



CONNECTS

Heterogeneous Integration for
Connectivity and Sustainability

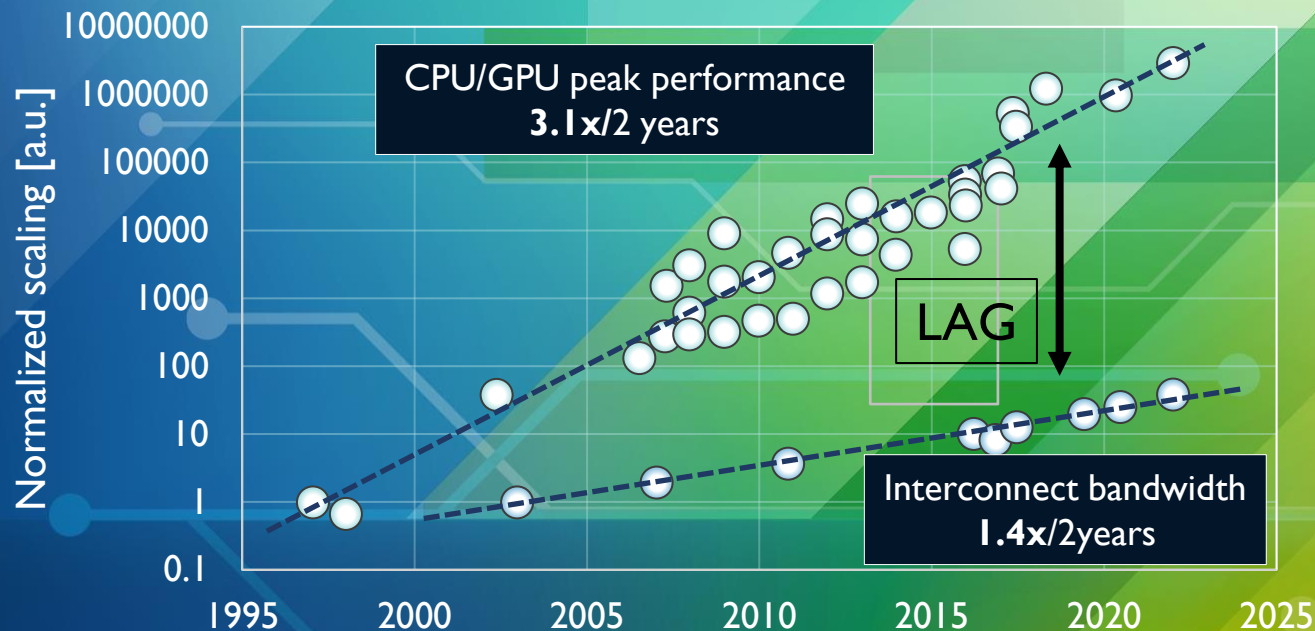
Demonstration of High-Speed Silicon Photonics I/O for Co-Packaged Pilot Line

Dr. Cheng-Jhih Luo- Silicon Photonics Pathfinding, IMEC

Chapter

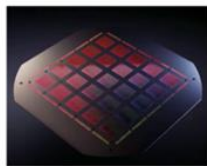
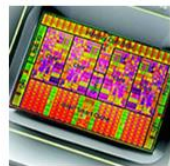
1. Optical Interconnect Landscape
2. Photonic Heterogenous Integration Pilot lines
3. Summary
4. Acknowledgement

The Bottleneck for Interconnect Bandwidth



Amir Gholami, et. Al. "AI and Memory Wall"

Short-Reach Interconnect Landscape



Chip

Package

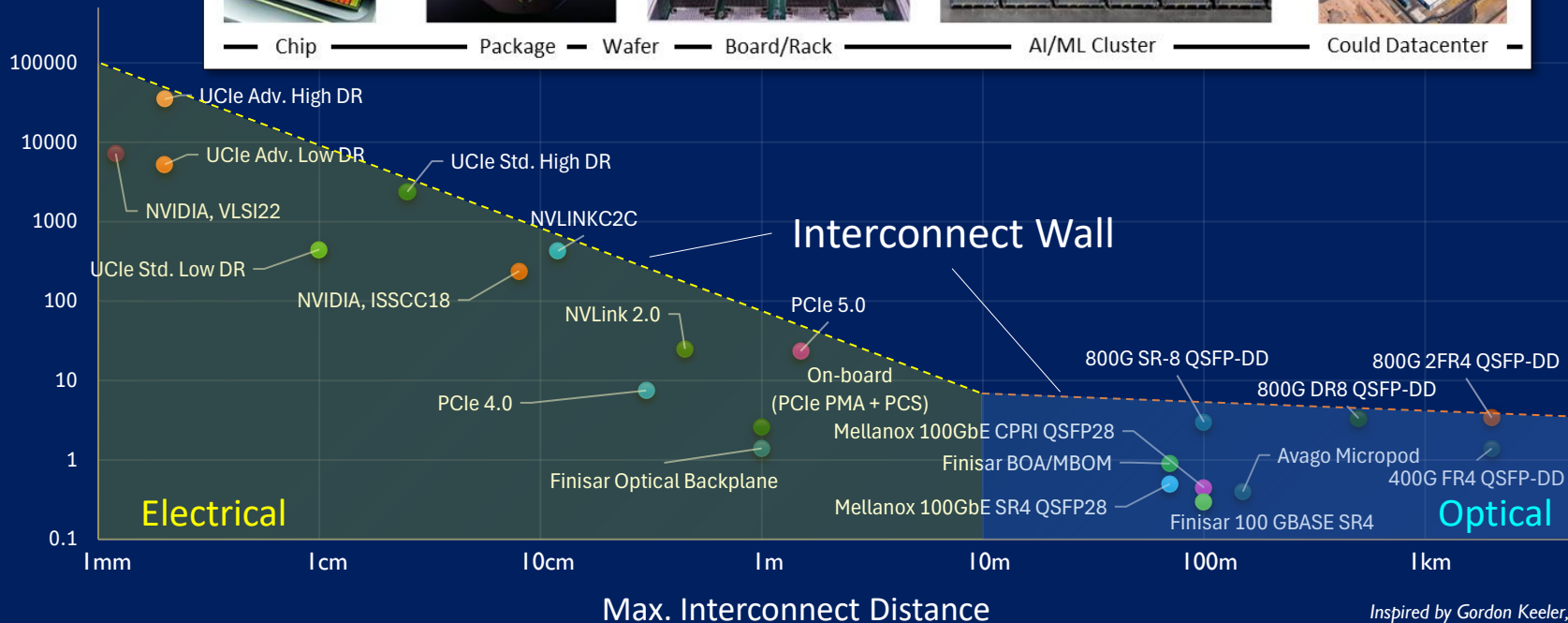
Wafer

Board/Rack

AI/ML Cluster

Cloud Datacenter

Edge BW Density * Energy Efficiency
(Gbps/mm)/(pJ/bit)



Inspired by Gordon Keeler, ex-DARPA

State-of-The-Art: Industrial News From Nvidia

GB200 NVL72 Compute and Interconnect Nodes



GB200 SUPERCHIP COMPUTE TRAY

2x GB200
80 PETAFLOPS FP4 AI INFERENCE
40 PETAFLOPS FP8 AI TRAINING
1728 GB FAST MEMORY
1U Liquid Cooled
18 Per Rack



NVLINK SWITCH TRAY

2x NVLINK SWITCH
14.4 TB/s Total Bandwidth
SHARPv4 FP64/32/16/8
1U Liquid Cooled
9 Per Rack

Compute Node GB200: 2x Blackwell GPU plus 1x Grace CPU

NVL72 “Scale-Up” Network

72x Blackwell GPUs all-to-all interconnected
through 18 NVL Switches
with Cu cabling (200Gbps, <1m)

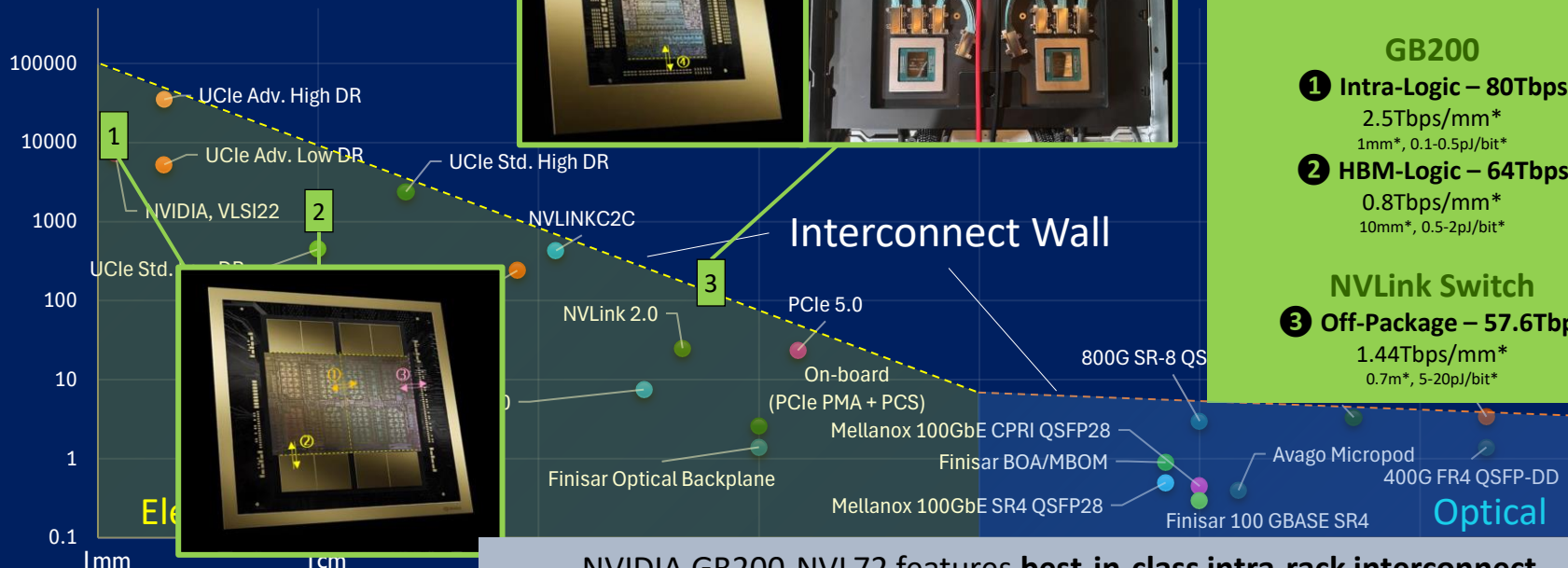


+ Scale-Out Optical Network

- 4 x 800Gbps Pluggable Optics Modules per Compute Node
- Overall GPU-Optical Module ratio = 1:2 to 1:3

State-of-The-Art: Industrial News

Edge BW Density * Energy Efficiency
(Gbps/mm)/(pJ/bit)



NVidia

Bandwidth-Power estimations*
(bidirectional)

GB200

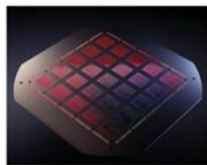
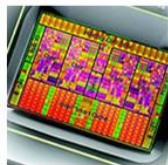
- ① Intra-Logic – 80Tbps
2.5Tbps/mm*
1mm*, 0.1-0.5pJ/bit*
- ② HBM-Logic – 64Tbps
0.8Tbps/mm*
10mm*, 0.5-2pJ/bit*

NVLink Switch

- ③ Off-Package – 57.6Tbps
1.44Tbps/mm*
0.7m*, 5-20pJ/bit*

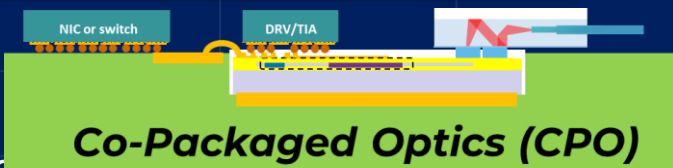
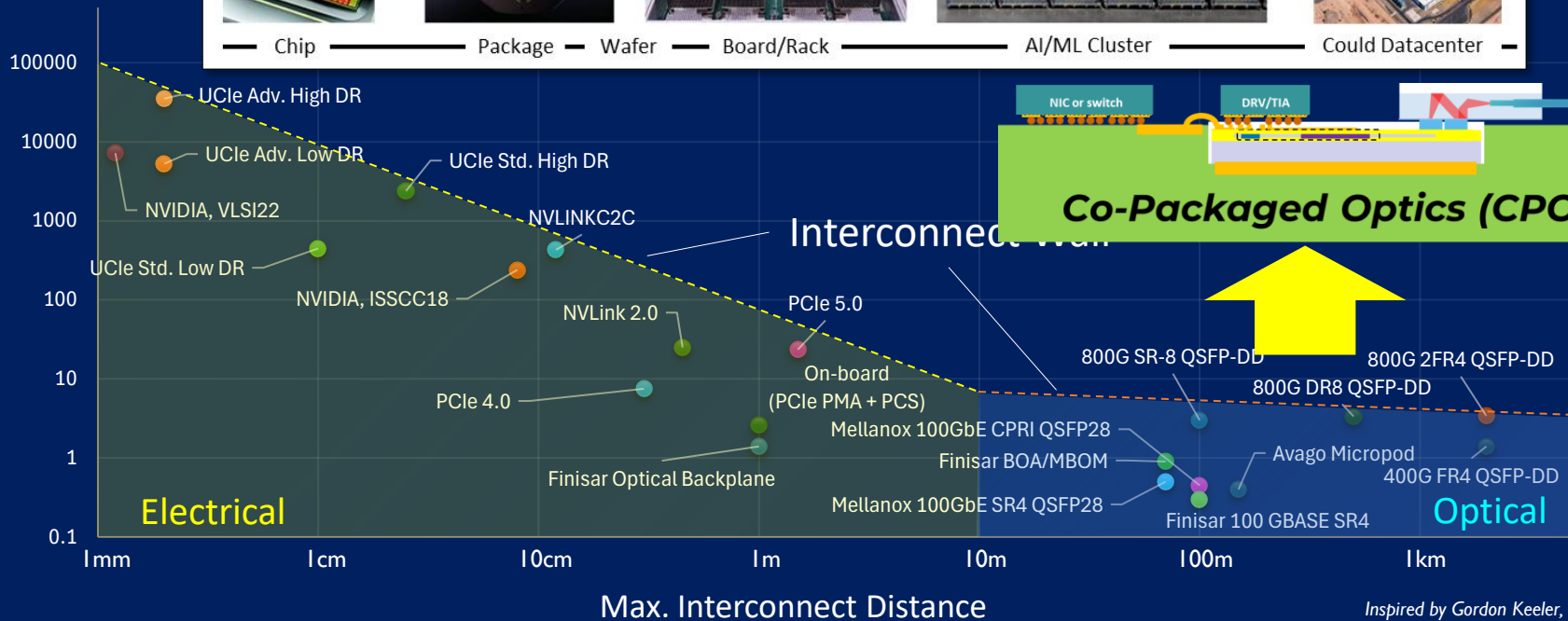
NVIDIA GB200-NVL72 features **best-in-class intra-rack interconnect** for <1m reach using **passive Cu cabling** at 200Gbps/lane

Co-packaged Optical Interconnect



— Chip — Package — Wafer — Board/Rack — AI/ML Cluster — Could Datacenter —

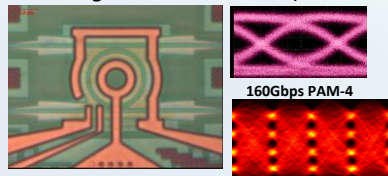
Edge BW Density * Energy Efficiency
(Gbps/mm)/(pJ/bit)



Inspired by Gordon Keeler, ex-DARPA

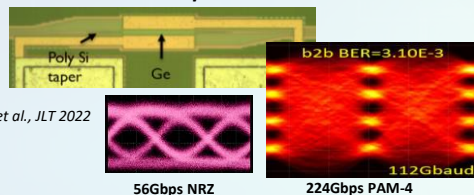
IMEC Silicon Photonics Platform

Silicon Ring Modulator



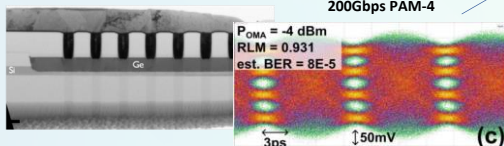
Y. Tong et al., PTL 2020

GeSi Electro-Absorption Modulator



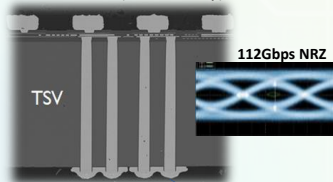
D. Chan et al., JLT 2022

Ge Photodetector

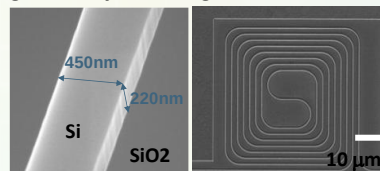


(c)

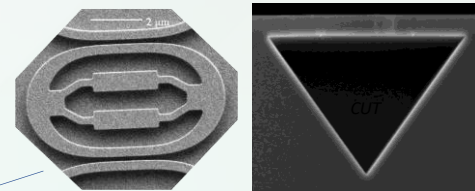
High-Speed TSV (300mm only)



High-density Si Waveguides (0.5-2dB/cm)

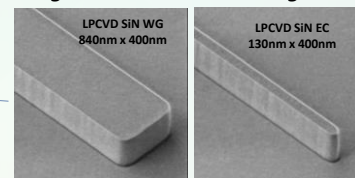


Ultra-Compact Si WDM filters (193nm immersion) with high thermal tuning efficiency

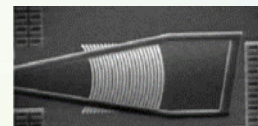


Deng et al., OFC 2024, W1A.3

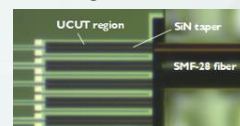
Integrated LPCVD SiN Waveguides



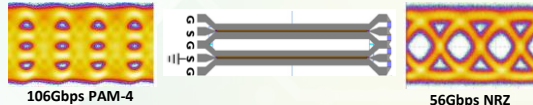
SMF Grating Coupler (<2dB)



High-NA (<2dB) & SMF Edge Couplers (~2dB)



Silicon Mach-Zehnder Modulator



iSiPP Silicon Photonics Platform

enabling next-generation 800G and 1.6T Pluggable Optics

Silicon Photonics in Hi CONNECTS Pilot Line

1 Silicon Photonic Components for Co-Packaged Optics

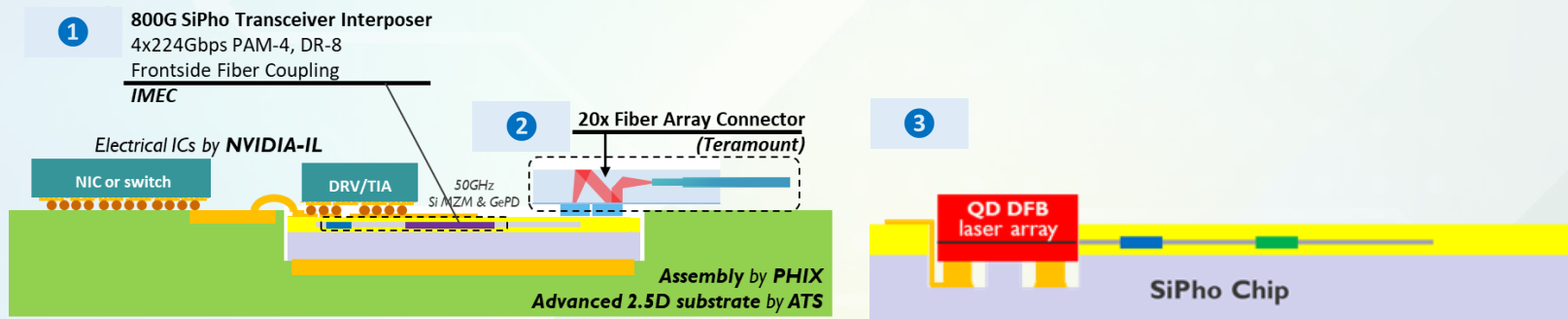
Partners: imec NOVA PROCESS INSIGHT SEMILAB E.ON Energy Research Center

2 Parallel Fiber Connectors for Co-Packaged Optics

Partners: Teramount phix imec

3 Light Sources for SiPho Co-Packaged Optics

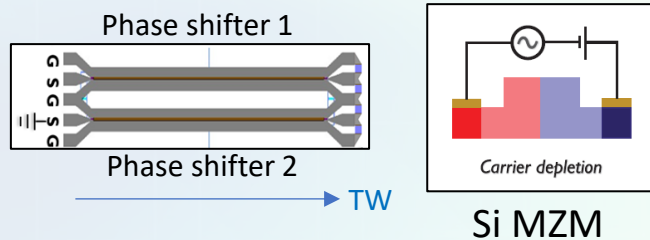
Partners: imec KLA (ICOS) innolume ASM AMICRA



High Speed Demonstration

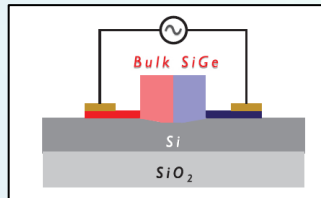
Silicon/Ge-Si optical modulator

Phase modulation



- Carrier concentration induced refractive change
- Performance quantification: $V_{\pi} * L$, Loss
- Need travelling wave (TW) design
- Challenges on impedance and group index matching

Amplitude modulation



Ge-Si FK EAM

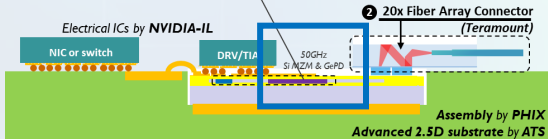
- Sub-ps response time
- Franz- Keldysh (FK) effect
- Short structure
- Performance quantification: $ER/Loss$, Loss

Abdul Rahim, Advanced Photonics, vol. 3(2), pp. 024003, 2021

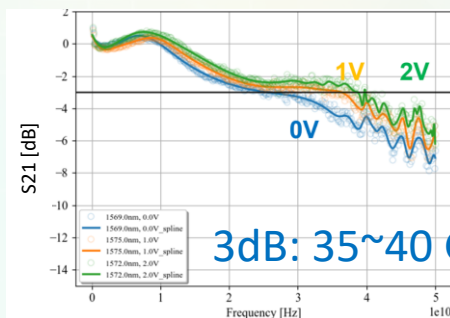
High Speed Demonstration

We are in:

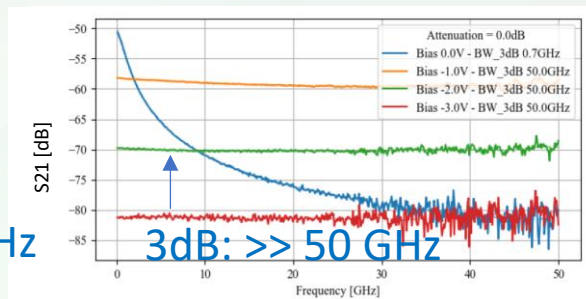
- 1 800G SiPho Transceiver Interposer
4x224Gbps PAM-4, DR-8
Frontside Fiber Coupling
IMEC



Si MZM



Ge-Si FK EAM



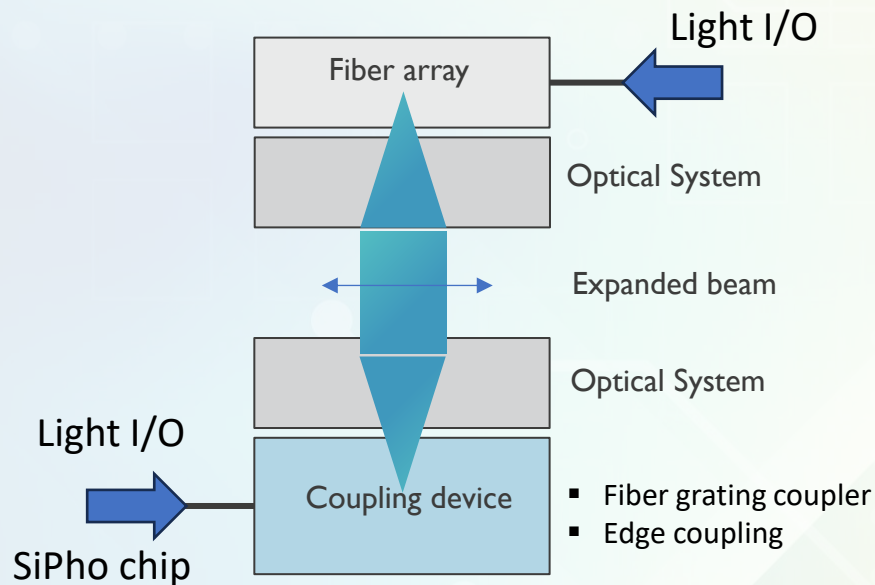
IMEC iSIPP 200/300 platform

- Si Mach-Zehnder modulators and Ge photodetectors with > 50 GHz bandwidth
- Ge-Si FK EAM exhibits wider bandwidth with smaller footprint
- Si- MZM exhibits lower loss compared to FK EAM
- With >> 50 GHz modulator bandwidth, it is possible to achieve 224 G bps for PAM4 modulation

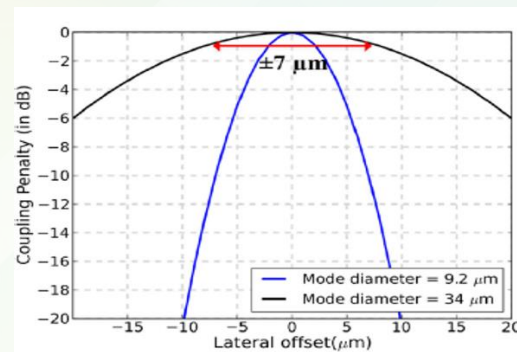
*X. Hu, OFC, Th3C.4, 2022

Fiber Array Assembly

Low-loss and high alignment tolerance interface



Alignment tolerance



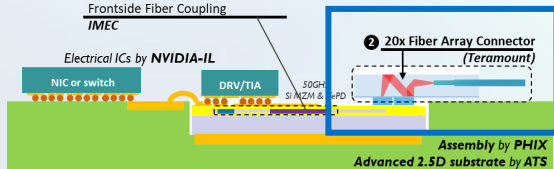
- High channel density
- Low coupling loss
- Detachable
- Passively alignment

Expanded-Beam Backside Coupling Interface for Alignment-Tolerant Packaging of Silicon Photonics (2020)

Fiber Array Assembly

We are in:

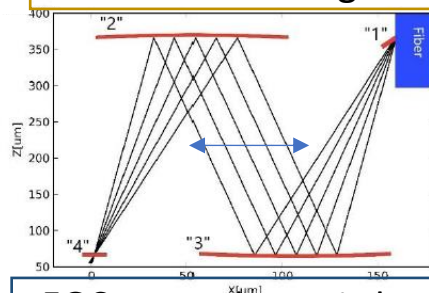
- 1 800G SiPho Transceiver Interposer
4x224Gbps PAM-4, DR-8
Frontside Fiber Coupling
IMEC



- Release large alignment tolerance by micro-optics
- Precisely passive assembly for tolerances $> \pm 20 \mu\text{m/dB}$
- 20 channel number, $250 \mu\text{m}$ pitch.

Photonic-Plug die side

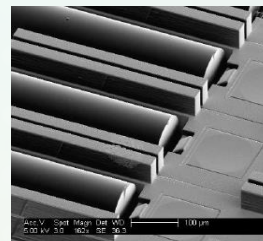
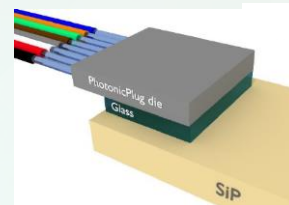
Mirror Turning mirror



FGC Photonic bump

Silicon photonics chip side

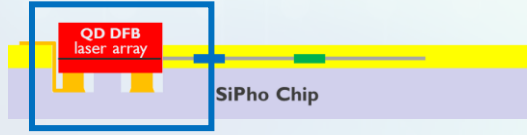
Schematic



*Photonic plug for scalable silicon photonics packaging, SPIE Proceeding, 2020

Light Source Integration

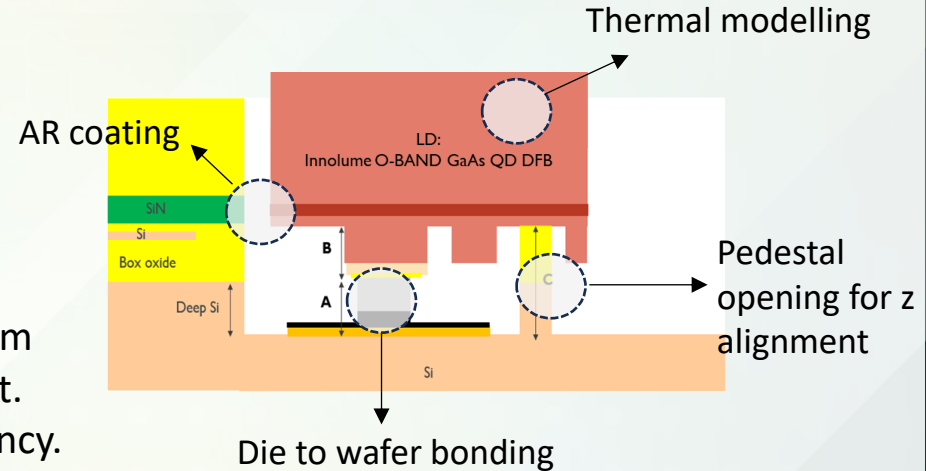
We are in:



imec KLA+ (ICOS) innolume ASM AMICRA

- Directly packaged GaAs QD DFB 8x laser arrays on SiPho passive-aligned flip-chip assembly at $< 0.3 \mu\text{m}$ precision for x, y axes and $< 0.2 \mu\text{m}$ for z alignment.
- AR coating is developed for better coupling efficiency.
- Thermal simulation is developed for laser thermal resistance control.

Structure



Summary

Silicon photonics-based pilot line targets advanced co-packaged photonics

- Build upon state-of-the-art 300mm Silicon Photonics Technology
- Co-design and Co-packaging Photonic and Electronic Components > 50 GHz Si MZM / FK Ge-Si EAM and Ge-Si detector
- High Performance Light source integration < 0.2 μm assembly precision (z axes)
- Development of scalable fiber assembly solutions with self-alignment technology
- Drive higher TRL productization ---NVIDIA Smart Networking Card and Switch

Acknowledgement

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**Co-funded by
the European Union**





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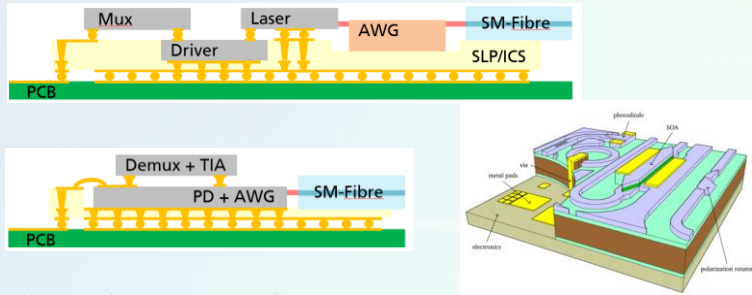
Heterogeneous Integration for
Connectivity and Sustainability

Thank you very much.

Hi CONNECTS Pilot Line

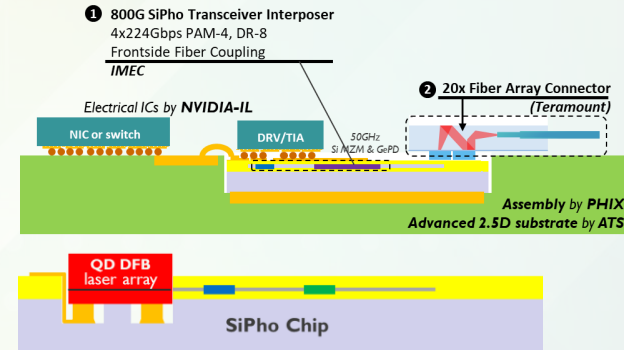
Photonic Heterogenous Integration - Pilot line

InP-based photonic components



* Link to RF Electronics HI

Si-based photonic components



NOVA

PROCESS
INSIGHT

KLA+

SEMILAB

Teramont

innolume

ASM

AMICRA

Fraunhofer

FBH
Labor
Ferdinand
Braun
Institut

ThermoFisher
SCIENTIFIC

TU/e
EINDHOVEN
UNIVERSITY OF
TECHNOLOGY

EUROPEAN
COMMISSION
2020
INSTITUTION
100

KLA+ (ICOS)

AXTRON

imec

phiX

excillum

deepXscan

HUBER
Diffraction and Positioning Equipment

BRUKER

EVG