Optical transceiver trends for data center applications – How much photonic integration do we need?

Robert Blum
April 23, 2015
MIT Microphotonics Center Spring Meeting
Rapid Growth In Global Network Traffic Is Helping Fuel A Significant Near-Term Growth Cycle

INTERNET OF THINGS

25B
connected objects by 2015\(^{(2)}\)

INTERNET OF THINGS

SMARTPHONES

Over 1.6 Billion
smartphones and tablets
to be sold in 2015\(^{(4)}\)

SMARTPHONES

CLOUD COMPUTING

Increased adoption
by businesses and consumers
for applications and infrastructure

CLOUD COMPUTING

APPs / SOCIAL

1.8 Billion
photos uploaded and shared every day\(^{(3)}\)

APPs / SOCIAL

OTT VIDEO

1M Minutes
of video content will pass through networks in 2018 every second\(^{(4)}\)

OTT VIDEO

NEW TECHNOLOGIES

Faster speeds through LTE, FTTH rollouts

NEW TECHNOLOGIES

Global Carrier Capex Spending\(^{(5,6)}\)  Data Center Network Equipment Spend\(^{(7)}\)

<table>
<thead>
<tr>
<th></th>
<th>CY13</th>
<th>CY18</th>
<th>CY13</th>
<th>CY18</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Other Capex</td>
<td>Optical WDM</td>
<td>Other</td>
<td>100G Equipment</td>
</tr>
<tr>
<td>'13-'18 CAGR:</td>
<td>9.3%</td>
<td>14.5%</td>
<td>1.3%</td>
<td>2.3%</td>
</tr>
<tr>
<td>Revenue</td>
<td>$350.8B</td>
<td>$378.3B</td>
<td>$10.4B</td>
<td>$13.2B</td>
</tr>
</tbody>
</table>

\(^{(1)}\) IDC Research.
\(^{(4)}\) Cisco VNI “The Zettabyte Era,” June 2014.
\(^{(6)}\) Infonetics, “Service Provider Capex, Revenue, and Capex by Equipment Type,” November 2014.
### Product Overview

**Serving Both Line Side (Telecom) and Client Side (Data Center) Applications**

<table>
<thead>
<tr>
<th>Line Side / Core Optical Network Leadership in 10G-100G</th>
<th>Client Side / Data Centers Leading Transceiver Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>100G Coherent Components, Micro-iTLA, and Lithium Niobate Modulators</td>
<td>Complete portfolio of short-reach and long-reach form factors for 10G, 40G, and 100G</td>
</tr>
</tbody>
</table>

- **iTLAs**
- **Modulators**
- **Subsystems**
- **CFP**
- **CFP2**
- **CFP4**
- **QSFP**
- **Receivers**
- **Coherent MSA-300**
- **Coherent CFP2**
- **XFP**
- **SFP+**
- **Lasers**
- **Photodetectors**

- A leading supplier of 100G Line Side and Client Side products
- Broad portfolio of 10/40/100G Line Side transceivers and Client Side pluggable transceivers
- Differentiated Indium Phosphide and Lithium Niobate materials technology
- Vertical integration from materials to modules
Data Centers and Enterprises Embracing High-Speed Networking Technologies

- **Growing complexity** for enterprise networks and data centers
- **Larger and more diverse data and higher quality expectations** of SaaS
- **Rapid adoption of 40G and 100G technologies**, creating a large opportunity of optical vendors
- **40/100G** growing from $0.2B in 2012 to $3.7B in 2017

### Data Center Network Switching Spending

($ Billions)

<table>
<thead>
<tr>
<th>Year</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
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<tbody>
<tr>
<td>Value</td>
<td>$7.0</td>
<td>$7.6</td>
<td>$8.3</td>
<td>$8.8</td>
<td>$9.3</td>
<td>$9.5</td>
</tr>
<tr>
<td>40/100G CAGR</td>
<td>86%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Source: Infonetics Data Center Network Equipment, December 2013*
Cloud Data Center Network Topology (Spine/Leaf)

Meshed architecture better suited for N-S and E-W traffic

<table>
<thead>
<tr>
<th></th>
<th>TODAY</th>
<th>NEXT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inter DC ≥40km</td>
<td>10/40G DWDM</td>
<td>100G DWDM</td>
</tr>
<tr>
<td>Spine-Core &lt;2km</td>
<td>40G</td>
<td>100G</td>
</tr>
<tr>
<td>Leaf-Spine &lt;500m</td>
<td>40G SMF</td>
<td>100G SMF</td>
</tr>
<tr>
<td>ToR-Leaf &lt;30m</td>
<td>AOC 4x10G</td>
<td>AOC 4x25G</td>
</tr>
<tr>
<td>Server-Top of Rack (ToR)&lt;3m</td>
<td>Cu 10G</td>
<td>Cu 25G</td>
</tr>
</tbody>
</table>
Trends in Mega Scale Data Centers

- Servers migrating from **10G to 25G**
- **10G SFP+** demand migrating to **25G SFP28**
- **40G QSFP** (4x10G optical) demand shifting to **100G QSFP28** (4x25G)
- Data centers increase in size and data rates limit multimode fiber reach
- **Single mode fiber infrastructures** are increasingly **adopted** in large data centers
  - New 500m and 2000m transceiver standards for 100G (4 x 25G)
  - Multimode still relevant for active optical cables (AOC’s)
- Router and transport equipment continues to require **100G CFP and CFP2** for **10km** applications, **with CFP4 LR4** now starting to ship in volume
Trends in Mega Scale Data Centers

- Switch silicon becoming available now supports 3.2 TB
  - 32 ports of 100GE, Broadcom StrataXGS® Tomahawk™
  - 36 ports of 100 Gb/s InfiniBand, Mellanox Switch-IB™
- Front faceplate densities can be met by QSFP or CFP4 form factors
  - 36 ports of QSFP28 or 32 ports of CFP4 per 17” rack unit (365mm faceplate, belly-to-belly)


1.3μm 25G/28G DML For QSFP28

- Based on proprietary InGaAlAs MQW DFB laser technology
- Suppression of spatial hole-burning using Corrugation Pitch Modulated (CPM) grating structure
- Un-cooled operation
- High speed and low power consumption via short cavity (~150um)

2. Nakahara et. al., OFC2013 OTh4H
Trends in Mega Scale Data Centers

- Pluggability is still valuable, but roadmap considerations and port density requirements are also driving need for standardized solutions with on-board optics
  - Network switches or adapter motherboards would benefit from optical modules that are placed closer to the network ICs
  - See [http://cobo.azurewebsites.net/](http://cobo.azurewebsites.net/) for COBO MSA
  - Charter is to define electrical and management interfaces, pin-outs and board layout, thermals and airflow, decide on board-mounted or socketed

- Data center architectures are evolving to deal with increased amount inside data center (East-West) traffic

- At the same time, data center interconnects (DCI) are becoming increasingly important – with large players controlling not just both end of the link but also the fiber itself
  - DCI’s between MSDC’s, between a MSDC and a smaller colocation facility, and between colo facilities

- Data sovereignty laws and latency requirements necessitate data to be stored locally
  - Even large cloud service provider are leasing space in colo facilities close to customers
LISEL Array for 100G On-Board Optics

- Lens-Integrated Surface Emitting Laser
  - Developed in conjunction with Hitachi Central Research Laboratory
- Combination of established high-reliability 1310nm DFB laser and surface emitting laser structure
  - High speed performance over 25Gbps at high temperature
  - Potential for very low cost through on-wafer testing and wafer-level burn-in
- Error free 103.2Gb/s transmission over 2km up to 70ºC

K. Adachi et al., W2A.54, OFC 2015
50Gbps Technology

- Most 50G technologies are expected to be available in 2017
  - Optics: Both InP EML and Si-photonics are feasible
  - ASICs: 50G is expected in 2017 using 16nm CMOS
  - QSFP/SFP cages are available now
- Open questions remain around interface definitions
  - Optical PAM4 or NRZ
  - Electrical PAM4 or NRZ
- Overall link budgets need careful assessment

Source: Rob Stone, "THE RATE DEBATE: SWITCH PERSPECTIVE", Ethernet Alliance Technology Exploration Forum 2014

Switch IC Trend

Source: G. Denoyer, ECOC 2014, PD.2.4

InP EML


Si Photonics

Source: http://www.ethernetalliance.org/the-rate-debate-presentations/?st=view
“Demand for 100G components and modules is a big driver for growth in WAN. We expect strong demand for pluggable coherent transceivers in 2015 and beyond. Vendors have a good reason to be optimistic about this market.”

Daryl Inniss, Practice Leader for Telecoms Components at Ovum
10G Footprint Evolution

TSFP+ TOSA has TOA functionality & wavelength tunability & control!
100G Analog Coherent CFP2
Differentiation Enabled by InP Photonic Integration

Mach Zehnder Modulator Chip
Tunable Laser Chip
Co-packaging of Key Indium Phosphide Elements
Coherent Receiver Chip
Integrated 100G InP Transmitter Package
InP Micro Coherent Receiver Package

“CFP2-ACO technology is the most important catalyst for cutting the cost of coherent equipment and accelerating the rollout of 100G metro networks.”

Andrew Schmitt, Principal Analyst, Infonetics Research

100G CFP2 Module
- Next generation 100G coherent pluggable
- Metro, regional and high performance long-haul applications
- Delivers maximum faceplate density
- Provides scalability to enable bandwidth as required
Packaged NLW Laser, Dual QPSK MZ and Polarisation Multiplexer with LO output

**1\textsuperscript{st} Generation**
Engineering Prototype Based on 40G DQPSK package

**2\textsuperscript{nd} Generation**
Transmitter designed for CFP2

RF on rear of package
DC on long side of package
I&Q Mach Zehnder EO RF performance

- Small-signal $S_{21}$ EO and $S_{11}$ measured on chip using a GSG probe into 50Ω termination
- Shallow linear roll off identical within inner I&Q MZs

Dual IQ MZ chip

$7 \times 1.9 \text{ mm}^2$
~ 170 die sites on 3” wafer
SOA Overview

- Semiconductor Optical Amplifiers (SOAs) integrated pre- and post Mach-Zehnder modulator
- Integration of SOAs onto dual polarization I&Q modulator chip allows enhanced output power for advanced modulation formats with large ‘modulation loss’
- Also provides greater flexibility for various applications
  - X-Y power balance
  - Trace-tone provision
  - VOA capability
- See Th4E paper at OFC 2015 for details
  - R. Griffin et al., “InP Coherent Optical Modulator with Integrated Amplification for High Capacity Transmission”
Today’s Packet-Optical Transport / Datacenter / Broadband Access Networks

Fiber Access
- Mobile Broadband Mobile Backhaul
  - 1G/3G/6G → 10G
- DSL
- PON
- Cable
- ADM
- Medium Business
- Government
- Access 100M to 2.5G

Packet-Optical Transport
- Metro Access
  - 1G/2.5G/10G → 10G/40G/100G
- Metro Core
  - 10G → 40G/100G
- DWDM Core
  - 10G/40G → 40G/100G/400G
- Optical DWDM Core
  - Up to 80ch 100G
- IP-Optical Convergence
- 1G/2.5G/10G → 25G/40G/100G

Data Centers

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Possible 80 x 100G Data Center Interconnect Architecture

- High bandwidth monolithically integrated laser + modulator
- 40/80 DWDM channels for 80km point-to-point link
- PAM4 or DMT modulation formats are being considered
Semi-Insulating InP MZ Operation

- For 32Gbaud operation, only small advantage for semi-insulating MZ EO performance at half-Nyquist frequency over N⁺
- For higher Baud rates the difference between N⁺ and SI more pronounced, SI becomes more advantageous
Possible Path to 400G Transceivers and Interconnects

- InP platform allows for integration of 4 lasers + 4 Mach-Zehnder modulators + output combiner if desired
  - Minimizes assembly, footprint, number of components
- Laser contacts can be reduced with ‘grid tuning’ – see example for 4x50GHz channels tuned together
- Drive requirements are similar to DP-I&Q PIC with 4 parallel MZMs

192.5, 192.55, 192.6, 192.65 THz
192.7, 192.75, 192.8, 192.85 THz
Conclusion: How much photonic integration do we need?

- 25G laser and modulator technology is very mature
  - Form factors based on CFP MSA have been shipping for many years with four directly modulated or electro-absorption modulated lasers
  - QSFP28 transceivers will be ramping production this year and next year primarily for 500m and 2km, but also 10km applications

- Data centers are primarily about $/Gbit for getting data from A to B
  - New solutions need to have cost differentiation
  - Packaging cost and other factors affect the cost significantly – cost of laser or modulator itself is only one BOM item

- 50G has been demonstrated in silicon photonics and InP EMLs
  - Cost and time to volume for a given solution will likely be deciding factor

- InP based integration has advantages for long haul and data center interconnects
  - Monolithic integration of lasers, SOAs, modulators onto single DWDM platform for coherent or advanced modulation formats for point-point links
Thank You

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