Photonic Integrated Circuits at Infinera

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Who is Infinera?

- Silicon Valley success story
  - Startup → NASDAQ IPO in 2007
  - 2015: $886M Revenue, 47.8% GM, 13.1% Profit

- Industry’s First Commercial Large-Scale Photonic Integrated Circuit (PIC)

- Industry’s First Transport Platform to Integrate OTN Switching with WDM
  - Enabled by advantages of PIC Size, Power, Cost, and Reliability

- Industry’s First Transport Platform >20 Tbps in Single Rack for DC Interconnect
  - Shipped at 50% less power than competitive (less integrated) solutions, enabled by PIC Size, Power, Cost and Reliability

- Transformed & Driving the Optical Transport Market
Why Use Photonic Integration?

- $ / Gbps
- Watts / Gbps
- mm\(^3\) / Gbps and mm\(^2\) / Gbps

Use unique **system-level** advantages:
- Super-channels with sliceability
- Instant Bandwidth
- Integrated OTN/WDM Switching

At both component **and** system/network level
Infinera Multi-Channel DWDM 100Gb/s Transmitter and Receiver Photonic ICs (2004)

Infinera 100 Gb/s Transmitter

- Integrated Optical Functions: >60
- Unique Integrated Functions: 8
- "Gold box" replacements: ~20-40
- Fiber coupling reduction: >100
Why Use InP for Photonic Integration?

- Platform capable of highest performance → no compromises vs. discrete for ULH, LH, Metro Regional/Core Markets

- Platform capable of integration of lasers and gain anywhere in circuit

- Converge multiple devices onto single manufacturing platform
  
  Leverage semiconductor learning curve

- Platform scalable (build generation upon generation)
Infinera PIC-based Subsea Deployments

- Over 250,000 route km of deployed subsea systems
- Longest deployed lengths:
  - 9,800 km (BPSK)
  - 4600 km (QPSK)
Infinera 100 Gb/s Photonic IC Pair (Tx+Rx)

- Optical Input
- Optical Output
- DC Electrical Bias and Control
- VOA Array
- EAM Array
- OPM Array
- Tunable DFB Array

1.64 B field hours
0 PIC Failures
<0.56 FIT@60%CL
Infinera Multi-Channel DWDM 500Gb/s Coherent Transmitter and Receiver Photonic ICs (2012)

**Infinera 500 Gb/s Coherent Transmitter PIC**

![Transmitter PIC Diagram]

**Infinera 500 Gb/s Coherent Receiver PIC**

![Receiver PIC Diagram]

### Integrated Optical Functions

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
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<tr>
<td>&gt;600 Integrated Functions</td>
<td></td>
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<tr>
<td>Unique Integrated Functions</td>
<td>10</td>
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<tr>
<td>“Gold box” replacements</td>
<td>&gt;100</td>
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<tr>
<td>Fiber coupling reduction</td>
<td>&gt;400</td>
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Infinera InP PIC Scalability (2014)

Infinera 2.25 Tb/s Transmitter PIC

>1700 functions InP-Based PIC

2.25 Tb/s in 1 THz-wide Super-Channel
Infinera’s World Leading Bandwidth Scaling (Per Module Pair)
Infinera Photonic Modules (To Scale)

100 Gb/s PIC Modules

2004 Release
11 Gbaud OOK
10 channels x 10G
Flexible Grid

500 Gb/s PIC Modules

2012 Release
16 Gbaud QPSK
5 channels x 100G (dual-cARRIER)
Flexible Grid
Super Channel

2.4 Tb/s PIC Modules

2016
32 Gbaud QPSK, 16QAM
12 channels x 200G (single-carrier)
Fully C-band tunable per channel,
Sliceable Super Channel
Key Considerations For the Future of Photonic Integration

- Co-design of PICs, drivers, package controls, test, and system
- Lack of co-design more than likely does not solve and sufficient problem
- **Cross-terms** are often the keys to ensuring sufficient cost, performance, reliability

**Key cross terms** include:
- DC & RF Electrical Interconnect → PIC on Carrier, Package and Board
- Optical Interconnect
- DC & RF Testing → PIC, Package, System
- Mechanical & Thermal Interfaces and Interconnects
- Controls → Algorithms, Firmware, Hardware
infinera
what THE NETWORK will be