Standards in Development:

Single wavelength (PSM4/Breakout)
- 400GBase-DR4
- 200GBase-DR4
- 50GBase-FR/LR
- 25GBase-LR

Multi wavelength
- 400GBase-FR8/LR8
- 200GBase-FR4
- 200GBase-LR4

Under Consideration
- 100G over 2km
  - 100G-FR Proposed
- 100G two lane over 500m
  - 100G-DR2 Proposed
• TSVs in the photonic die **eliminate power supply wire bonds** from photonic die to package:
  - Lower inductance interconnect for power and ground
  - Shorter electrical interconnect lengths on photonic die (voltage drop)
  - More compact packaging form factors (no need for bond pad ring)
• TSVs allow **lower parasitics** for the high speed interfaces
Large consumption of optical transceivers is in networking/computing and mobile infrastructure, in particular Cloud applications.

High performance Silicon Photonics optical transceiver products have been commercialized since 2009 and are being deployed in advanced datacenter applications.

Why silicon photonics for optical transceivers?

- Enables low-cost single mode fiber interconnect
- Single mode fiber enables scalability to higher data rates, advanced modulation and WDM without penalizing reach
- **External modulation** of light
  - Simple mode of operation
  - Light source does not have to be integrated with transceiver
- **Reliability**:
  - Use of mature InP laser diodes and inherent reliability of Si Photonics
  - More than 10 billion accumulated transceiver operating hours: random failure rate < 0.1 FIT
- **Roadmap to ASIC integration** by combining silicon photonics with 3D electrical integration
  - System power reduction
  - Ultimately no more stand alone transceivers
Acknowledgement:
This presentation contains work of the entire Luxtera team and its technology partners, their contributions are greatly acknowledged.

Thank you for your interest.