EU - SOUTH KOREA – Joint Researchers Forum
on Semiconductors

Integrated Photonics: Enabling the Progression of Digital Society

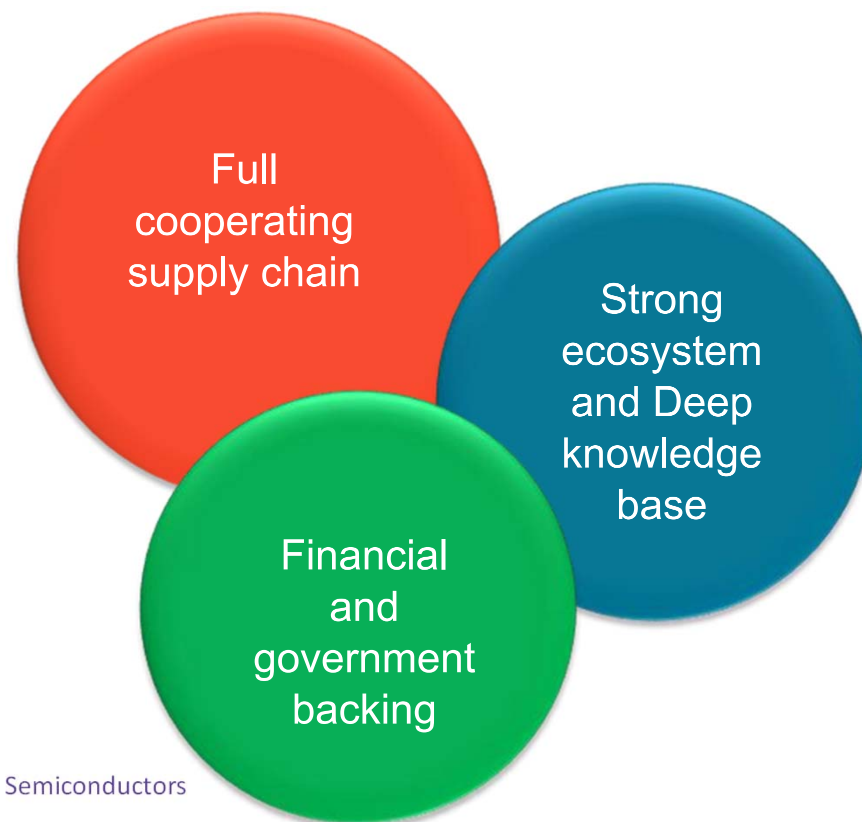
Dr. Abdul Rahim

PhotonDelta

About PhotonDelta

- A cooperating **ECOSYSTEM** of companies and R&D organizations in Integrated Photonics

- PotonDelta **ORGANIZATION** to support
  - economic and ecosystem development
  - Execution of 1.1 B€ growth fund program
  - International and EU relations
  - Market and Talent development
  - Start up support and seed investment



Current state of PhotonDelta ecosystem

1. Design

LioniX International
Bright Photonics
epiphany

Tech partners

SYNOPSIS

2. Fabrication

LioniX International
Smart Photonics
NEW ORIGIN
ALUVIA

Tech partners

ASML
AIXTRON

3. Packaging

phix
PHOTONFIRST

Tech partners

CITC
ETTEPLAN
TYNDALL
SALLAND
IMS
MICROALIGN
AIXSCALE

4. Applications

Data & Telecom

EFFECT PHOTONICS
AIRCISION
astrape
Pilot
Signify

Medical

DELTA DIAGNOSTICS
SURFIX
Nostics
EFI
AMAZEC PHOTONICS
Scinvivo
VitalWear

Sensing

SCANTINEL PHOTONICS
MEMSCAN
Tarucca
FUQON
SENERGETICS
NXP
PHOTONFIRST
DEMCON
SENSING360
Neuruno
Spectrik
MantiSpectra
OMMATIDIA
Deloq
VTEC LASERS & SENSORS

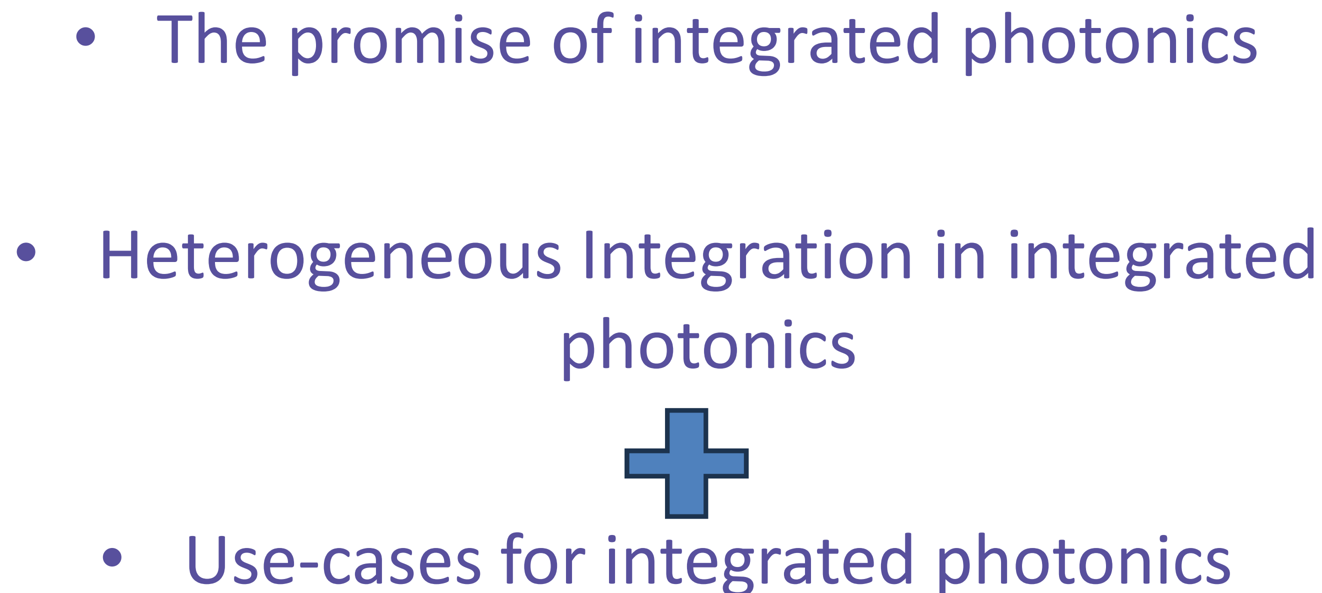
Quantum

QUIX
CUbIQ
amPICo

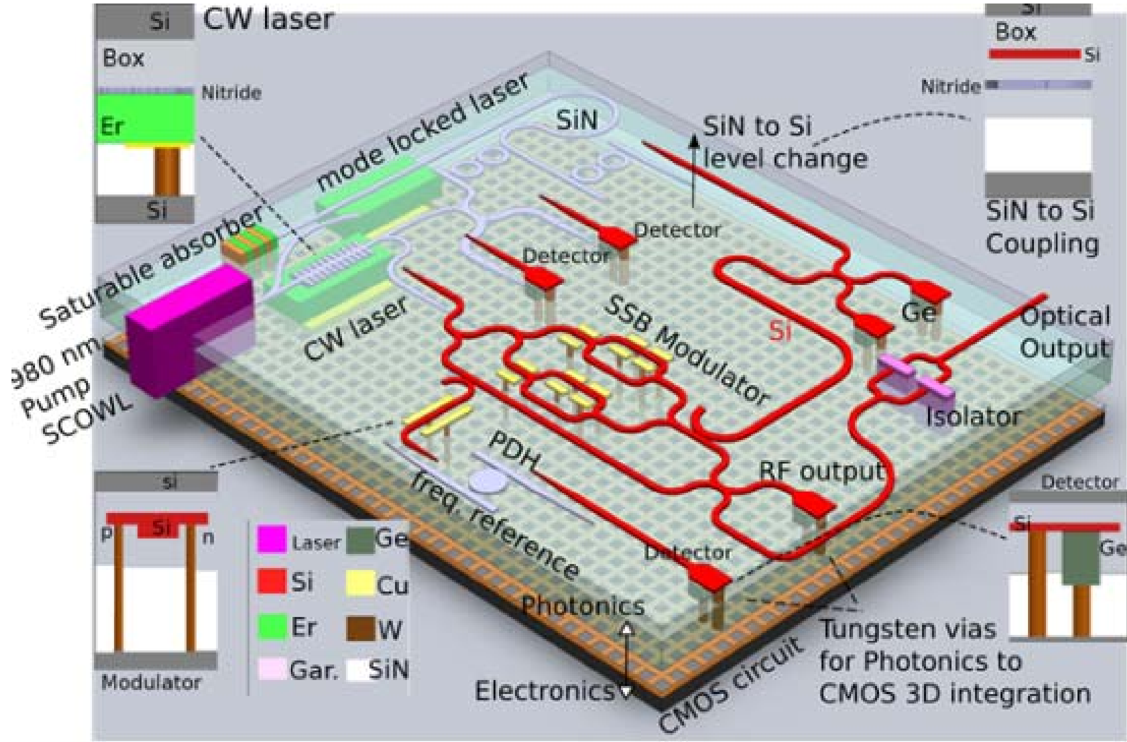
Tech partners

HIGH TECH XL
NTS OPTEL
CHILAS
SUPERLIGHT

Outline



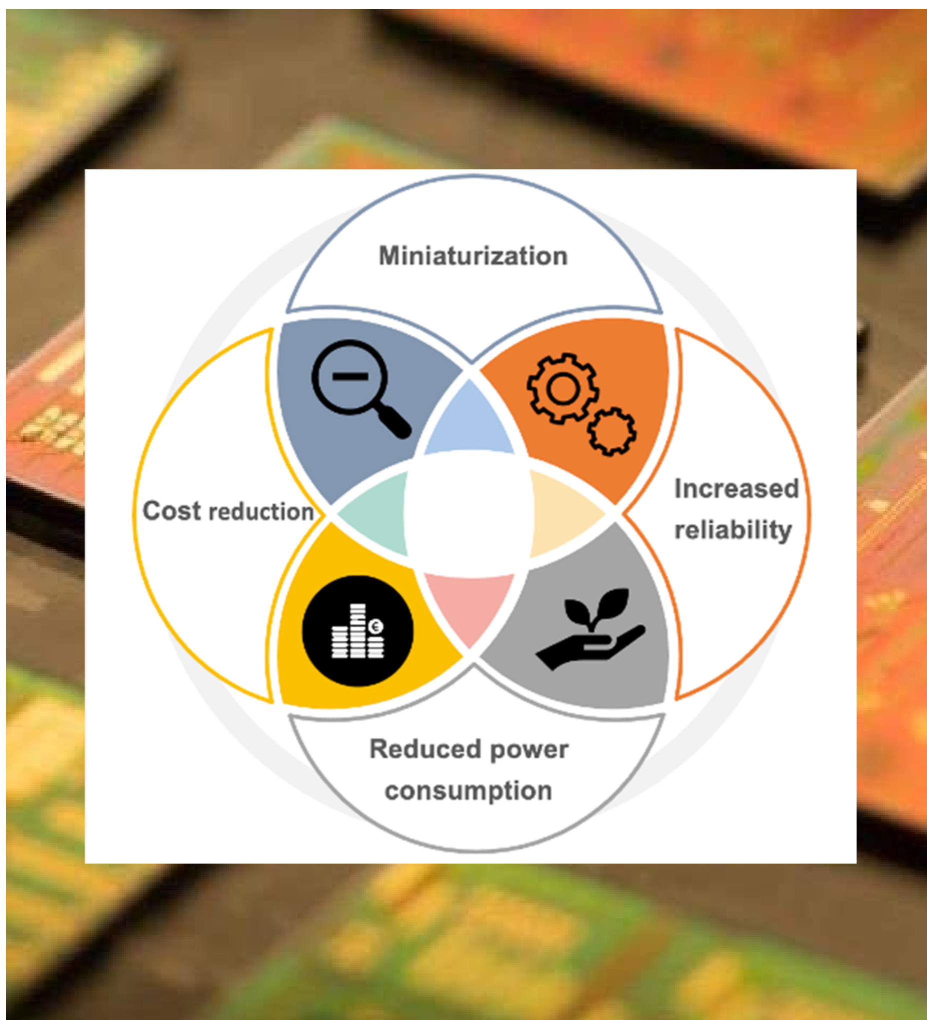
Photonic Integration: the vision



Laser Doppler Vibrometer for
Cardiac Health Monitoring

Photonic integration provides a route to commoditize photonics at larger volumes and lower costs

The promise of photonic integration



- Photonic integration enables complex optical functions to be delivered on a single chip
- Photonic Integrated Circuits (PIC) can be fabricated by leveraging existing microelectronics infrastructure
- This enables a new level of functionality and disruptive market models to address global challenges

European Commission

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Integrated photonics can revolutionize markets

Datacom	Quantum/AI	Mobility	Healthcare	Agrifood

Grand Challenges

Datacom	Quantum/AI	Mobility	Healthcare	Agrifood
Digitization of Society Exponential growth data usage	Secure communication Digitization of society	Autonomous driving Electric vehicles	Point-of-care Aging population	Sustainable farming Climate change Precision agriculture

in the same way semiconductors did, disruptive solutions for volume markets.
Addressing global challenges

Status of the mainstream PIC techs.

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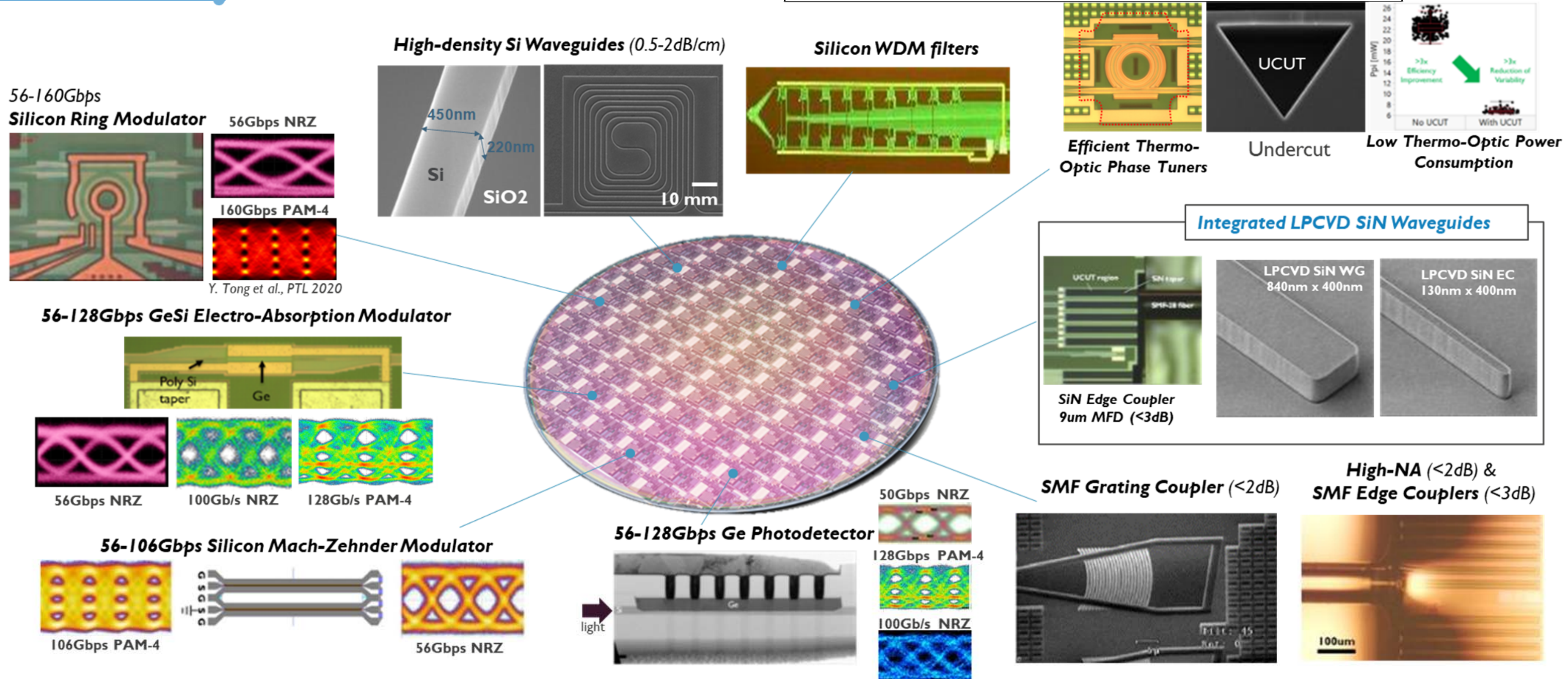
Silicon Photonics Technology



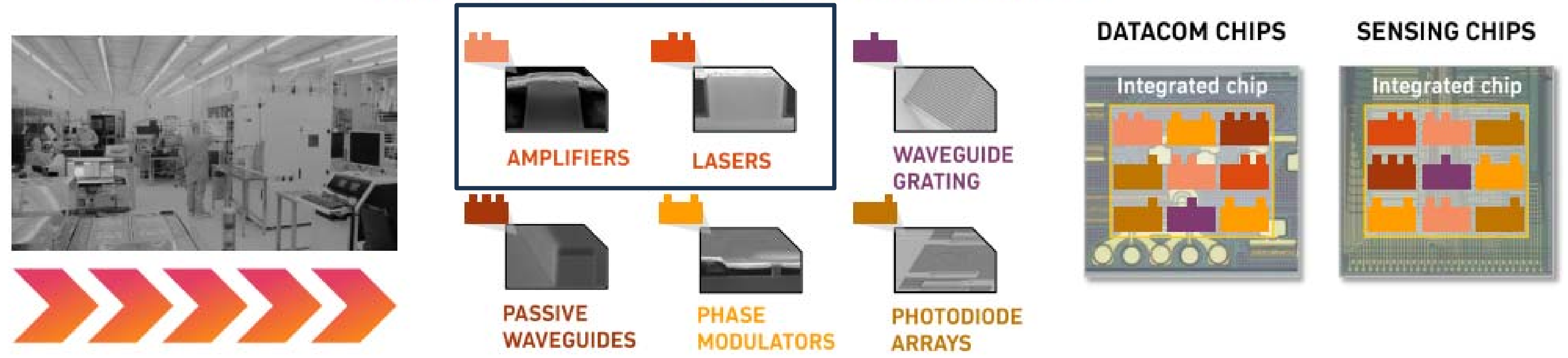
Fully Integrated Silicon Photonics Platform for 1310nm/1550nm Wavelengths

- Low-loss Passive Silicon Waveguide Devices and Fiber Coupling Structures
- 56Gb/s+ (Ge)Si Modulators and Ge(Si) Photodetectors

Status of the mainstream PIC techs.

Indium Photonics Technology

KEY ELEMENTS: PROCESS KNOW-HOW AND PROCESS DESIGN KIT (PDK)



50+ Proprietary building blocks

10+ Years of refining PDK

20+ Issued and pending patent families

PDKS HELP OUR CUSTOMERS:

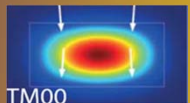
- Customize designs
- Leverage experience
- Reduce time to market
- Leverage infrastructure

SMART PHOTONICS

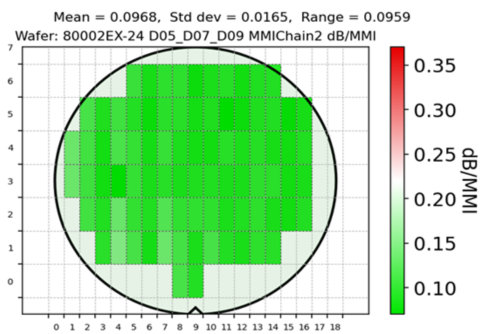
Status of the mainstream PIC techs.

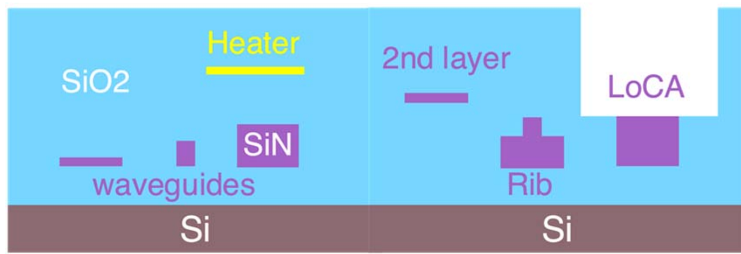
Silicon nitride technology

The Basics



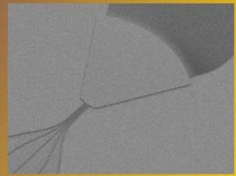
- ✔ High Mode Confinement
- ✔ Low Loss (< 0.1dB/cm)
- ✔ Small Footprint (50µm bend)
- ✔ High Power (>10W)
- ✔ nonlinear dispersion engineering





Full Creativity (PDK)

- ✔ Couplers
- ✔ Mux / DeMux
- ✔ MZIs / DLIs
- ✔ Resonators
- ✔ **Polarization control**

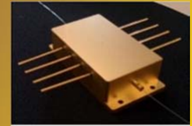


Actives

- ✔ Electrical Tuning
- ✔ Modulators (hybrid)
- ✔ Lasers (hybrid)
- ✔ Detectors (hybrid)

World Connections

- ✔ Edge / Grating Coupler
- ✔ Spot Size Converter
- ✔ Arbitrary Die Shape
- ✔ Bond pads
- ✔ Cladding opening for sensing



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PhotonixFAB: A value chain incorporating mainstream PIC technologies

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VALUE CHAIN

- Photonic design/EDA: LUCEDA
- PIC foundry and testing: xfab, LIGENTEC
- Heterogeneous integration: xfab
  - Active material III-V chiplets
- Packaging & testing: phix
- Systems and applications: NOKIA, NVIDIA, aryballe, BROLIS, PHOTONFIRST

R&D support: cea, imec

PIC Technologies to build optimal solution

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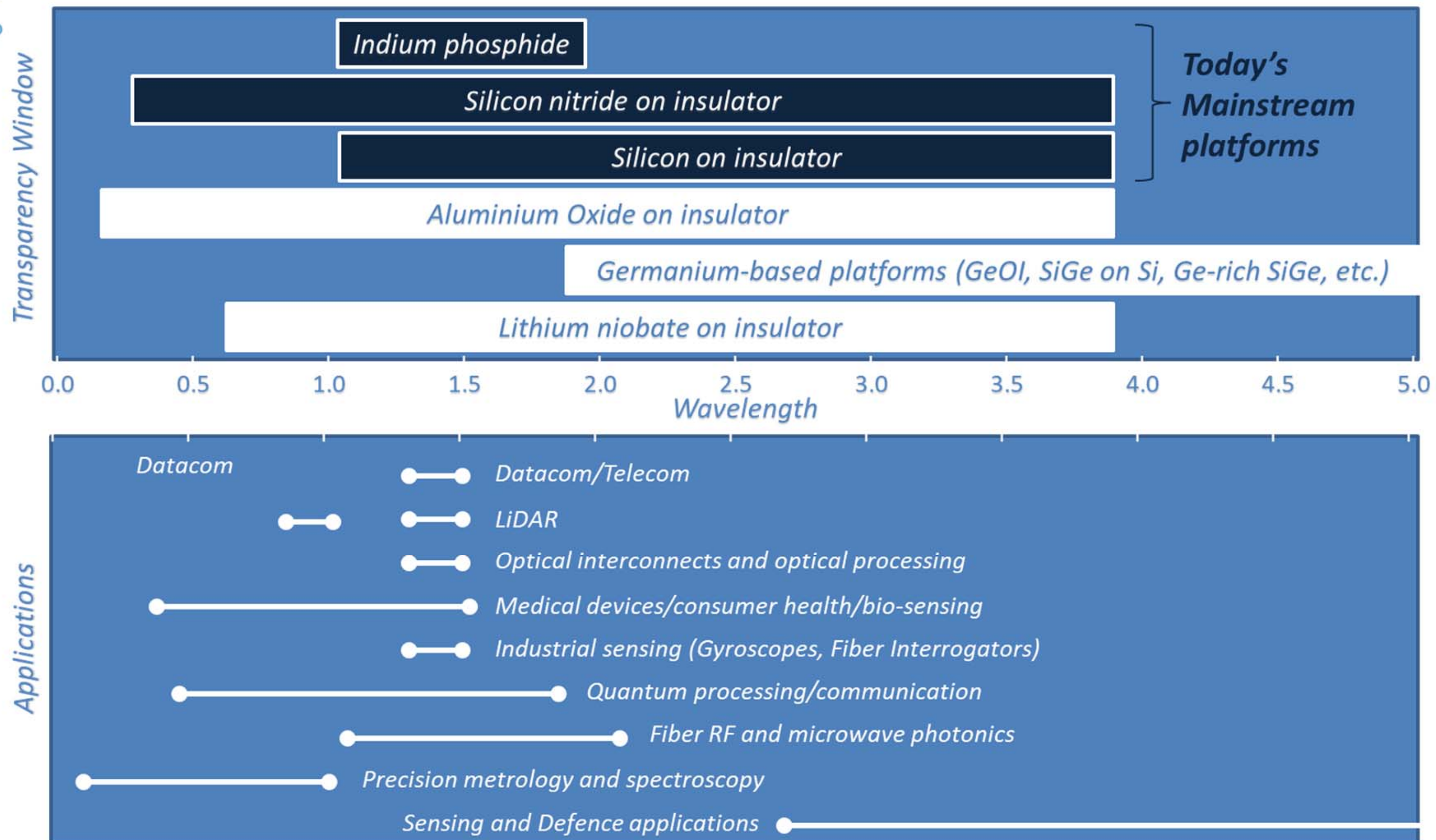
Not exhaustive



There is no one-shoe fit-all technology. Heterogeneous integration or advanced packaging is necessary to build an optimal solution

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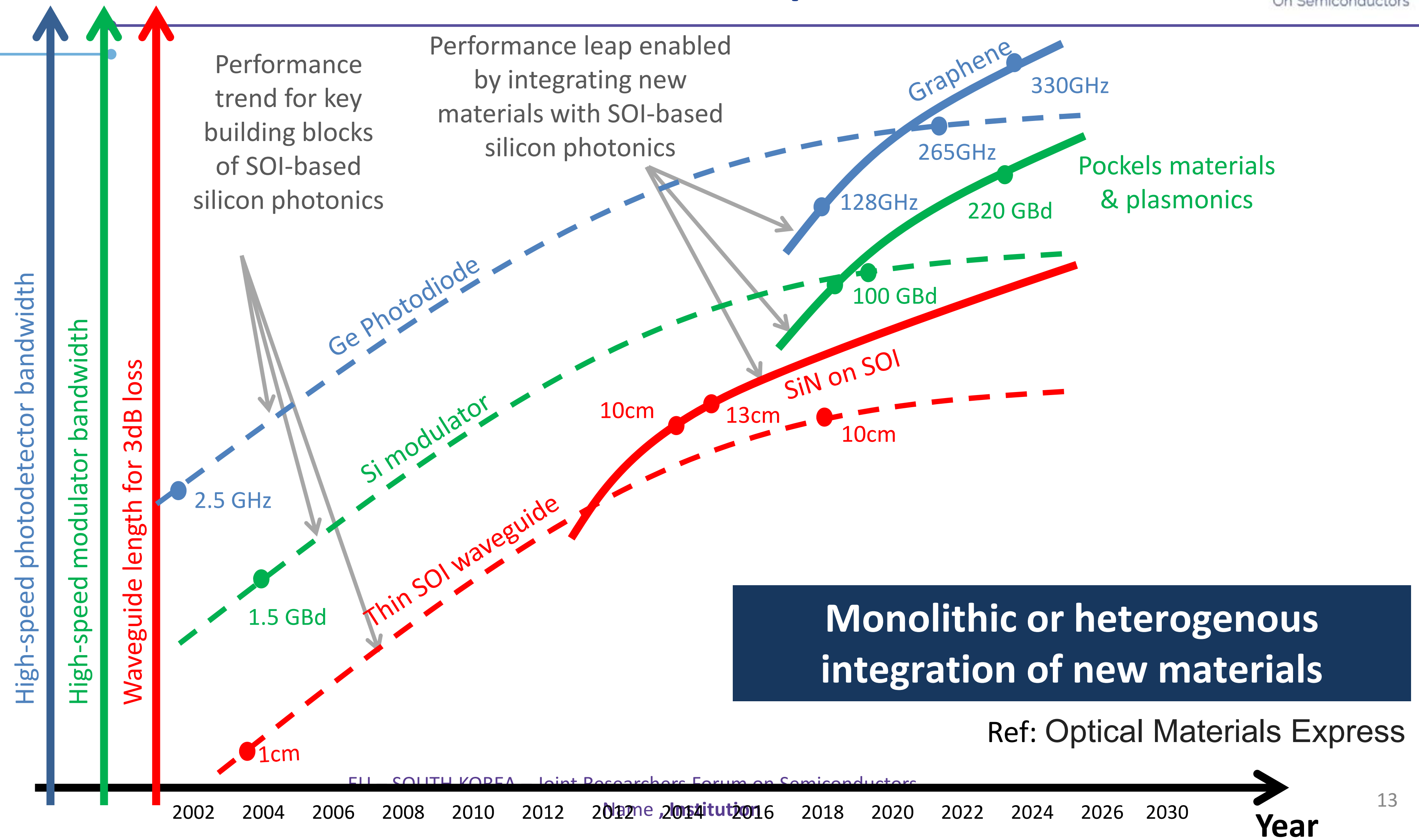
Performance leap for PICs

The case of Silicon photonics



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Heterogenous Integration in PICs

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LaMP

- ✓ Use mature III-V technology
- ✓ Wafer level test on source
- ✓ Known good die
- — Fairly efficient optical coupling
- — No waveguide-in / waveguide-
- — Sequential population of SiPhw
- — Can be integrated on back-end

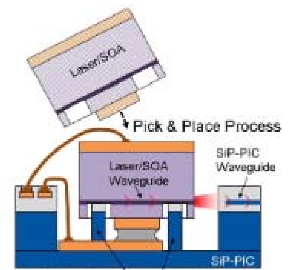
Flip-chip Integration

ng

hwafer

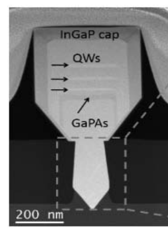
fficult

oval



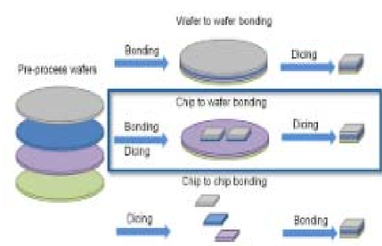
III-V integration using hetero-epitaxy

- ✓ Front end monolithic integration
- ✓ Efficient evanescent coupling
- — Develop completely new process flow
- — Demonstrate yield and reliability



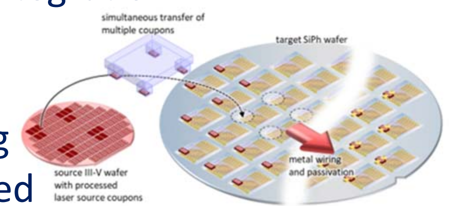
Die-to-wafer bonding

- ✓ Efficient optical coupling
- ✓ Waveguide in-out devices
- ✓ Parallel processing of devices
- ✓ Wafer-level test on target wafer
- — III-V processing on target wafer
- — No known good III-V die
- — Front-end / back-end NRE



Micro-transfer printing

- ✓ III-V process & test prior to integration
- ✓ Back-end integration
- ✓ High throughput integration
- ✓ Efficient evanescent coupling
- — Supply chain being established
- — To demonstrate yield and reliability



Established heterogenous integration tech.

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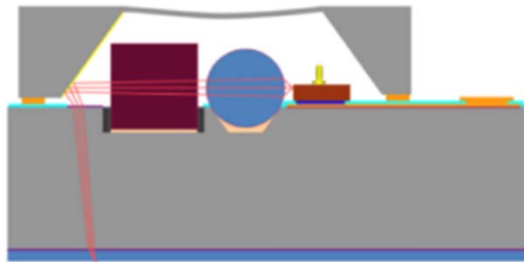
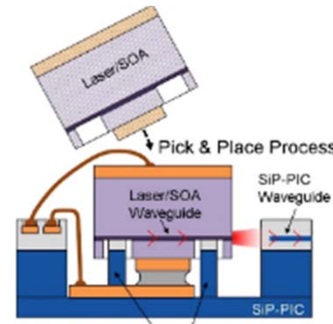
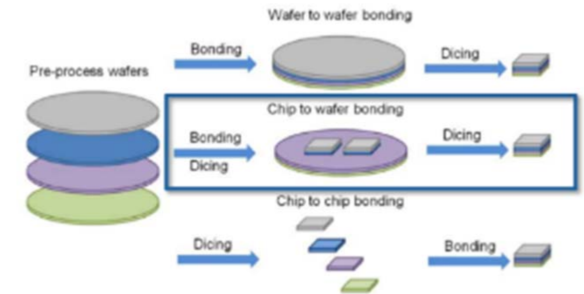
Laser Micro-Package (LaMP) | **Flip-chip integration (FC)** | **Die-to-wafer bonding (D2W)**





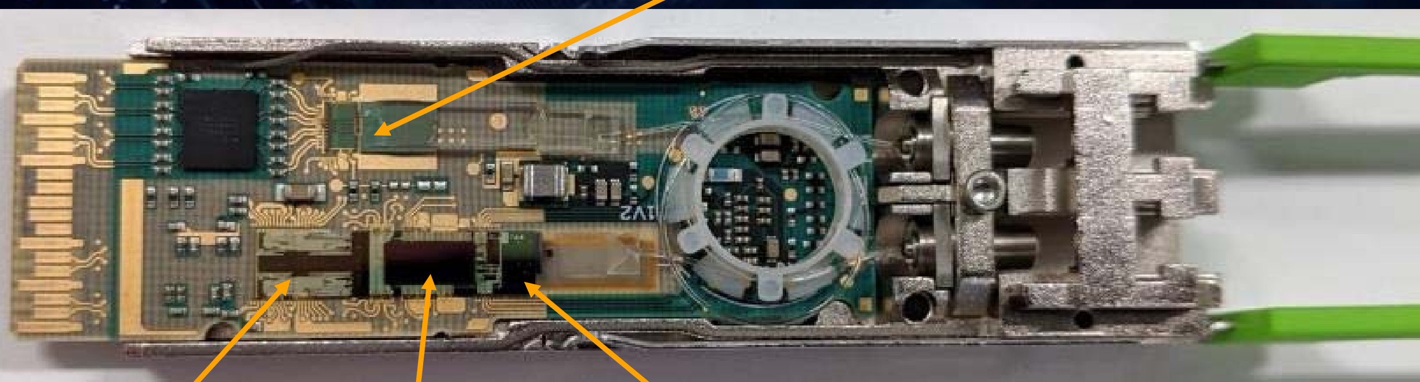


Tech Performance Scores Max score = 5	Technology / Criteria	Versatility	III-V tech	TF tech	KGD	throughput	SiPhot flow modification	Coupling efficiency	TRL
	Laser micro-package	1	5	1	5	1	5	3	5
	Flip-chip integration	2	5	1	5	3	4	4	4
	(Die-to-) wafer bonding	3	3	3	1	5	2	5	4
	Micro-transfer printing	5	4	5	4	5	4	5	3

Credit: Roel Baets

Silicon photonics HIGH VOLUME Transceivers

CWMD4 with NO Hermetic packaging, key Functions integrated



- Transmitter chip integrates 4 lasers, 4 modulators, optical multiplexer on a single die
- Receive path is a separate chip with 4 high speed photodiodes
- Data center operation or industrial temperature range (-40°C to 85°C)

R. Blum et al, Photonics West 2020

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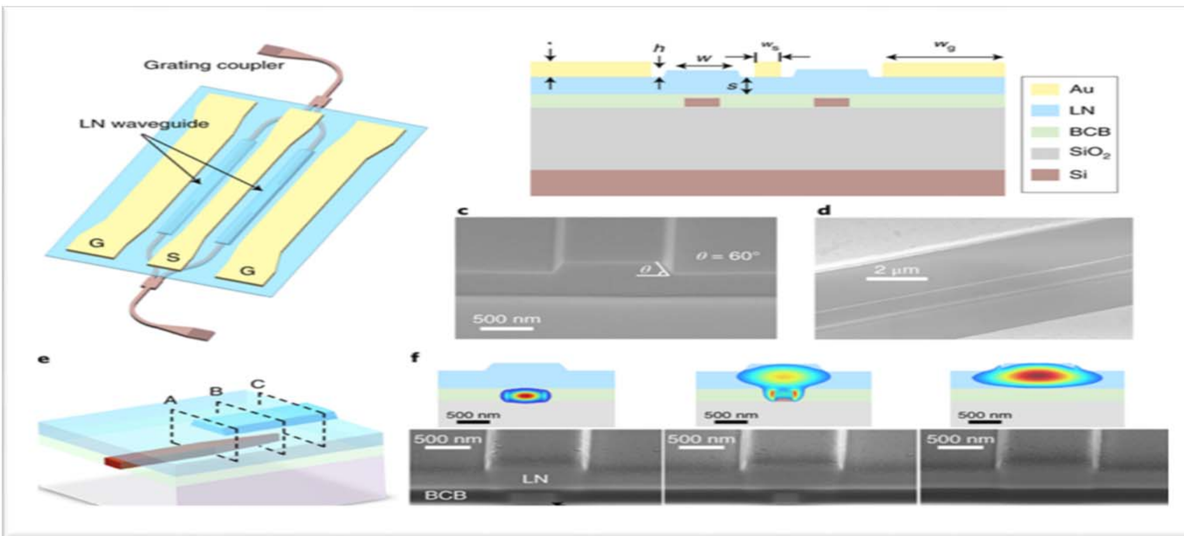
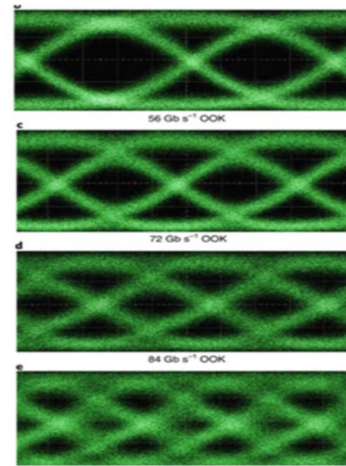
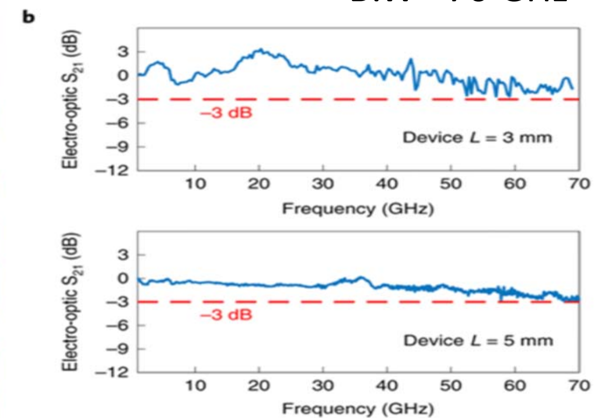
Heterogenous integration

- Wafer-scale integration of novel materials to boost the performance of silicon photonics building blocks
  - Example: high-speed phase modulator

I.L = 2.5 dB
Vpi.L = 2.2 V.c
B.W =70 GHz







https://www.nature.com/articles/s41566-019-0378-6

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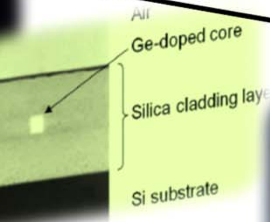
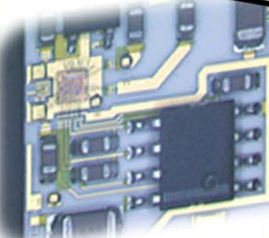
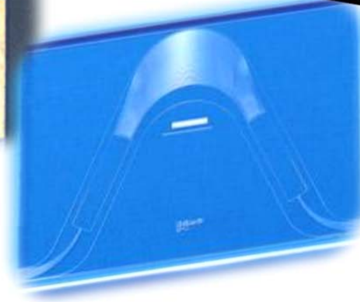
Scaling integration density of PICs

Transistors — Integrated Circuits — Microprocessors — DSP — FPGA — SOC with FPGA







1950 1960 1970 1980 1990 2000 2010 2020

laser diode

Fiber Optic links

Waveguide circuits

Opto-electronic circuits

Photonic Integrated Circuits

Silicon Photonics

Credit: Wim Bogaerts

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Large scale photonic integration

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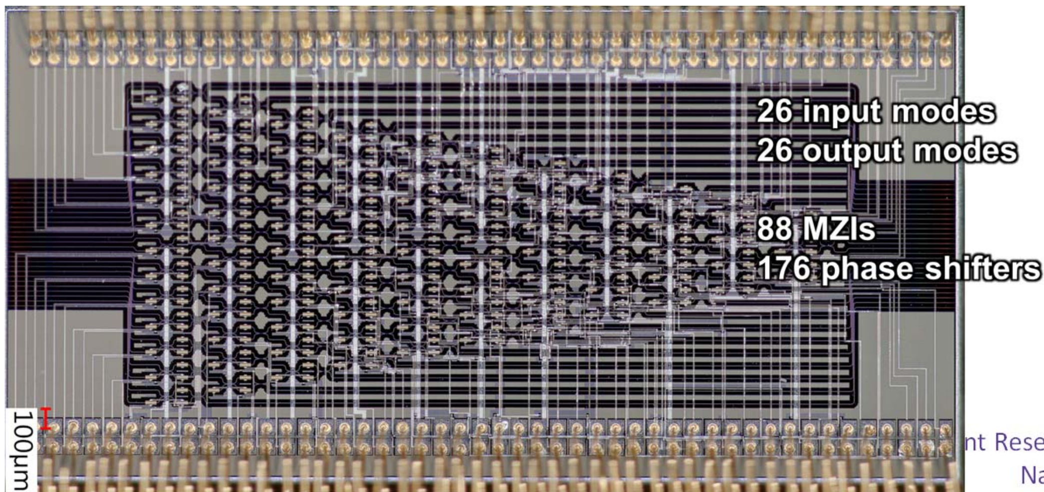
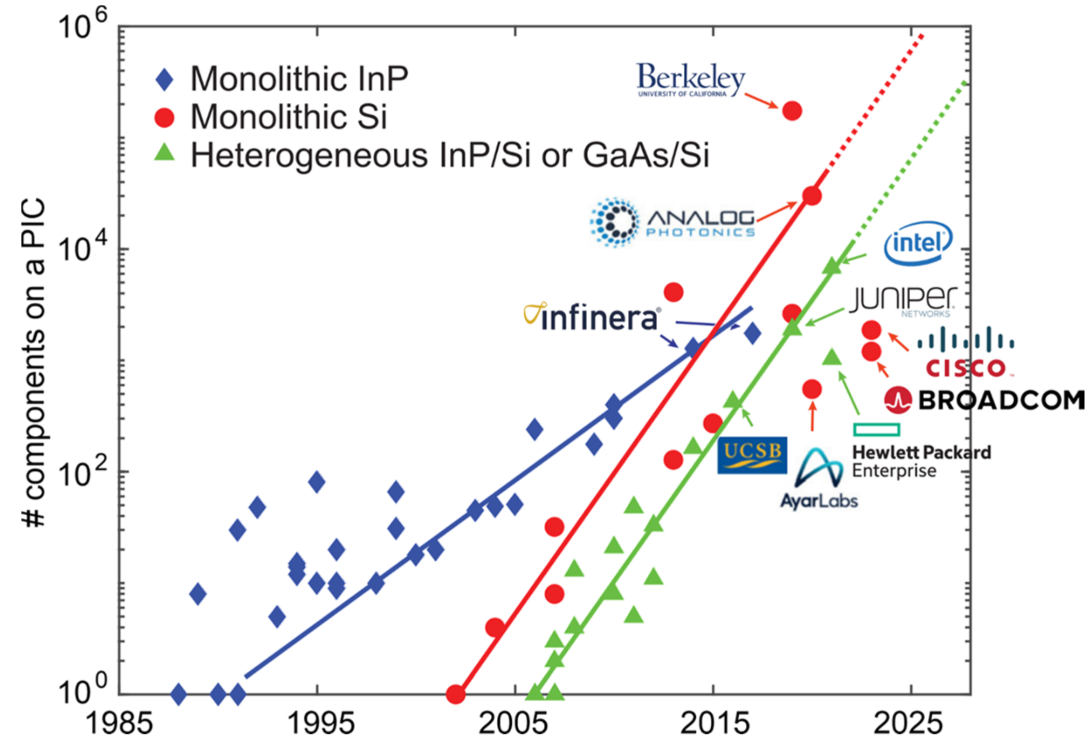
- Growing order of integration; 10Ks of components
- photonics + electronic drivers
- different applications (AI, ML, LiDARs, Computing)
- Small chip volumes (compared to electronics)

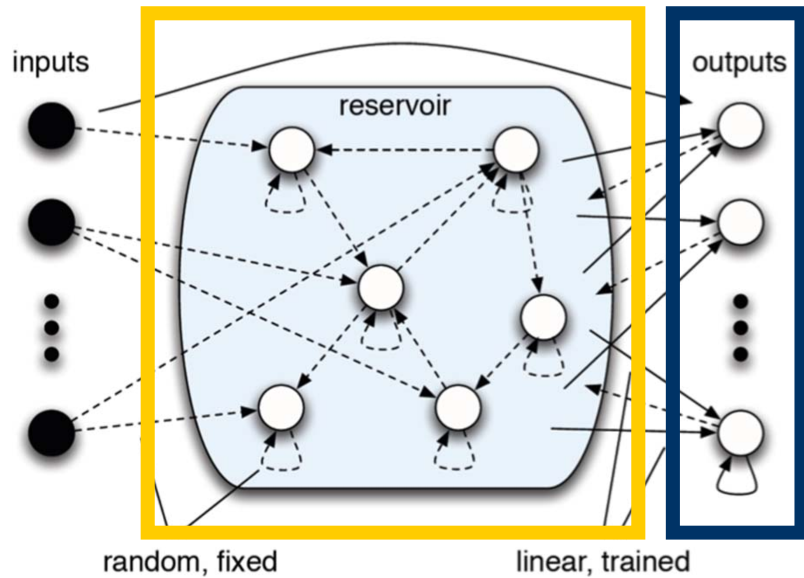


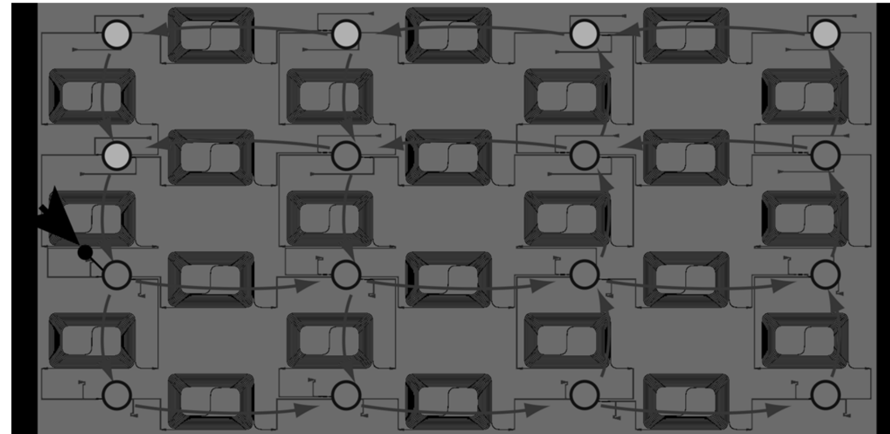


Margalit et al, APL, 2021

Photonic Reservoir Computing

reservoir readout



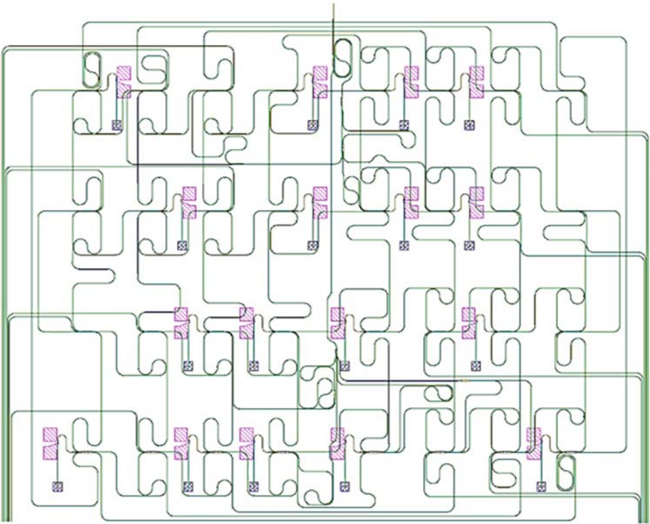


- Silicon photonics: mature technology
- Giant multipath interferometer
- Nodes are simple splitters/combiners
- Non-linearity in readout suffices
- No active power consumption inside chip
- No longer limited by timescale of non-linearity

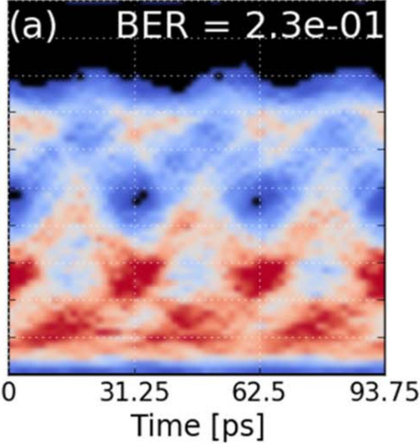
Credit: Peter Bienstman, Ugent-imec

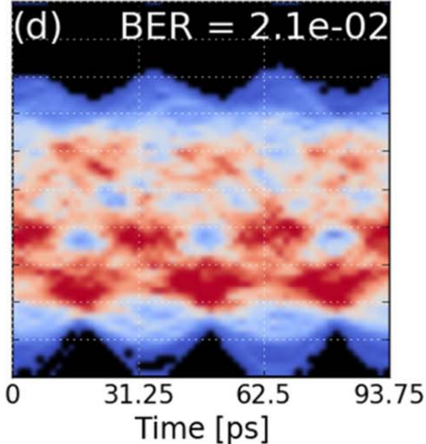
Vandoorne et al, Nature Comms, 5, 3541, 2014

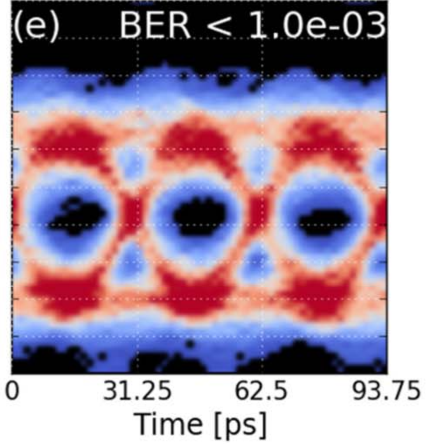
Photonic Reservoir Computing

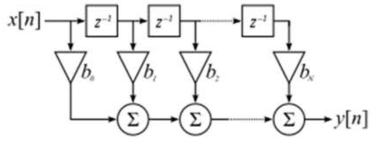


Credit: Peter Bienstman, Ugent-imec

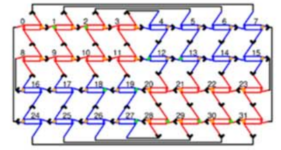








Same number of copies as the reservoir has nodes



is better than linear equalizer to mitigate non-linear fiber impairment

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128x128 pixel FMCW LiDAR

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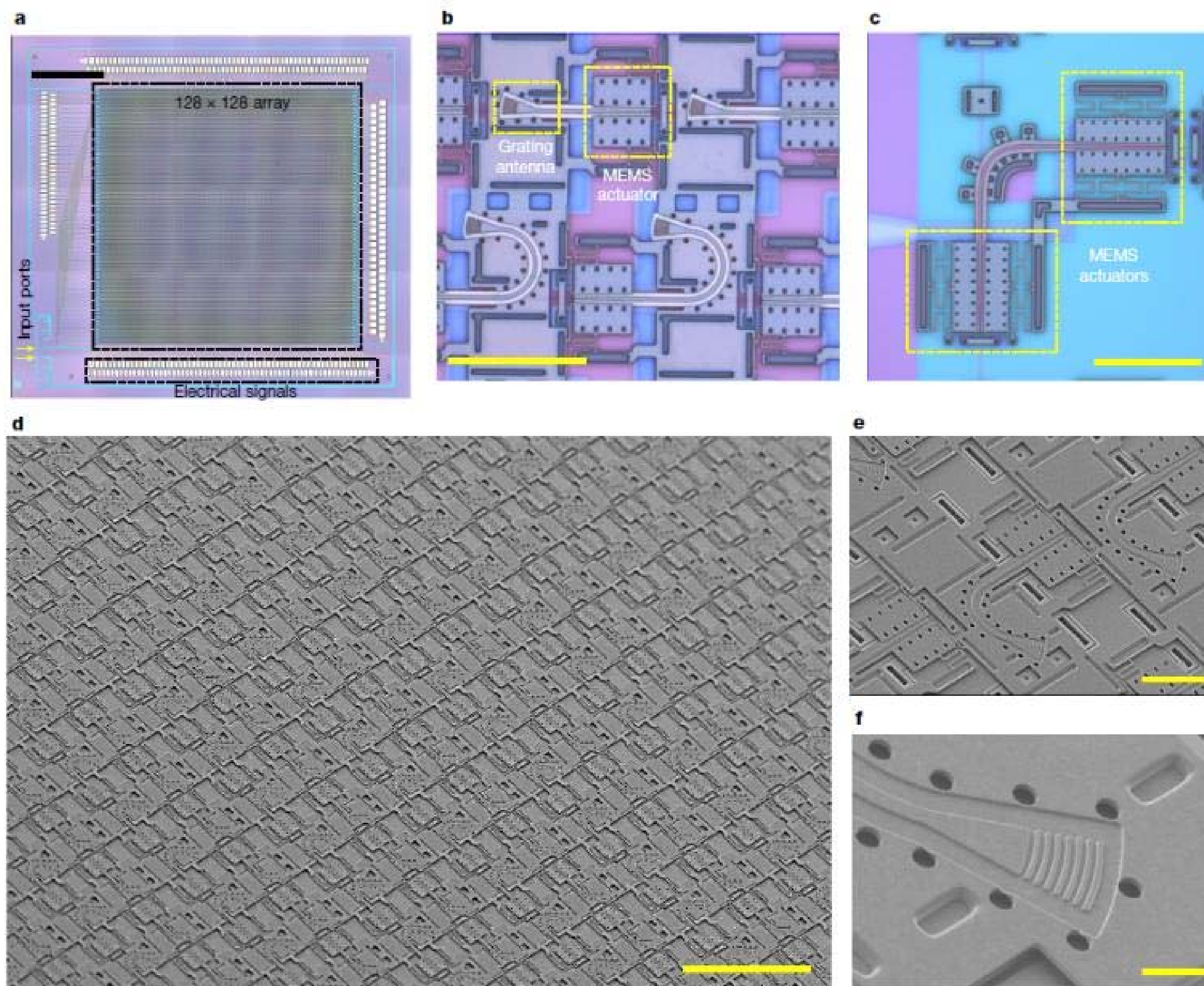
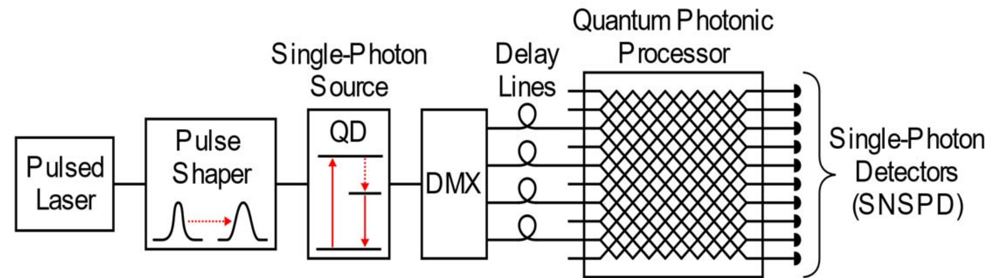


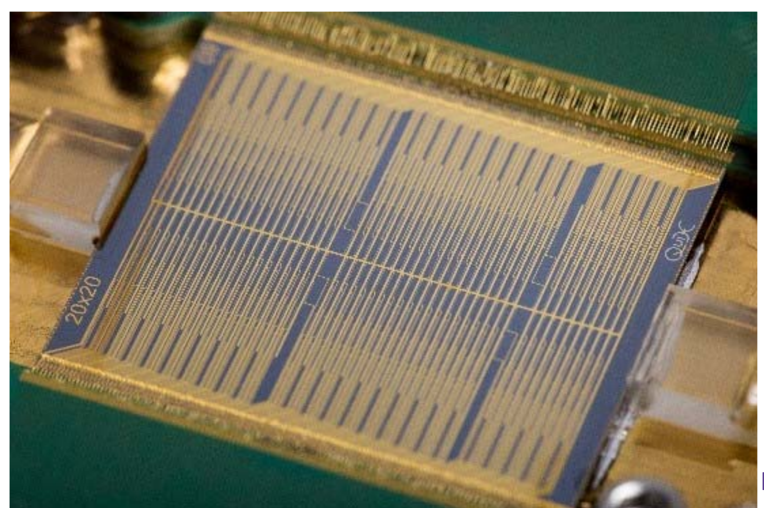
$10 \times 11\text{-mm}^2$ silicon photonic chip
FoV: 70° × 70°
Resolution: 0.6° × 0.6°

X. Zhang, et al, M. Wu, Nature (2022)

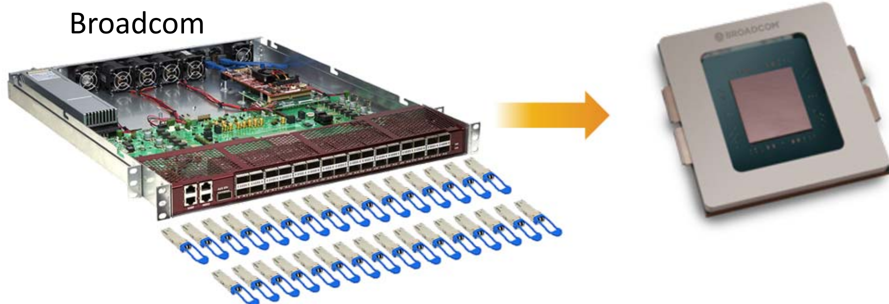
Quantum Processors using PICs

- 20 channel programmable forward-only circuit
- > 3000 wirebonds





Enhanced intimacy b/w electronics and photonics



Co-Packaged Optics

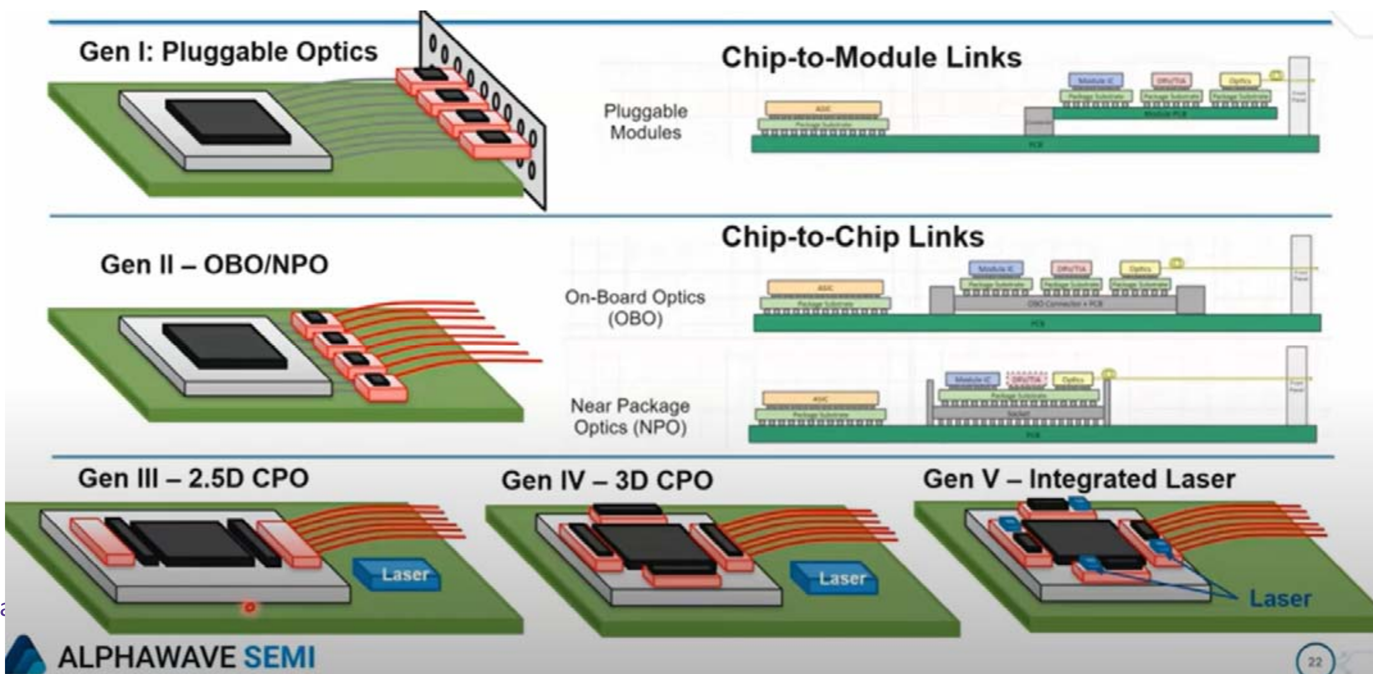
- Integration of optical engines on a common package substrate
- Objective: alleviate the "interconnect density bottleneck"

➡

- Low power
- Low cost
- Low latency
- Higher IO bandwidth

Challenges:

- Power heat management in ASIC
- Complex assembly
- Difficult field service
- Restricts competition with concentrated R&D to a few companies



The role of integrated photonics in the semicon. industry

- There is an acceptance of PIC technology in the semicon world
- Current approach is Silicon Photonics with InP, SiN and other novel materials

Summary

- There is a diversity of platforms available in silicon photonics
- Heterogeneous integration provide routes to boost the performance of silicon PIC building blocks
- Datacom/telecom is the major driver today. Other applications are on the horizon
- European silicon photonics eco-system offers a fully supply chain for PIC innovation

This project has received funding from the European Union's Horizon Europe research and innovation programme under GA Nº 101092562

www.icos-semiconductors.eu