



CONNECTS

Heterogeneous Integration for
Connectivity and Sustainability

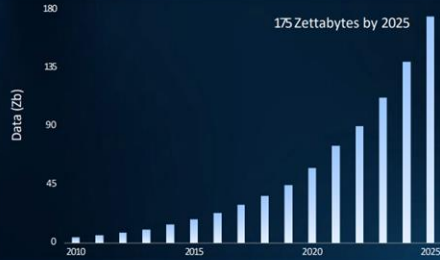
Photonics Heterogeneous Integration Pilot Line

Dr. Dimitrios Velenis - 3D and Silicon Photonics Technologies

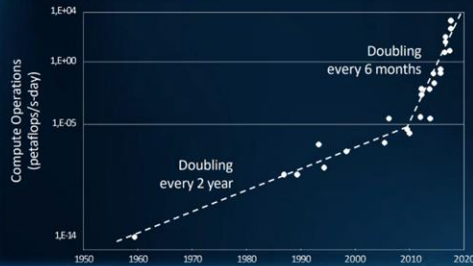
Data traffic explosion



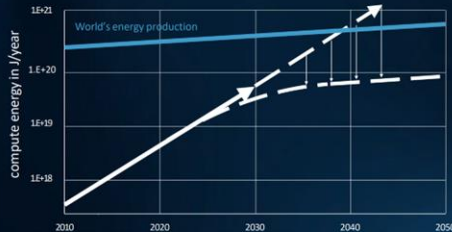
Heart of data traffic and AI queries: datacenters



Bandwidth needs for
global data growth



Compute needs for
AI/ML



Massive improvement needs
in energy efficiency



NVIDIA

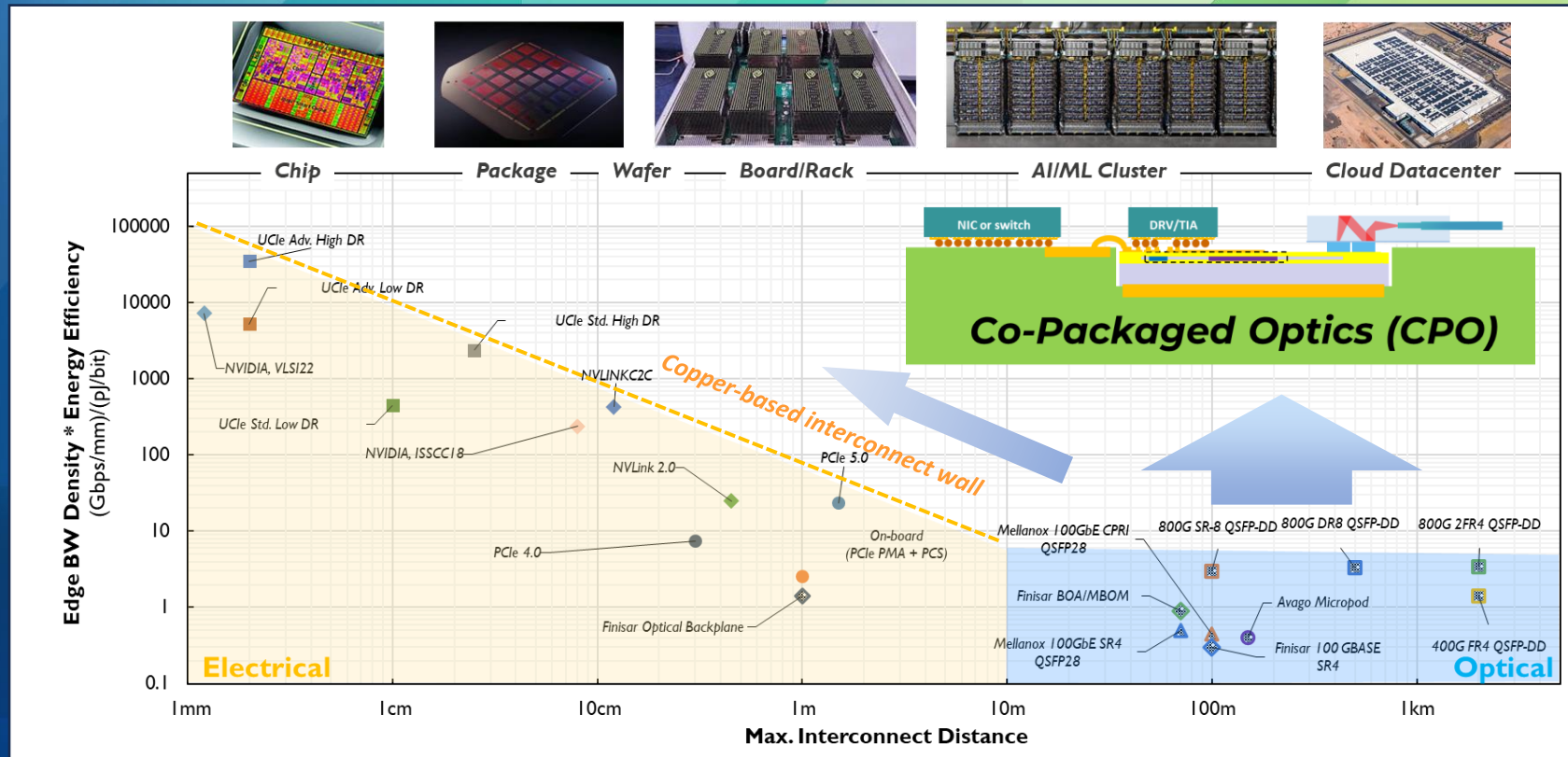
**Data Centers and
edge connectivity**

Next generation smart NIC
and switch platform (TRx)

via co-packaging
and multi-chip module (MCM)
with Si-photonics connections,
up to 70% energy per bit reduction,
and 1,6 Tbs capacity.

I/O interconnect: industry state-of-the-art

Performance figure of merit = bandwidth density x energy efficiency

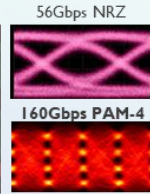


Tackling optical interconnect challenges in HiCONNECTS

- **Co-packaged Optics (CPO)**
Next generation short-reach optical interconnects
- **Heterogeneous Integration Pilot line**
Tackle requirements regarding:
 - Material compatibility
 - Heat dissipation
 - Accurate component placement
 - Cleanliness of process flows
- **Build-up of Photonic Integrated Circuit (PIC) demonstrators**
 - Smart Networking Card and Switch applications by NVIDIA

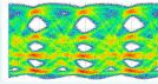
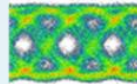
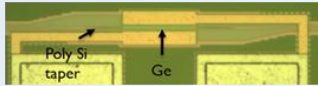
State-of-the-art silicon photonics technology platform

56-160Gbps
Silicon Ring Modulator



Y. Tong et al., PTL 2020

56-128Gbps GeSi Electro-Absorption Modulator

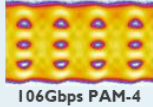


56Gbps NRZ

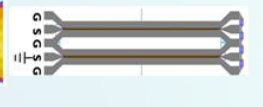
100Gb/s NRZ

128Gb/s PAM-4

56-106Gbps Silicon Mach-Zehnder Modulator

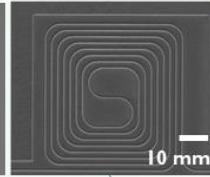
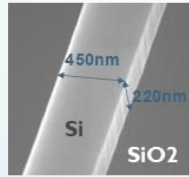


106Gbps PAM-4

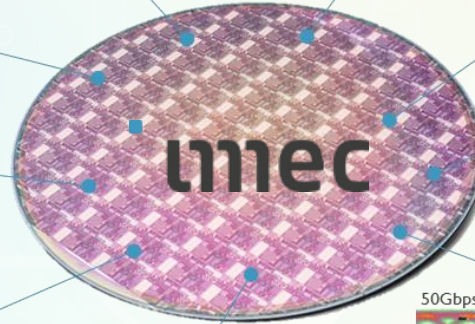
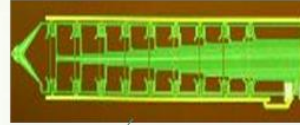


56Gbps NRZ

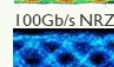
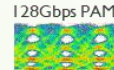
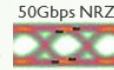
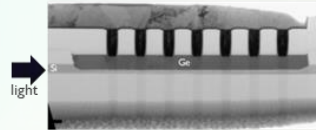
High-density Si Waveguides (0.5-2dB/cm)



Silicon WDM filters



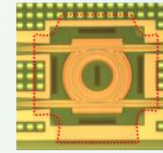
56-128Gbps Ge Photodetector



50Gbps NRZ

128Gb/s PAM-4

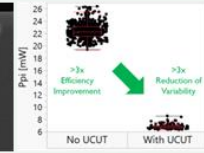
100Gb/s NRZ



Efficient thermo-optic
phase tuners

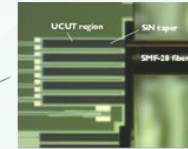


Undercut

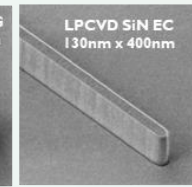
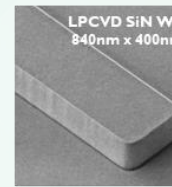


Low thermo-optic power
consumption

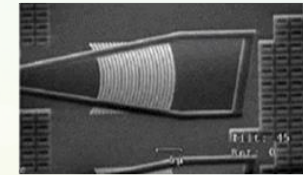
Integrated LPCVD SiN Waveguides



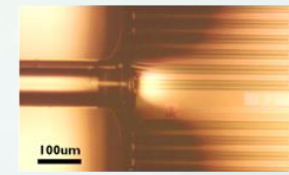
SiN Edge Coupler
9μm MFD (<3dB)



SMF Grating Coupler (<2dB)



High NA (<2dB) &
SMF Edge Couplers (<3dB)

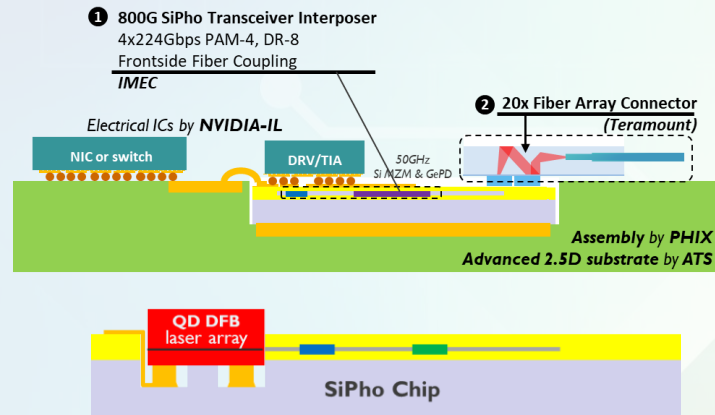


Photonics platform as key enabler for heterogeneous integration

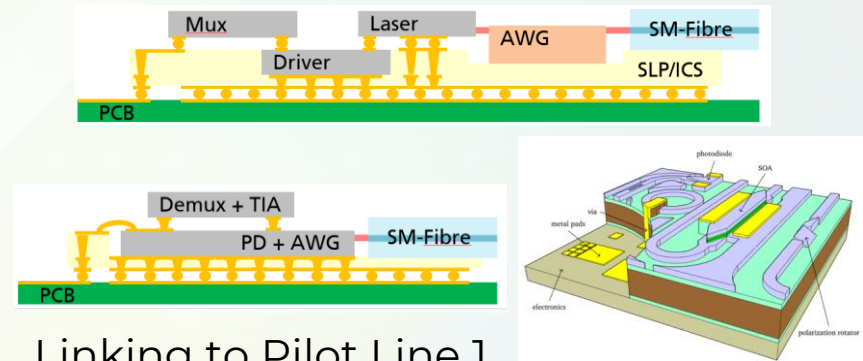
Photonic Components for Heterogenous Integration - Pilot line



Si-based photonic components



InP-based photonic components



Linking to Pilot Line 1
developments (RF Electronics HI)

Pilot line developments

Silicon Photonic Components for Co-Packaged Optics

Partners: imec NOVA⁺ PROCESS INSIGHT KLA⁺ SEMILAB

Parallel Fiber Connectors for Co-Packaged Optics

Partners: TeraMount phix imec

Light Sources for SiPho Co-Packaged Optics

Partners: imec KLA⁺ (ICOS) innolume ASM AMICRA

High-Speed Lasers for Heterogenous Integration

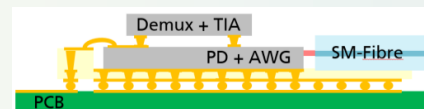
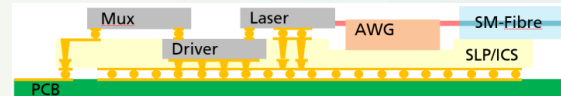
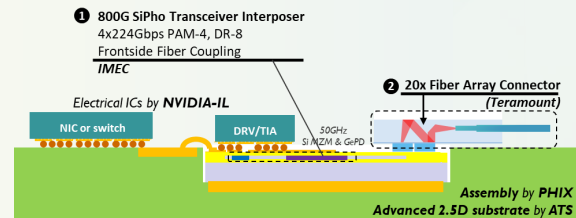
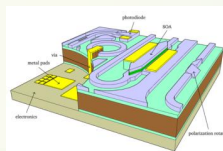
Partners: Fraunhofer FBH Leibniz Ferdinand Brauns Institut AIXTRON exillum deepX scan HUBER Diffraction and Positioning Equipment

High-Speed Photodetectors for Heterogenous Integration

Partners: Fraunhofer FBH Leibniz Ferdinand Brauns Institut AIXTRON ThermoFisher SCIENTIFIC deepX scan

IQ-MZM PIC for Heterogenous Integration

Partners: TU/e Eindhoven University of Technology AIXTRON BRUKER EVG



Silicon Photonic Components, Parallel Fiber Connectors for Co-Packaged Optics

- Development of SiPho platform with >50 GHz bandwidth
 - Driver/TIA EIC and PIC Co-design by **imec**
 - Develop inline metrology and characterization for Co-package photonic processes
- Development of scalable fiber assembly solution
 - 20-fiber connector using wafer-level processing
 - Utilize **Teramont** Photonics Plug and Photonics Bump technology
 - Assembly of Photonic Bump carrier on SiPho chip with <1μm accuracy by **phix**

NOVA PROCESS INSIGHT

KLA+

SEMILAB



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

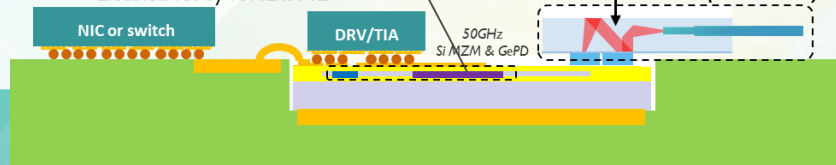
Electrical ICs by **NVIDIA-IL**

NIC or switch

DRV/TIA

50GHz
Si MZM & GePD

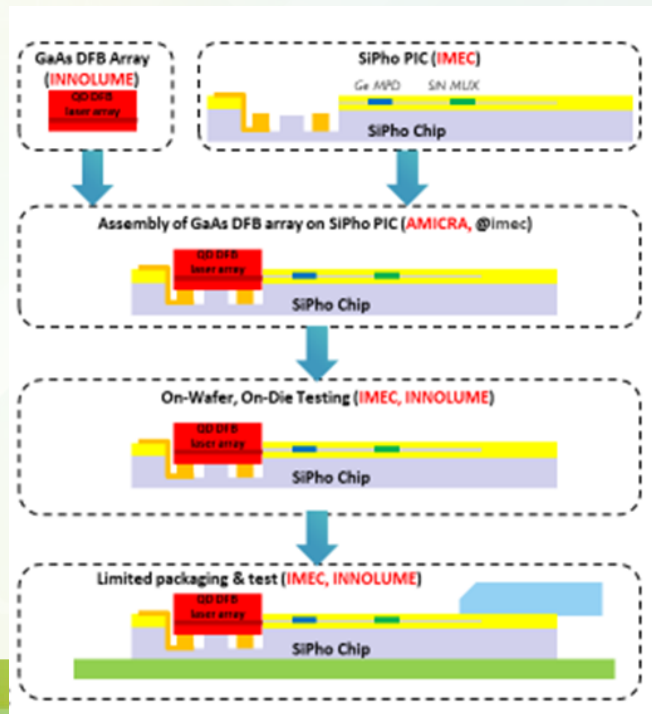
20x Fiber Array Connector
(**Teramont**)



Advanced 2.5D substrate by **ATS**
Assembly by **PHIX**

Light Sources for Si-Pho Co-Packaged Optics

- Develop innovative (remote) light sources which will act as the “optical power supply” for the CPO modules
 - SiPho chips with laser array assembly interface by **imec**
 - Design, fabricate and test innovative GaAs quantum-dot (QD) DFB laser arrays by **INNOLUME**
 - High-precision (<300nm) flip-chip assembly processes by **ASM** **AMICRA**
 - Inline metrology of laser interface by **KLΛ+** (**ICOS**)



High-Speed Lasers and Photodetectors for Heterogenous Integration

- Heterogeneous Integration of InP optoelectronics with electronics
- High speed O-band DMLs with >100GHz bandwidth for intra-datacenter interconnects
- Symbol rates: 200 Gbaud
- Collaboration of:
 - 8x WDM, 200 Gbaud PAM 4 for intra datacenter interconnects
 - Heterogenous integration of InP TIA+ demux onto the InP photodetector chip
 - Collaboration of:

Direct Modulated Laser chip

High speed electronics

Regrowth optimisation MOCVD

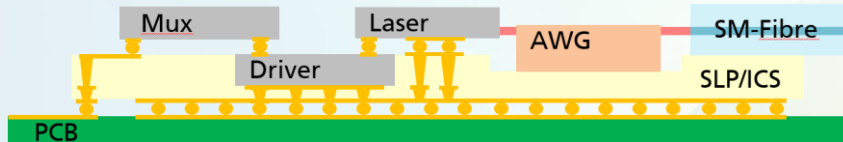
p-contact metal/semiconductor interface



AIXTRON



ThermoFisher
SCIENTIFIC



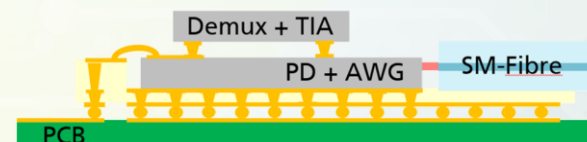
Photodetector chip

High speed electronics

Sb Growth in MOCVD

Analysis of AuSn flip chip μ bumps

TEM analysis of doping interfaces



IQ-MZM PIC for Heterogenous Integration

- Design, technology development and fabrication of IMOS MZM & DFB laser with heterogenous integrated BiCMOS driver
- InP membrane (IMOS) platform
- Mach-Zehnder modulator for coherent In-phase Quadratic (IQ) transmitter
- >50 GHz bandwidth
- Collaboration by

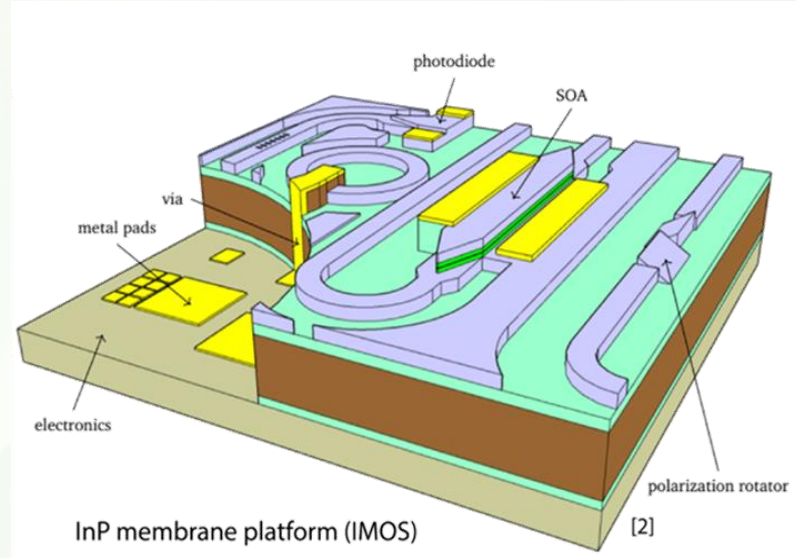
Laser-modulator chip: **TU/e** EINDHOVEN UNIVERSITY OF TECHNOLOGY

Epitaxial growth: **RIXTRON**

Epi process inspection: **BRUKER**

IMOS bonding process:

Strain measurements:



Summary

HiCONNECTS Pilot line 2 targets the Heterogeneous Integration of advanced Co-Packaged Photonics

- Build upon state-of-the-art 300mm Silicon Photonics Technology
- Co-design and Co-packaging Photonic and Electronic Components
- High Performance Light source integration
- Development of scalable fiber assembly solutions
- Enable InP Heterogeneous Integration from HiCONNECTS Pilot Line 1
- Drive higher TRL productization
 - NVIDIA Smart Networking Card and Switch

Acknowledgment



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!