Heterogeneous Photonic Integration for WDM based Optical Interconnects

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OSA Optical Interconnects for Extreme-Scale Computing Incubator
August 9-11, 2015
Evolution of Photonics

Using the silicon manufacturing supply chain to make photonics

<table>
<thead>
<tr>
<th>Conventional</th>
<th>Silicon Photonics</th>
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</thead>
<tbody>
<tr>
<td>In House Fabrication</td>
<td>Foundry Infrastructure</td>
</tr>
<tr>
<td>Custom Packaging Techniques – Cooling, Gold</td>
<td>OSAT Packaging - Self Hermetic, Uncooled</td>
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<tr>
<td>Box Hermetic Packaging</td>
<td></td>
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<td>$$$$</td>
<td>$</td>
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<tr>
<td>Physics Based Simulations</td>
<td>Silicon Based EDA</td>
</tr>
<tr>
<td>Transmission Line and decoupled drivers (cm)</td>
<td>Electronic Co-design (&lt;mm)</td>
</tr>
<tr>
<td>~10 pJ/bit</td>
<td>~pJ/bit</td>
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</tbody>
</table>

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Heterogeneous Integration: Materials and Silicon Technologies

Heterogeneous Photonic Systems on Chip (SoC)

Heterogeneous Electronic/Photonic System in Package (SiP)

Heterogeneous Integration for Si photonic PICs: Combining multiple materials into a photonic circuit to use the best material for the function, while remaining compatible with Si foundry tools and processes.

Heterogeneous Electronic/Photonic Integration: Combining multiple Silicon technologies, including photonics together into a chip-scale microsystem.
Scaling Bandwidth

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Drivers for WDM in the Emerging Data Centers

• Scale of largest Data Centers is driving >500m interconnect lengths which require Single Mode Fiber.

• IEEE Standards for SMF use WDM for reaches beyond 500m.
  • 40G LR4 (10 km)
  • 100G LR4 (10km)
  • 400G FR8 (2km) & 400G LR8 (10km) (approved)

• Industry Standard based solutions need to be cost effective to avoid fragmentation.

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Enabling Uncooled WDM

Lasers operating over a wide temperature range

Modulators operating over a wide wavelength range

Close integration of electronics and photonics

Electronics-like packaging

[B. Koch et al., OFC 2013, PDP5C.8]

[B. Lee et al., OFC 2015, Tu3.G3]
Heterogeneous Components and Processing for Uncooled WDM
Heterogeneous Integration Process

- Die Placement
  - Mature silicon photonics passives
  - Integration of multiple III-V Materials

- Substrate Removal
  - Reduced topology for Standard Processing

- III-V Processing
  - Active materials defined by lithography
  - No critical alignment

- Interconnect
  - Hermetic at Chip Scale
  - Wafer scale processing
Demonstration of an Heterogeneous Integration platform for Silicon Photonics

- Processed on Silicon wafers using Foundry Infrastructure.
- Optimized III-V Materials for Active Components with Silicon Photonics.
- Heterogeneous III-V Components on Silicon Match and even **Exceed** performance of Native III-V substrate.

Heterogeneous Integration:
Platform and Component Library Overview

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Uncooled Lasers on Silicon

Heterogeneous O-Band Laser
- Uncooled (no TEC)
- > 40 dB side mode suppression
- <400 kHz linewidth
- RIN <-145 dB/√Hz
- Laser diode efficiency: ~15% at T=80°C
- Reliability demonstrated:
  - >4M laser accelerated aging device-hrs and counting
WDM Laser Arrays

High yield integrated laser breaks cost barrier
- Large WDM arrays processed in parallel

Uncooled operation
- Wavelength-locking across temperature (20-80C) without a TEC
- 200GHz (or 800GHz) grid

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High Speed Modulators

Electroabsorption Modulator (EAM)
- >35GHz 3dB bandwidth
- Vpp=1.0 V (>4dB ER), 2V (~9 dB ER)
- Compact (<200um), <3 dB IL
- <0.5 pJ/bit at 32 Gb/s with CMOS driver

Mach-Zehnder Modulator (MZM)
- 23 GHz, 3dB bandwidth
- < 3 V for Pi phase shift
- >15 dB ER
- < 3 dB IL

See OFC2015 Paper Tu3G.3
High Speed Photodiodes

Heterogeneous Waveguide PD

• p-i-n photodiode with InGaAs absorber and Si waveguide layer

• 3dB bandwidth >35GHz

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Low Loss Passives

- Low-loss (<1dB/cm) silicon waveguides and low-loss crossings.
- High yield complex MUX/DEMUX structures with 200mm fabrication tooling.
- Athermal operation for uncooled WDM.
Heterogeneous Integrated Photonic Circuits and Packaging for Uncooled WDM
Heterogeneous Photonic Circuit Manufacturing

- Silicon photonics PIC using foundries
- Assembly using silicon OSATs
- Complete BGA transceiver
- Low cost optical connector attach
Conclusions

WDM is effective and necessary approach for bandwidth scaling, yet brings challenges.

Heterogeneous Integration on Silicon Photonics addresses the challenges:

• Cost effective integration of laser and other III-V materials.

• Athermal and tunable optical elements for wavelength.

• Intimacy with electronics for control and signal integrity through advanced Si packaging.