



CONNECTS

Heterogeneous Integration for
Connectivity and Sustainability

Heterogeneous Integration of Co-Packaged Optics to navigate AI complexities

Dimitrios Velenis, Connectivity Pathfinding, IMEC

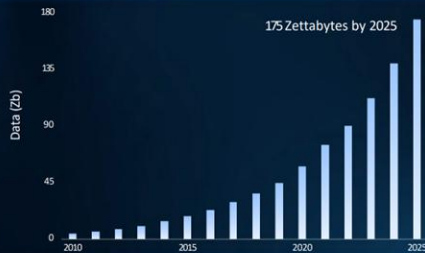
Outline

1. Optical Interconnect Landscape
2. Silicon Photonics Platform
3. Photonic Heterogeneous Integration Pilot line
4. Summary
5. Acknowledgement

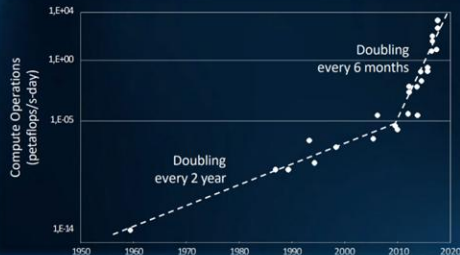


Photonics Heterogeneous Integration Pilot Line

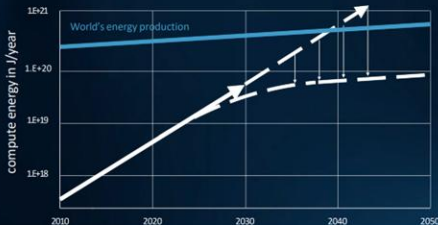
Data Traffic Explosion



Bandwidth needs for global data growth



Compute needs for AI/ML



Massive improvement needs in energy efficiency

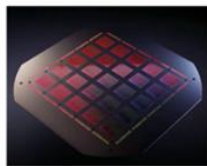
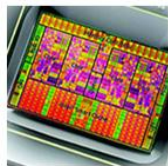
September 2024

BIG TECH'S ENERGY NEEDS

- Oracle: designing 1 gigawatt data center
- Amazon: bought nuclear-powered data center for \$650M
- Microsoft: investing \$10B+ in renewable energy capacity

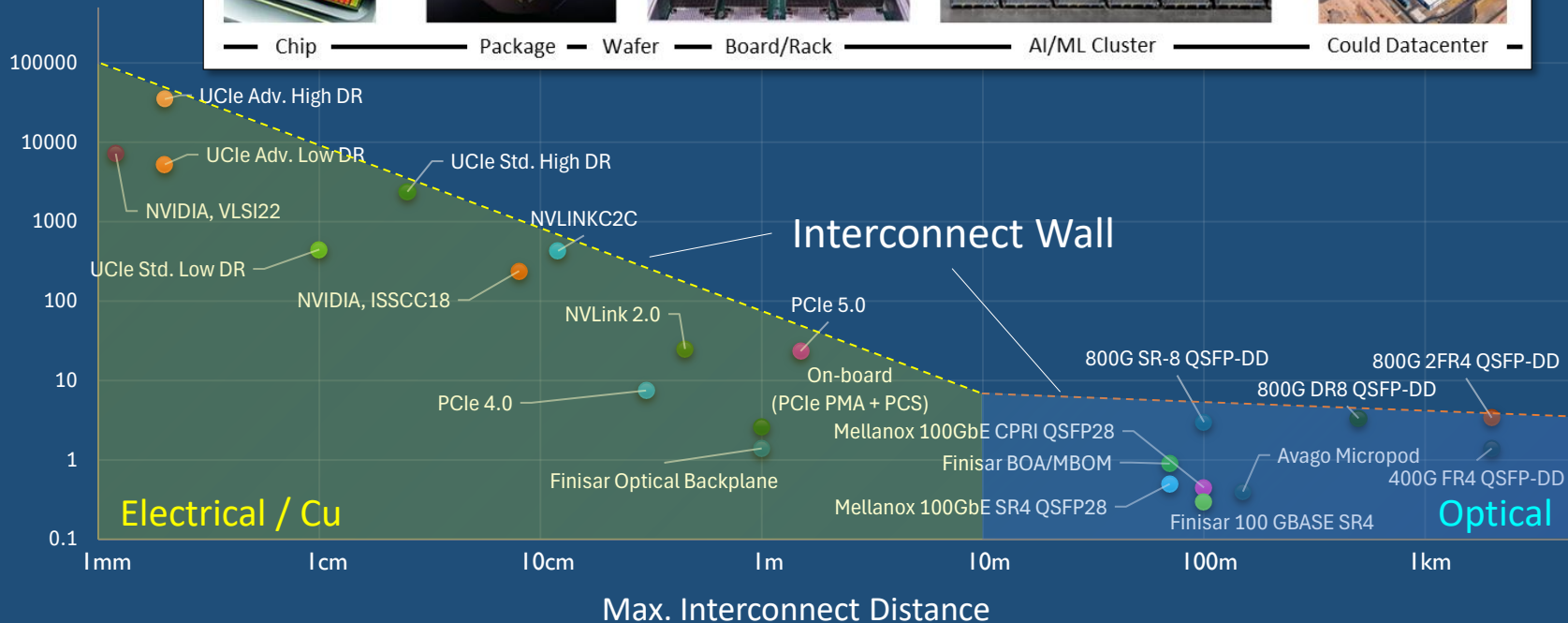


Short-Reach Interconnect Landscape



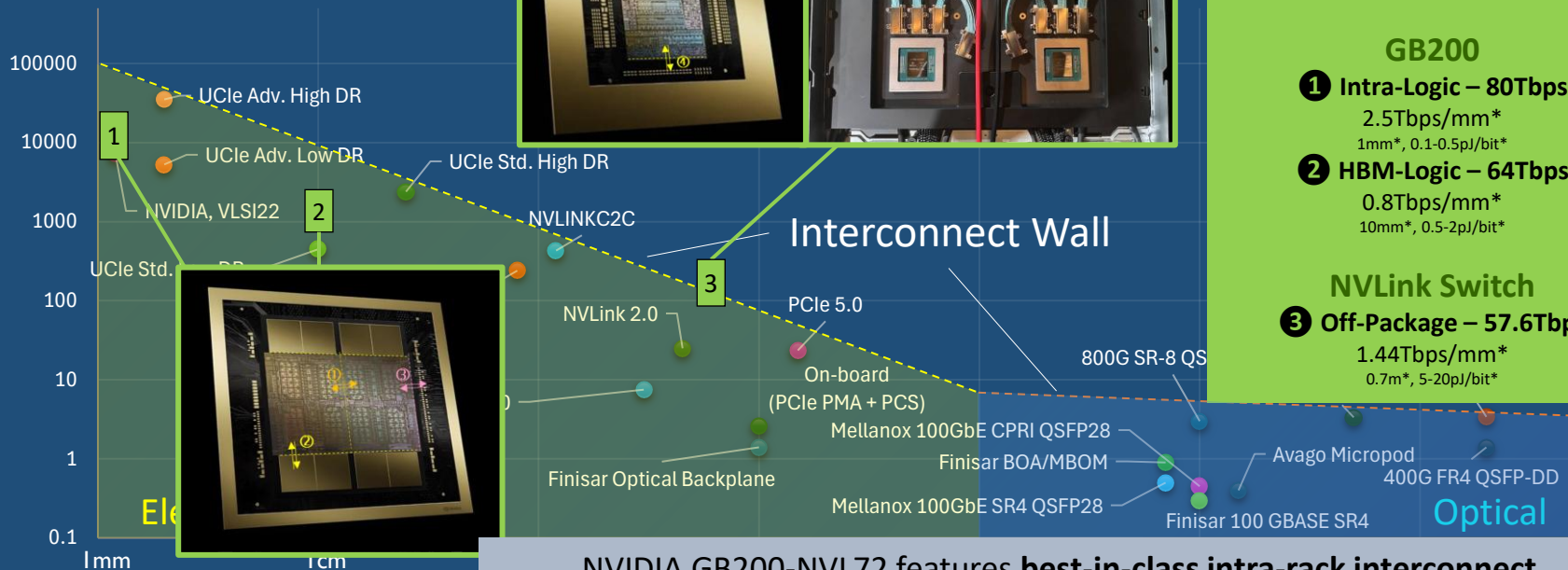
Chip Package Wafer Board/Rack AI/ML Cluster Cloud Datacenter

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



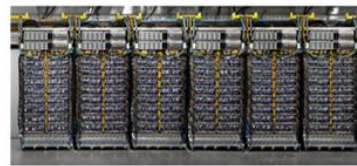
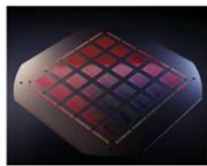
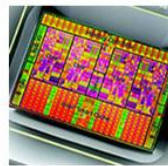
AI Hardware Benchmark: NVIDIA Blackwell GPUs

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



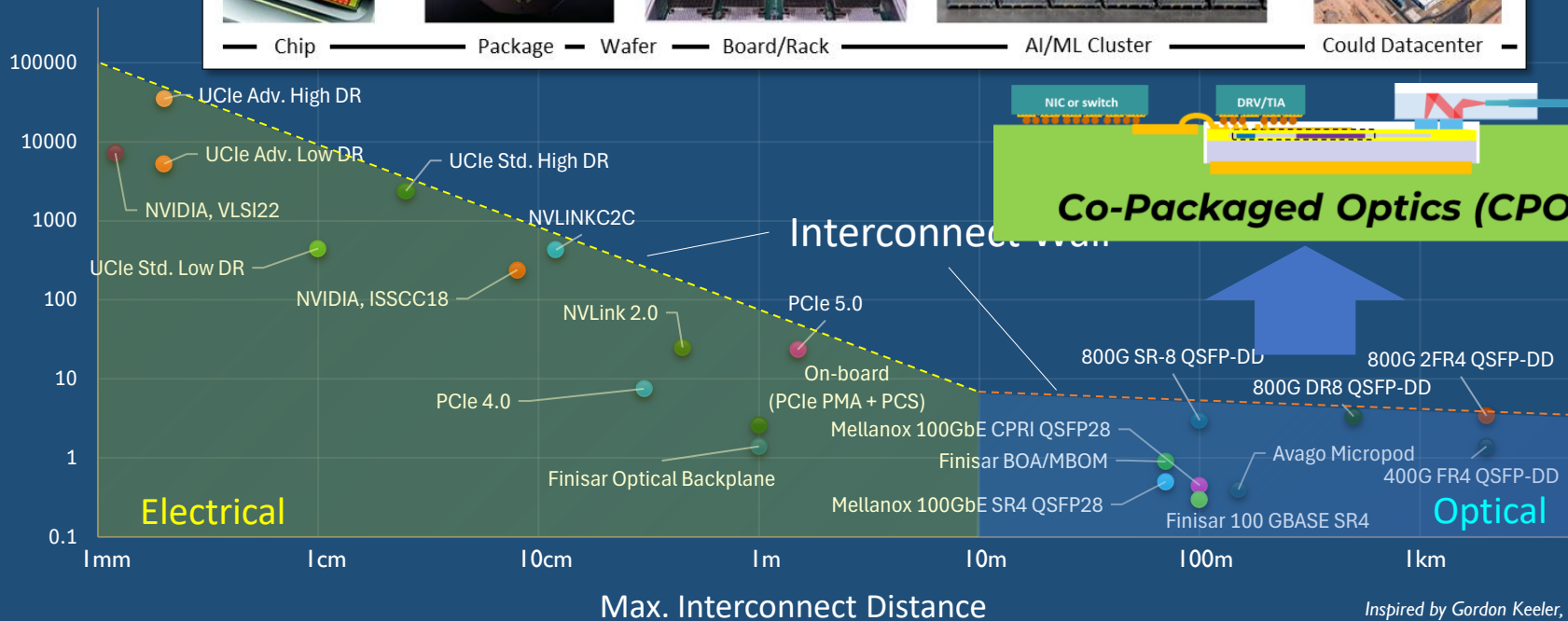
NVIDIA GB200-NVL72 features **best-in-class intra-rack interconnect** for <1m reach using **passive Cu cabling** at 200Gbps/lane

Breaking the Wall: Co-packaged Optical Interconnects



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

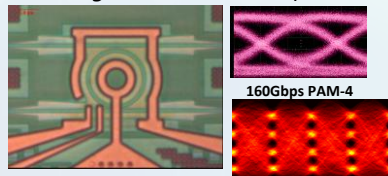
Edge BW Density * Energy Efficiency
(Gbps/mm)/(pJ/bit)



Inspired by Gordon Keeler, ex-DARPA

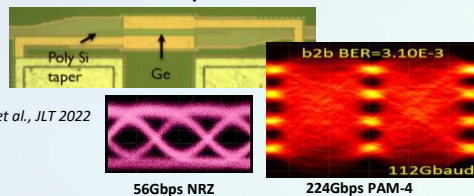
IMEC Silicon Photonics Platform

Silicon Ring Modulator



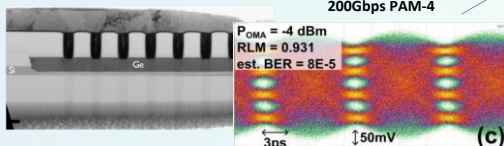
Y. Tong et al., PTL 2020

GeSi Electro-Absorption Modulator



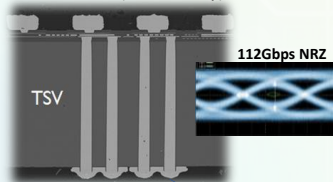
D. Chan et al., JLT 2022

Ge Photodetector



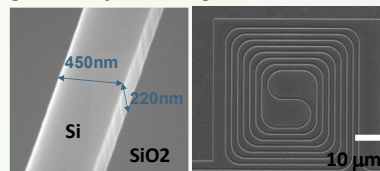
High-Speed TSV

(300mm only)



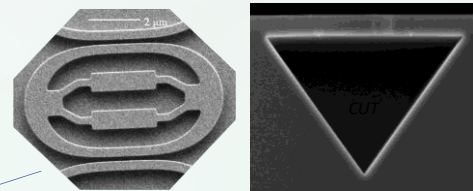
High-density Si Waveguides

(0.5-2dB/cm)



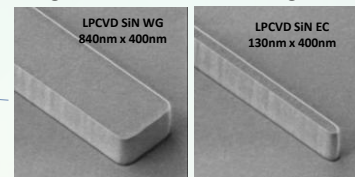
Ultra-Compact Si WDM filters

(193nm immersion)
with high thermal tuning efficiency



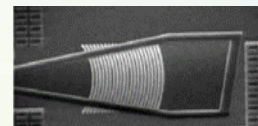
Deng et al., OFC 2024, W1A.3

Integrated LPCVD SiN Waveguides

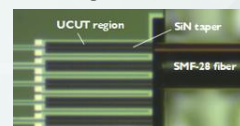


SMF Grating Coupler

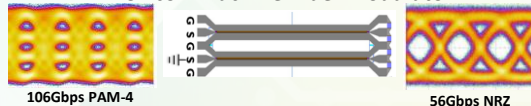
(<2dB)



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



Silicon Mach-Zehnder Modulator



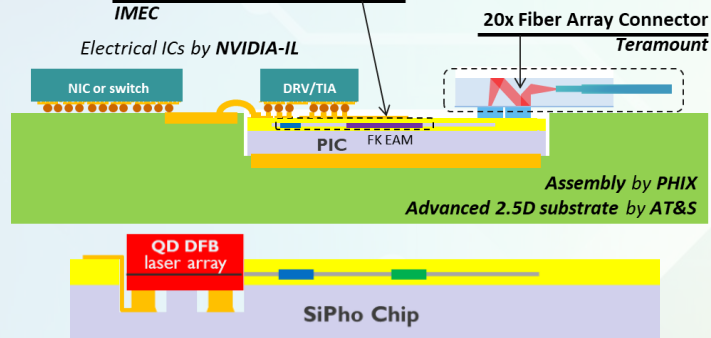
Hi-Connects is leveraging: iSiPP Silicon Photonics Platform
enabling next-generation 800G and 1.6T Pluggable Optics

Co-Packaged optics productization Heterogenous Integration Pilot line

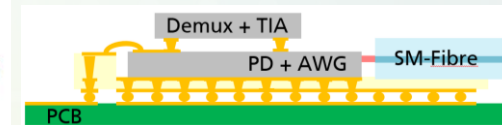
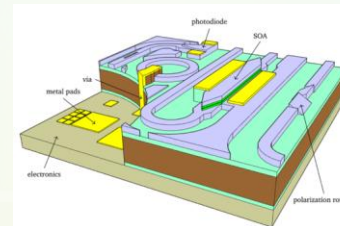
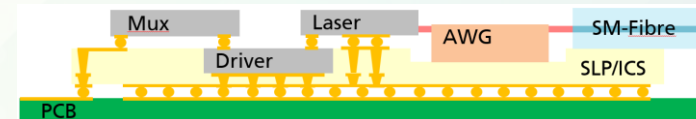


Si-based photonic solutions

1.6T SiPho Transceiver Interposer
8x224Gbps PAM-4, DR-8
Frontside Fiber Coupling
IMEC



InP-based photonic solutions



Silicon Photonics Solutions

Silicon Photonic Components for Co-Packaged Optics [CPO] ①

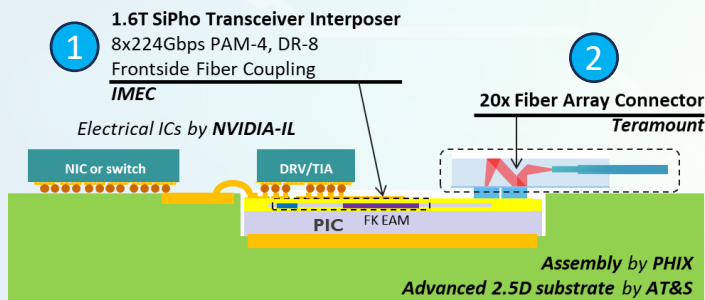
Partners: imec NOVA PROCESS INSIGHT SEMILAB EDA

Parallel Fiber Connectors for Co-Packaged Optics ②

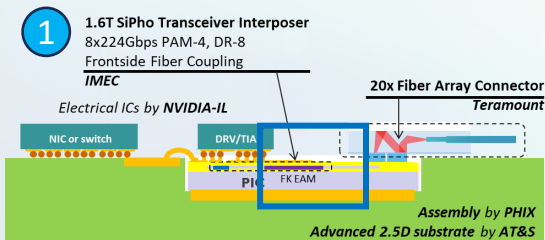
Partners: Teramount phix imec

Light Sources for SiPho Co-Packaged Optics ③

Partners: imec KLA (ICOS) innolume ASM AMICRA



High Speed CPO demonstrator

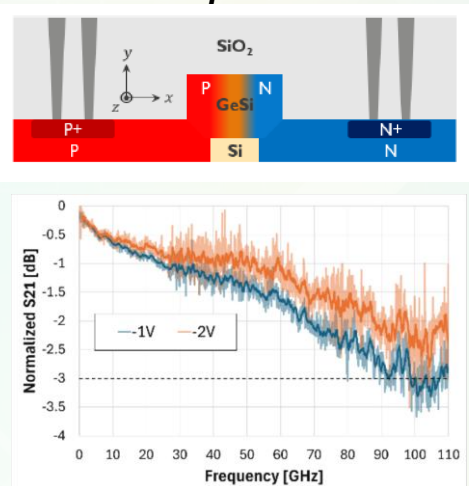


- GeSi FK EAM modulators with > 100GHz bandwidth (C-band)
- 1.6Tbps 8-channel demonstrator enabled by EIC/PIC flip-chip assembly

Transceiver Demo to pave the way towards 400Gbps per lane

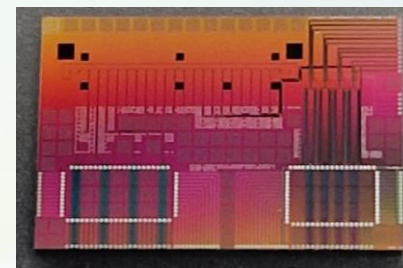
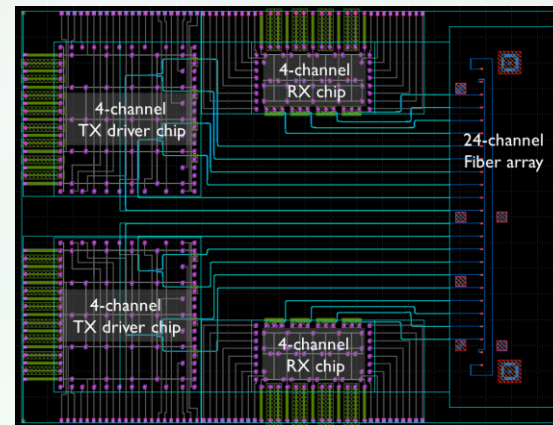
More details in following presentations by PHIX and AT&S

GeSi Frank-Keldysh ElectroAbsorption Modulator



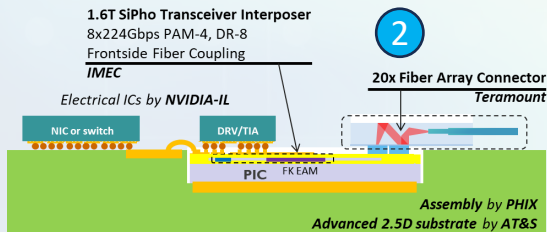
3dB bandwidth > 100GHz

Demo2: 8-channel 1.6T transceiver PIC design

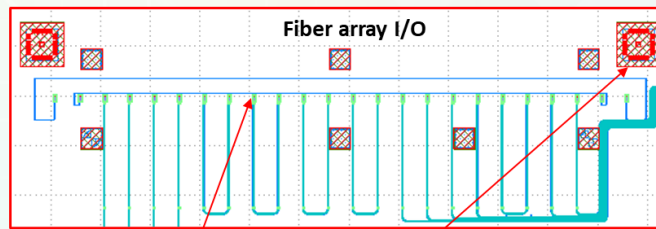


Demo1: 4-channel PIC die

Fiber Array Assembly



- 24 channels I/O ports
- Partially etch waveguide for loss reduction
- Loopback structure included
- Polarization maintaining coupling included

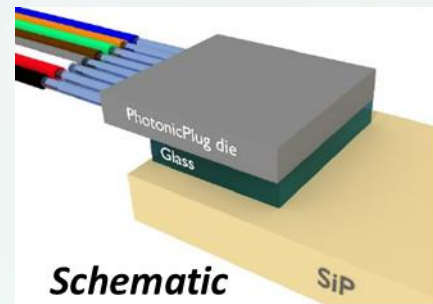
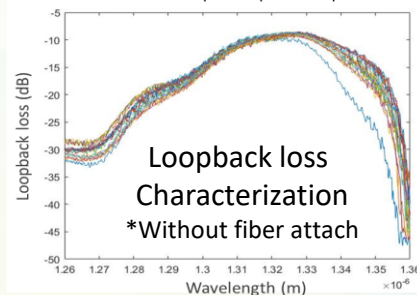


Fiber grating coupler

- Center at O band
- Low coupling loss between 2.5 ~3 dB
- Channel pitch 250 μm

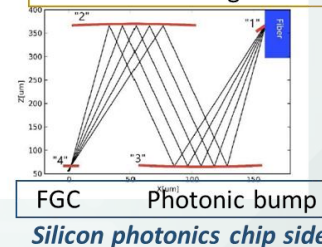
Fiducials

- Dedicated alignment marks
- 3 different shapes for process optimization



Photonic-Plug die side

Mirror Turning mirror

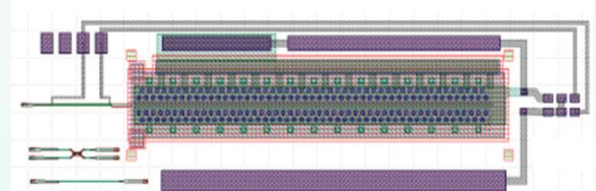


imec NOVA KLA SEMILAB TeraMount

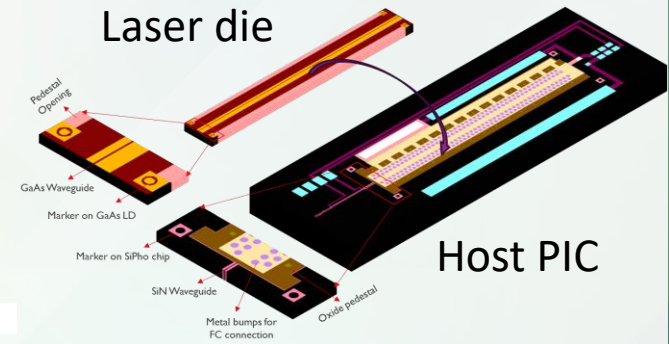
- Release large alignment tolerance by micro-optics
- Precisely passive assembly for tolerances $> \pm 20 \mu\text{m/dB}$
- 20 channel number, 250 μm pitch.

Demonstrate high-tolerances with passive fiber array alignment

Light Source Integration

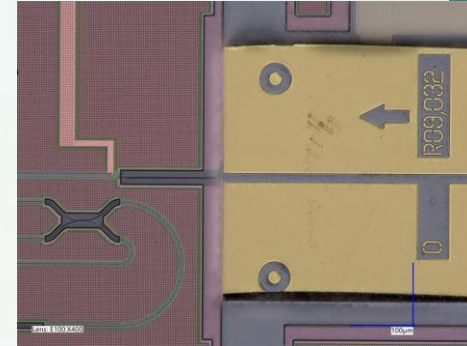
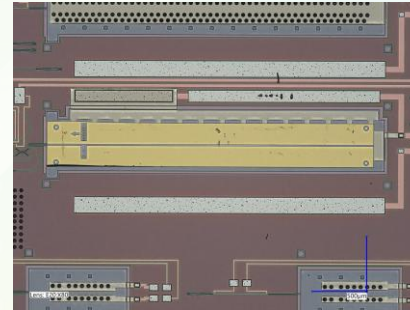


Landing site design example



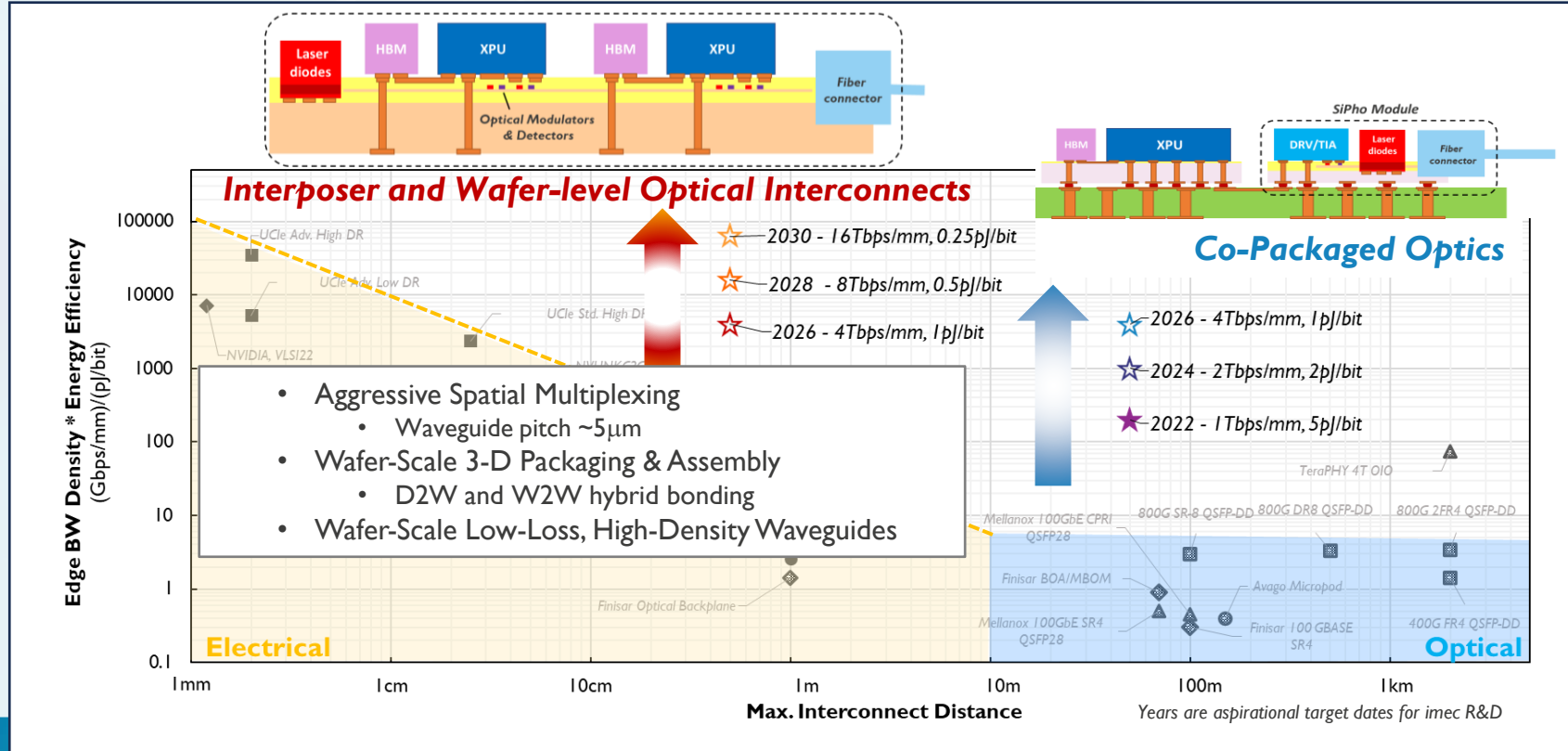
imec KLA+ (ICOS) innolume ASM AMICRA

- Directly packaged GaAs QD Distributed Feedback (DFB) 8x laser arrays on SiPho passive-aligned flip-chip assembly
- Initial results: $< 0.5 \mu\text{m}$ with first tests on X,y axis
- Initial results: $< 0.2 \mu\text{m}$ on z axis
- AR coating is developed for better coupling efficiency.



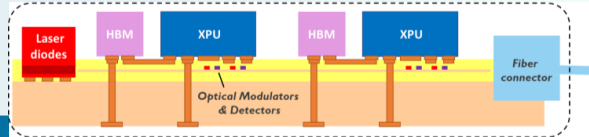
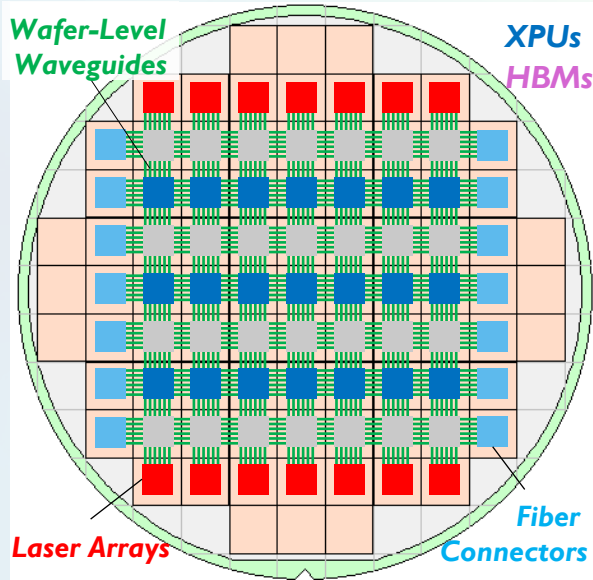
Wafer-level flip-chip integration of Quantum-dot DFB lasers

Pushing Forward: Optical Interconnects at the Interposer and Wafer level

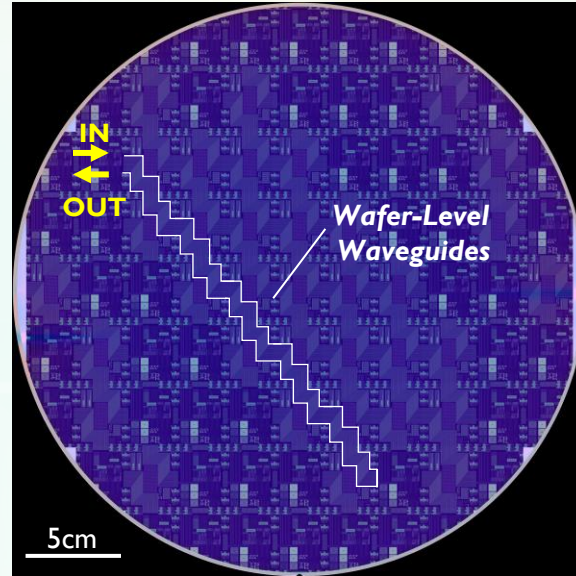


Vision: Towards Optically Interconnected Systems-on-Wafer

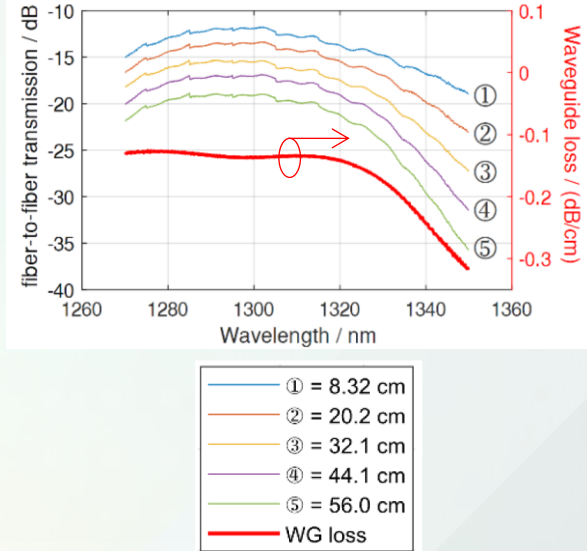
Optically Interconnected System-on-Wafer



First 300mm wafer-level reticle-stitched interconnect waveguides (imec)



Measured Wafer-level Loop-back SiN Waveguides



P. Xu et al., OFC 2024

<https://opg.optica.org/viewmedia.cfm?r=1&URI=ofc-2024-M4A.3>

300-mm wafer-level waveguides up to 56cm long,
with low all-in propagation loss (0.15dB/cm)

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 for High-Speed demonstrators.
- Development of scalable fiber assembly solutions with self-alignment technology
- High Performance Light source integration < 0.5 μm assembly precision
- Roadmap - AI applications: : Optical Interconnects are strong candidates to replace long-range Cu interconnects
 - At the Interposer and Wafer level,
 - Leveraging 3D-enabled Silicon Photonics

Acknowledgement



The project has received funding from the KDT Joint Undertaking (JU) under grant agreement No 101097296. The JU receives support from the European Union's Horizon EU research and innovation programs and Austria, Belgium, Denmark, Finland, France, Germany, Greece, Hungary, Israel, Italy, Netherlands, Romania, Sweden, Switzerland and Turkey



CONNECTS

Heterogeneous Integration for
Connectivity and Sustainability

Thank you very much.