Photonic Integration in Indium Phosphide for Metro and Data Center Interconnects

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September 30, 2015
ECOC 2015 Market Focus
Rapid Growth In Global Network Traffic Is Helping Fuel A Significant Near-Term Growth Cycle

INTERNET OF THINGS

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

SMARTPHONES

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

CLOUD COMPUTING

Increased adoption
by businesses and consumers
for applications and infrastructure

INTERNET OF THINGS

Global Carrier Capex Spending\(^{(5,6)}\)

Data Center Network Equipment Spend\(^{(7)}\)

Global Carrier Capex Spending

'13-'18 CAGR: 1.5%

'13-'18 CAGR: 5.0%

Data Center Network Equipment Spend

'13-'18 CAGR: 2.3%

\(\text{CY13} \quad 341.5 \quad 10.3 \quad 10.4B\)

\(\text{CY18} \quad 363.8 \quad 11.6 \quad 13.2B\)

\(\text{Other Capex} \quad \text{Optical WDM}\)

\(\text{Other} \quad \text{100G Equipment}\)

SMARTPHONES

Over 1.6 Billion

INTERNET OF THINGS

SMARTPHONES

Over 1.6 Billion

CLOUD COMPUTING

Increased adoption

APPS / SOCIAL

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

OTT VIDEO

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

NEW TECHNOLOGIES

Faster speeds through LTE, FTTH rollouts

(1) IDC Research.


Cloud Data Center Network Topology (Spine/Leaf)

<table>
<thead>
<tr>
<th></th>
<th>TODAY</th>
<th>NEXT</th>
<th>FUTURE</th>
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<tbody>
<tr>
<td>Inter DC 20km–metro</td>
<td>10/40G DWDM</td>
<td>100/200G DWDM</td>
<td>200/400G DWDM</td>
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<tr>
<td>Spine-Core 500m–2km</td>
<td>40G SMF</td>
<td>100G SMF</td>
<td>200/400G SMF</td>
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<tr>
<td>Leaf-Spine 300m–2km</td>
<td>40G MMF or SMF</td>
<td>100G SMF</td>
<td>200/400G SMF</td>
</tr>
<tr>
<td>ToR-Leaf 100m–500m</td>
<td>40G MMF or SMF</td>
<td>100G MMF or SMF</td>
<td>200/400G MMF or SMF</td>
</tr>
<tr>
<td>Server-Top of Rack (ToR) 1m-30m</td>
<td>10G Cu or AOC</td>
<td>25G Cu or AOC</td>
<td>50G Cu or AOC</td>
</tr>
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</table>
Trends in Mega Scale Data Centers (1/3)

- 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 (2/3)

- Switch silicon becoming available now supports 3.2 TB
  - 32 ports of 100GE, Broadcom StrataXGS® Tomahawk™
  - 32 ports of 100GE or 36 ports IB, Mellanox Spectrum™ and 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)

[Diagram showing front faceplate densities]


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 (3/3)

● **Pluggability is still valuable today**, 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 70°C

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 or below
  - QSFP/SFP cages are available now
- Open questions on module form factors and standard vs. non-standard
  - 4x100G PAM4 vs. 8x50G PAM4 for 400G
  - Faceplate density and power dissipation
  - Pluggable vs. on-board optics
- Overall link budgets need careful assessment
TSFP+ TOSA has TOA functionality & wavelength tunability & control!
100G Analog Coherent CFP2
Differentiation Enabled by InP Photonic Integration

“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

- 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

1st Generation
Engineering Prototype Based on 40G DQPSK package

2nd 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

7 $\times$ 1.9 mm$^2$
~ 170 die sites on 3” wafer
Lossless Modulator Through SOA Integration

- 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”*
Two Segments for Data Center Interconnect Market

A) 200-300km typ. reach
600G – 2T line cards with CFP2-ACO
PM-QPSK/16-QAM

B) 20-80km typ. reach
4T – 8T line cards / switches with QSFP28 PAM4 single wavelength 100G
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 InP 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 are ramping production starting next year primarily for 500m and 2km, but also 10km applications

- **Data centers are primarily about $/Gbit** for getting data from A to B and ability to deliver in high volume
  - 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-to-point links
Thank You

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