leti
cea tech

June 4, 2019
Leti Photonics & MicroLED Displays Workshop
NTUH International Convention Center, Taipei, Taiwan

PHOTONICS INTEGRATED CIRCUITS FOR COMMUNICATIONS AND BEYOND

Eleonore HARDY
Business Developer, Silicon Photonics
CEA-LETI, Grenoble, FRANCE

OUTLINE

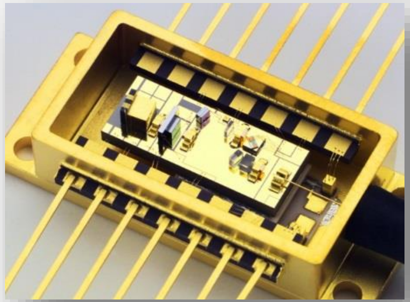
1. Why use Photonic Integrated circuits
2. Why use Silicon Photonics
3. Communications
4. Advanced computing
5. Sensors
6. Value Chain

WHY USE PHOTONIC INTEGRATED CIRCUITS

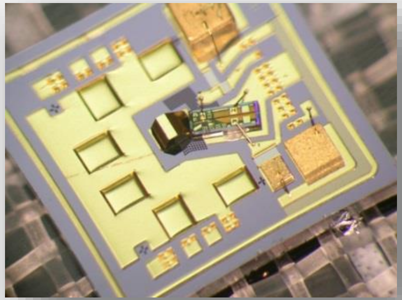
Legacy optics

Discrete components — 1990

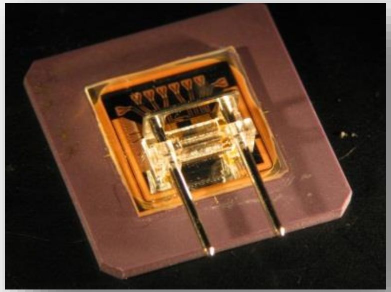
Micro-bench — 2000



Axsun



Hymite



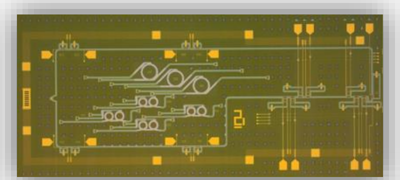
Intexys / CEA

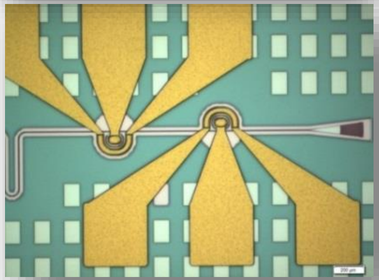
Complex assembly = High cost & Low reliability

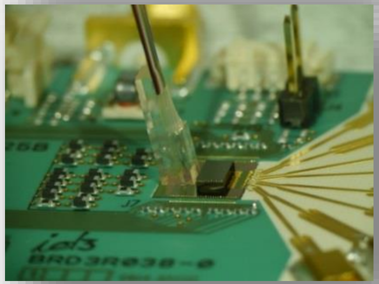
Photonic integrated circuits

3D assembly with electronics — 2010

Switch, NoC & more… — 2020

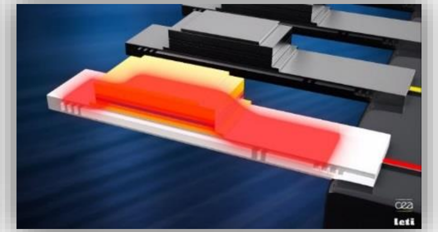




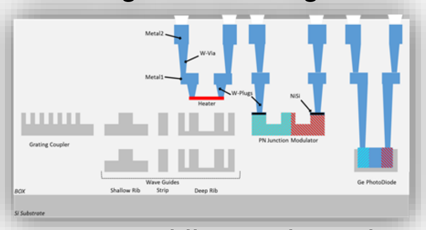


CEA

Network on chip



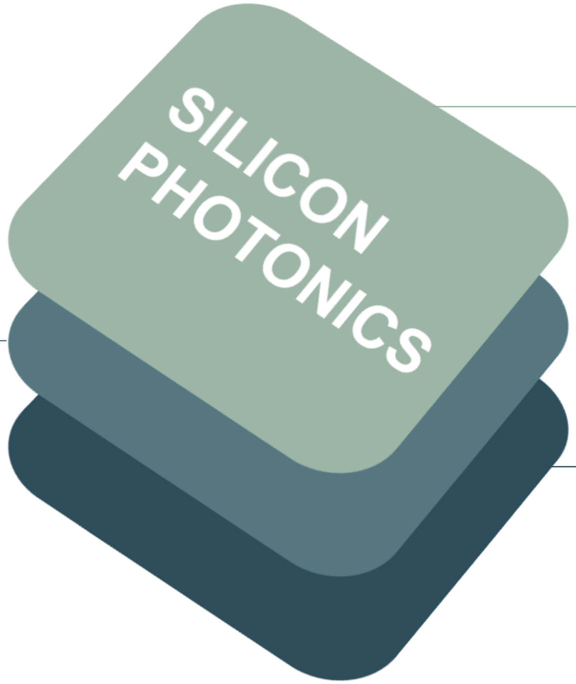
Heterogeneous integration



Multilayer photonics

WHY USE SILICON PHOTONICS

Large scale integration CMOS friendly process



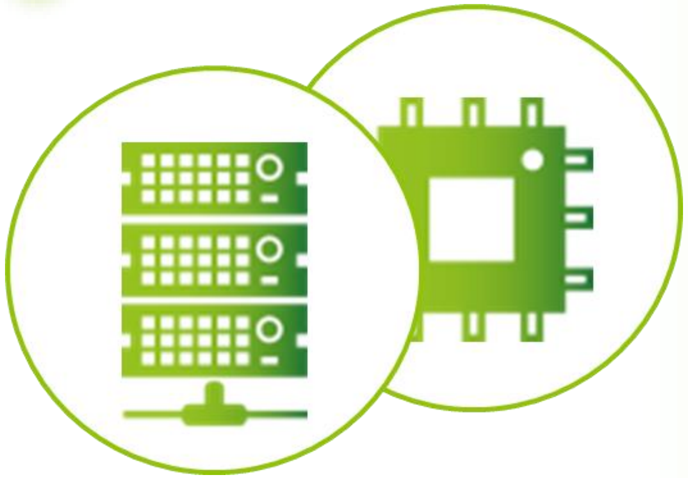
REDUCED COST
Cheap material
CMOS good yield and low cost

REDUCED POWER CONSUMPTION
Easy photonic-electronic integration

REDUCED FOOTPRINT
High miniaturization process

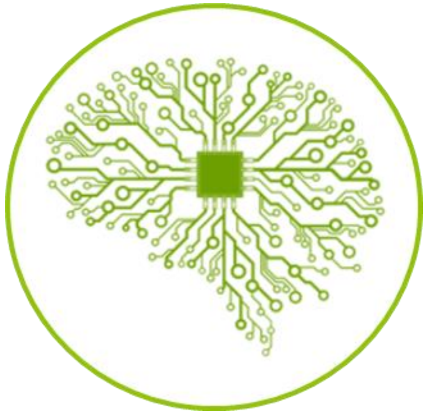
SILICON PHOTONICS MARKETS

SILICON PHOTONICS APPLICATIONS



COMMUNICATIONS

- TELECOMMUNICATION
- DATA CENTER
- COMPUTER COMMUNICATION

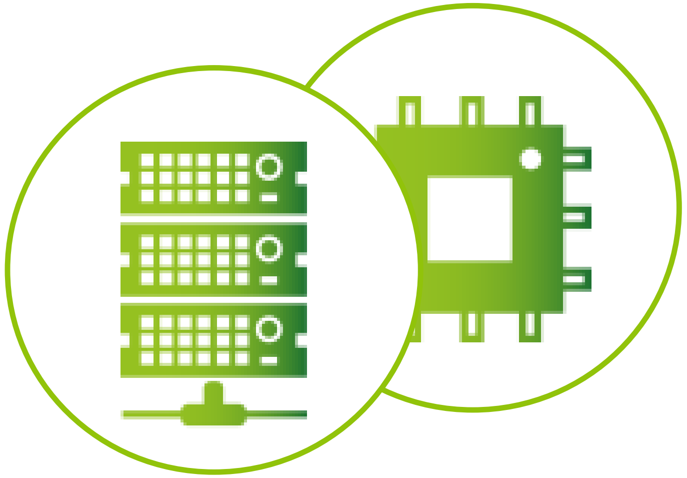


ADVANCED COMPUTING

- QUANTUM COMPUTING
- NEUROMORPHIC COMPUTING

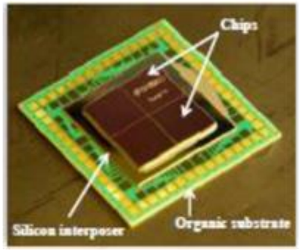
SENSORS

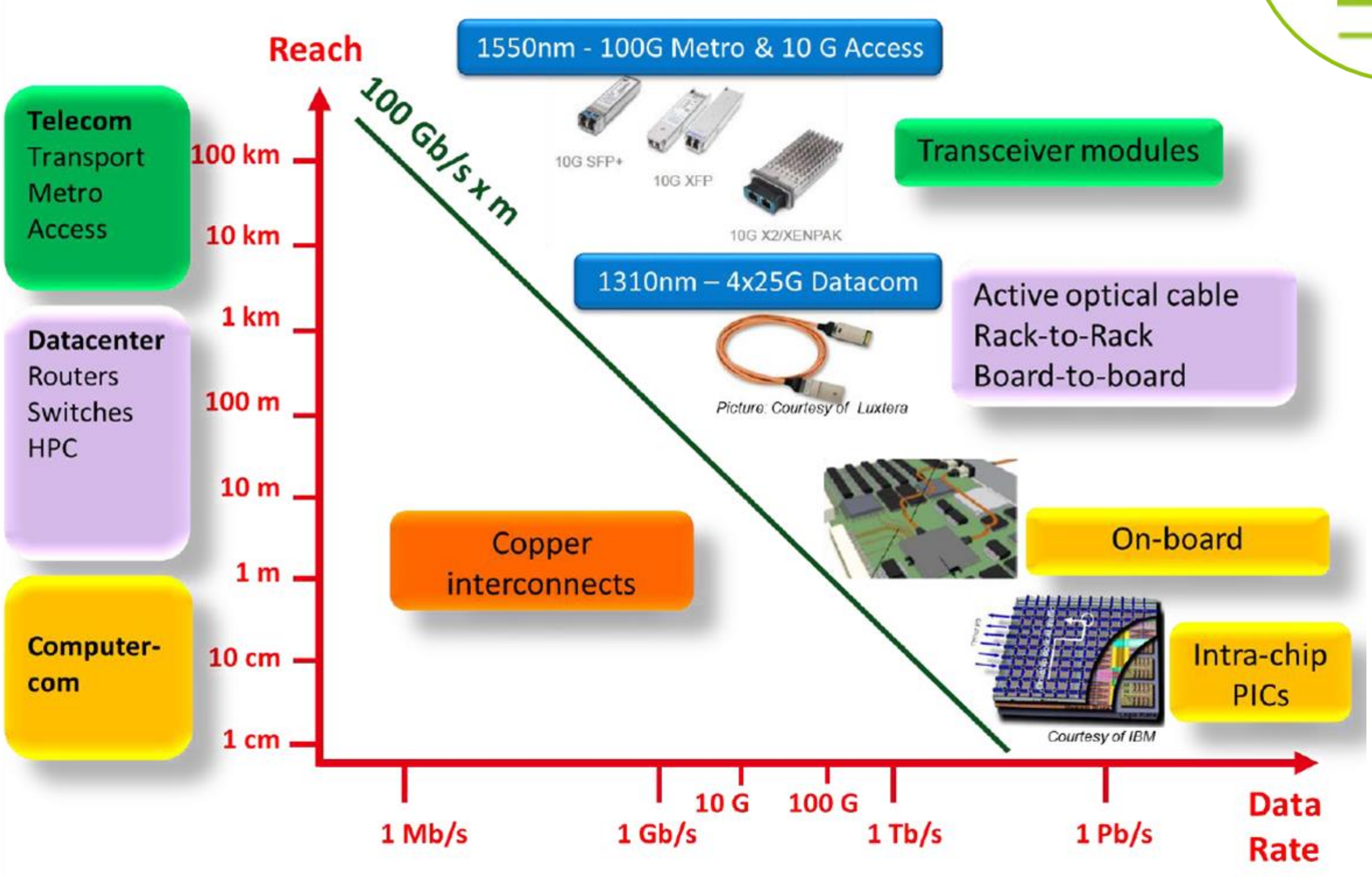
- LIDAR
- GAS SENSOR



TELECOM
DATA CENTER
COMPUTER COMMUNICATION

SILICON PHOTONICS FOR COMMUNICATIONS

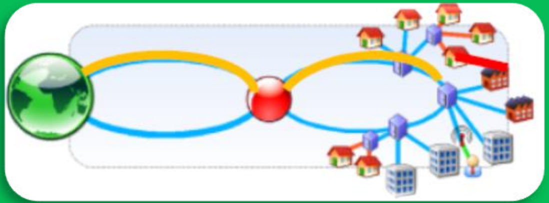




SILICON PHOTONICS FOR COMMUNICATIONS

TELECOM

> 2 km
Transport
Metro
Access



λ=1550 nm
100G → 400G Metro
10G → 25G Access
Small form factor optical transceivers modules

DATA CENTER

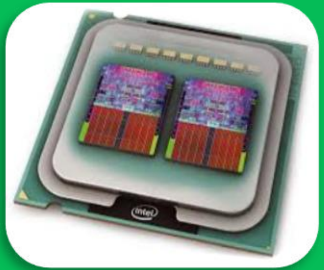
1m – 10 km
Routers
Switches

λ=1310 nm
100G → 400G → 1 Tb/s

Rack-to-Rack
Board-to-Board
Mid-Board

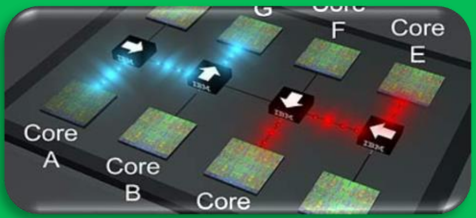
COMPUTERCOM

< 1m
Photonic Integrated Circuits on Chip



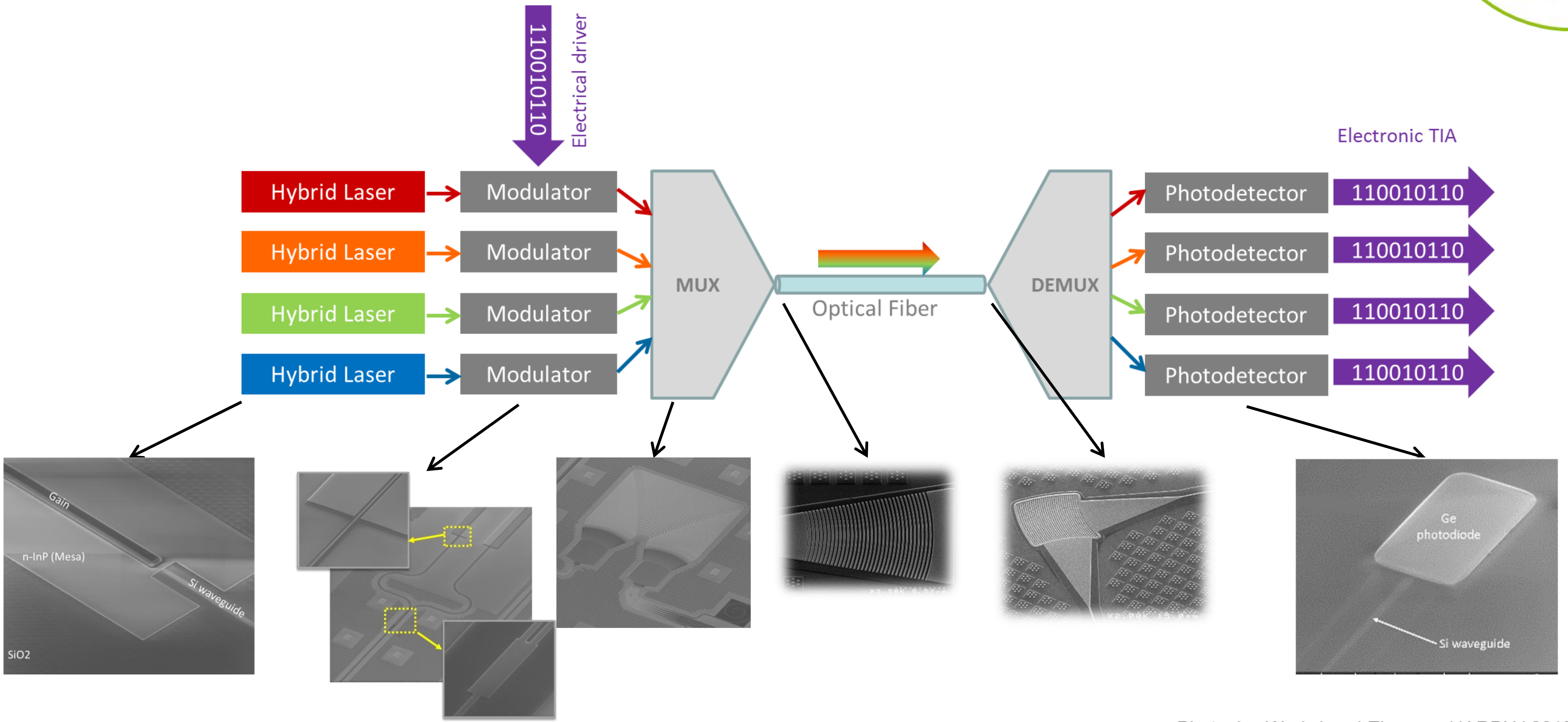
λ=1310 nm
> 1 Tb/s

Photonic transceivers on Chip

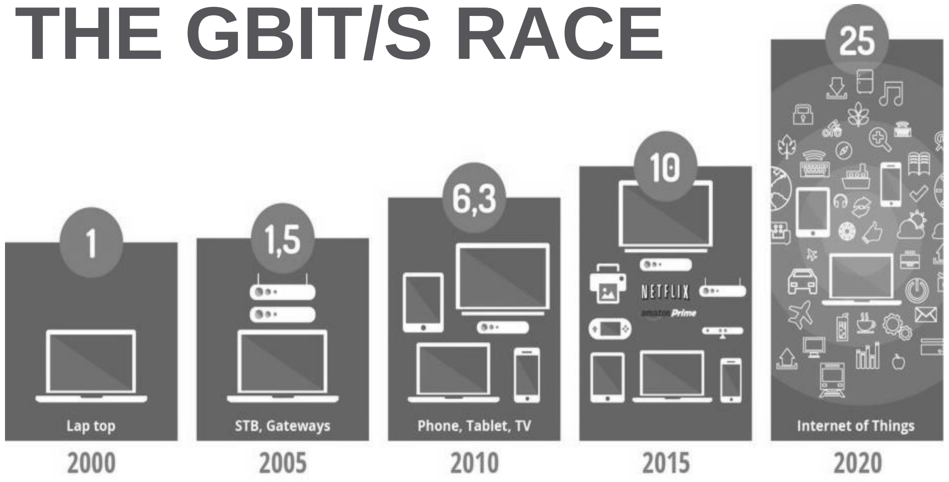


SILICON PHOTONICS FOR COMMUNICATIONS

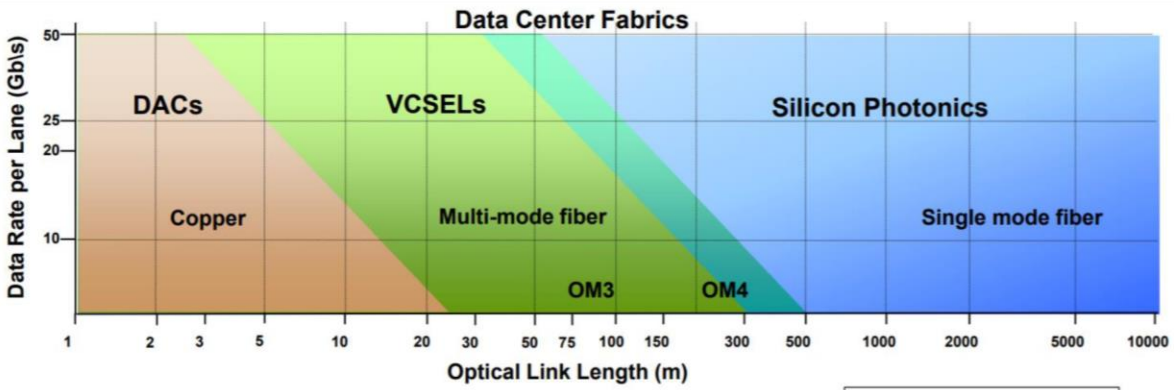
SILICON PHOTONICS BUILDING BLOCKS AT 50 GIGABAUD PER SECOND



THE GBIT/S RACE



Setelia Strategy Consultants



Direct Attach Copper	Active Optical Cables	VCSEL Transceivers	SiP Transceivers
• Zero power • Demo'd 8m at 100G • Best fit 3m	• VCELs or SiP • Reaches to 200m • Best fit for 5-20m	• Reaches to 100m • Best fit for MMF	• Reaches to 2km • Best fit for SMF • Parallel or WDM

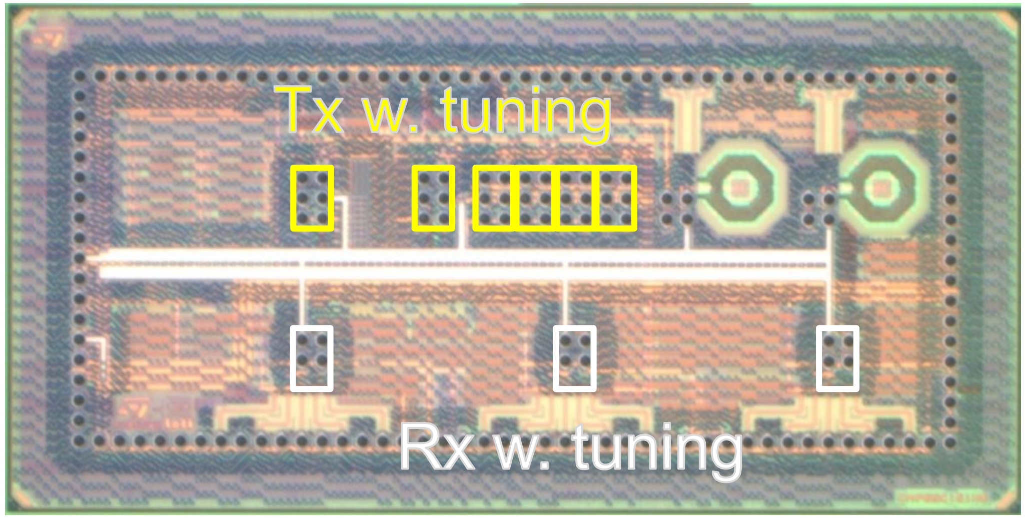
Source Mellanox

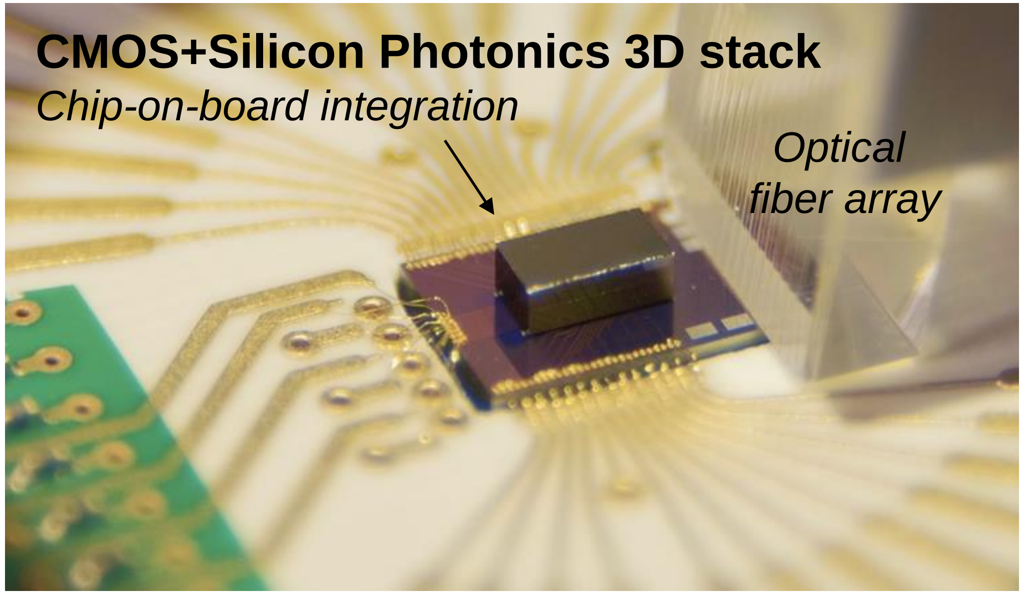
- ✓ INTER DATA CENTER
- ✓ IINTER RACK
- ✓ INTRA RACK

« Silicon Photonics appears to be 'self-selecting' to meet our price/volume needs.»

Mark Filer, Optical Network Architect, Microsoft @OFC2018

SILICON PHOTONICS FOR COMPUTER COMMUNICATION



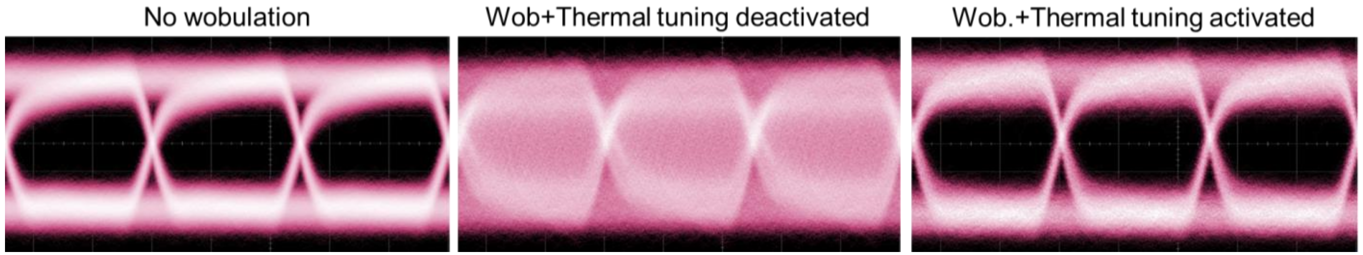


Optical communication on interposers

Goal = integrate optical & electrical functions

Demonstration of a thermally tuned WDM electro-optical link:

- **1Tbps/mm²** bandwidth density
- Tight technology integration of E/O ring modulators within a 3D stack
- Integrated thermal tuning, robust to compute fabric heating



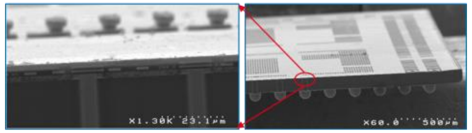
Y. Thonnart & al. ISSCC'2018

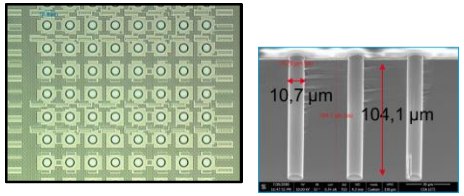
SILICON PHOTONICS FOR COMPUTER COMMUNICATION

Optical communication on interposers

For next generation computing

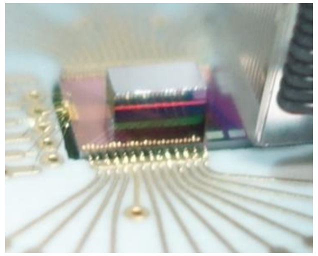
Packaging

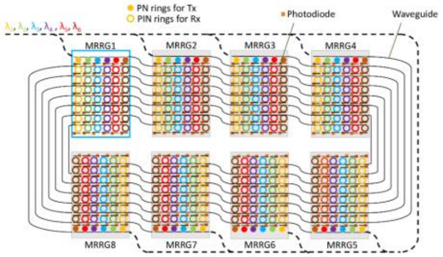




TSV for CMOS — **TSV for Si-Pho**

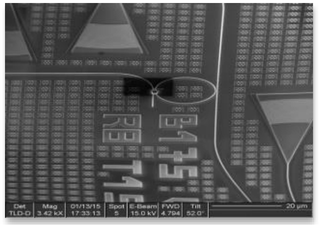
Architecture



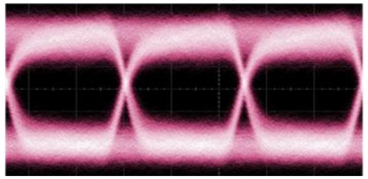


WDM link — **ONoC**

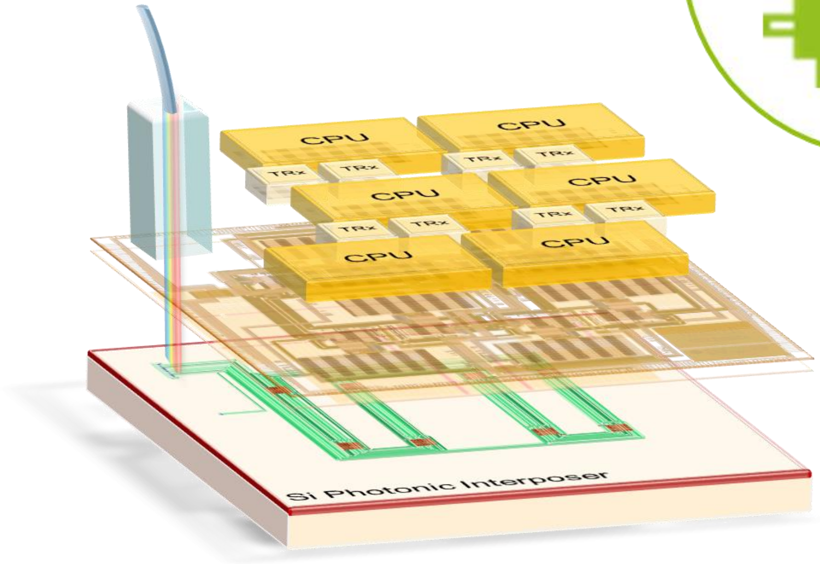
Si-Photonics



Wob.+Thermal tuning activated

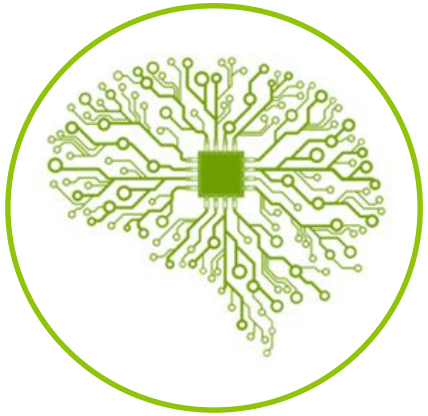


E/O Micro rings — **Thermal tuning**



Target demonstrator:

- **96-core cache-coherent processor**
- **Generic E/O chiplets**
- **8-node optical NoC**
  - 56 Gbit/s aggregated bandwidth
  - 384 microring resonators
  - ~10 ns electro-optical latency



Quantum & Neuromorphic computing

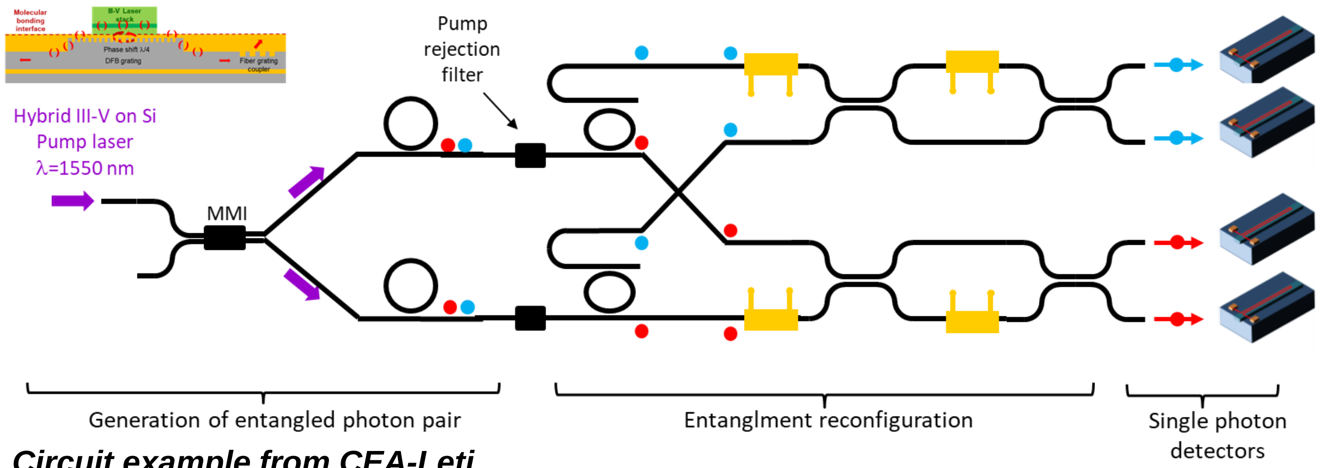
SILICON PHOTONICS FOR QUANTUM COMPUTING

Quantum computing emitter for absolute security and computing

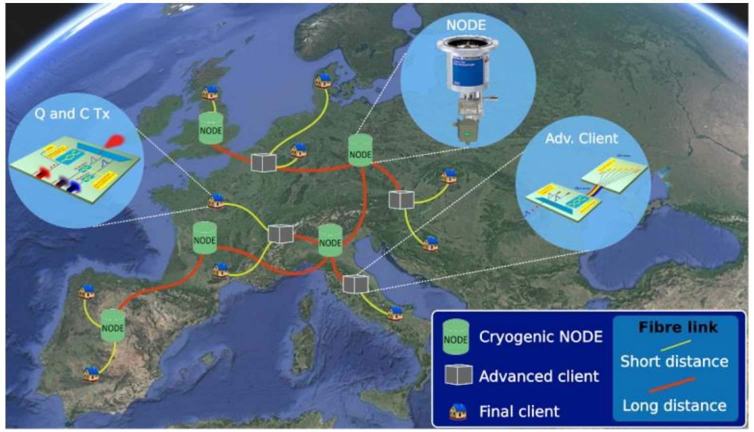
- ✓ Absolute security guaranteed by quantum physics laws
- ✓ No need for mK operating temperature (compared to superconductors or trapped ions)
- ✓ Scalable technology for computing

- Silicon photonics components: Low-loss waveguides, MZ interferometers with phase shifters, low-loss modulators, photodiodes and III-V on Si laser

➢ **Quantum Fibre Networks: transceiver/receiver for quantum cryptography (QuantERA SQUARE project – 2018/2021)**



Circuit example from CEA-Leti



Courtesy of DTU

SILICON PHOTONICS FOR NEUROMORPHIC COMPUTING

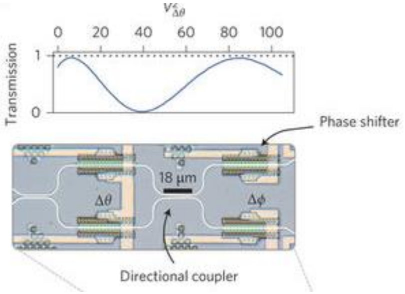
Towards a photonic neural network on a chip

- Silicon photonics components: III-V on Si laser, PIN phase shifters, photodiodes

Photonic neural nets architectures potentially sport better than electronic in:

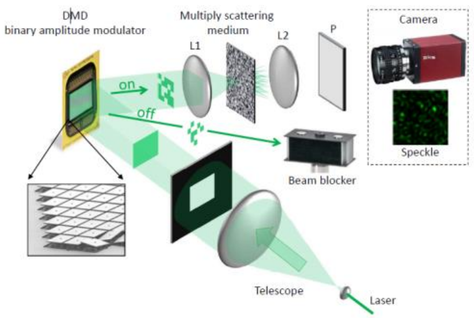
- ✓ Speed
- ✓ Information density
- ✓ Energy efficiency

2018	2021	2023	2025

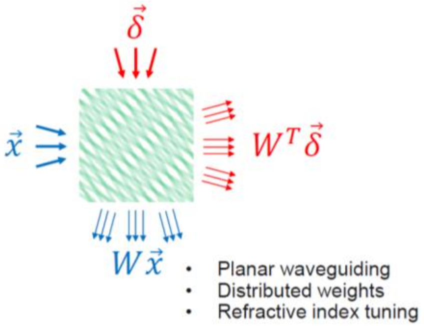


State of the art:

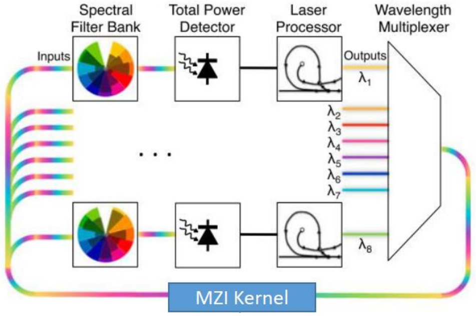
- ***Low loss waveguide 1 dB/cm***
- ***PiN phase shifter 10 pJ/bit***
- ***Photodiode 0.6 A/W***



Compressive sensing demonstrator



Photorefractive matrix multiplier



Spiking Neural Network

LIDAR
GAS SENSOR

SMART MINIATURIZED LIDAR – A PROMISING MARKET

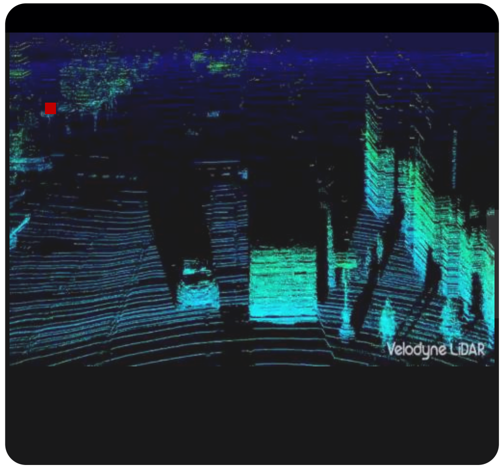
LIght
Detection
And
Ranging

Industry

ROBOTICS

REAL-TIME

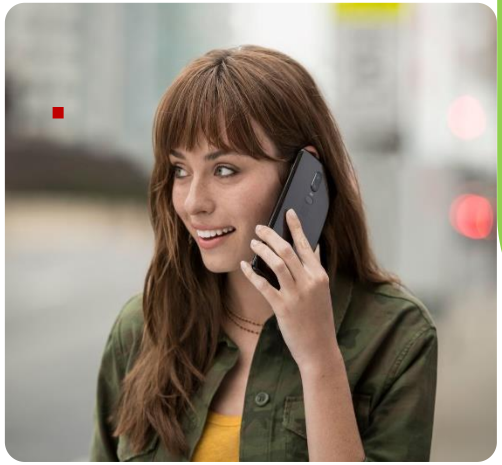
Mobility



SELF-DRIVING

REAL-TIME & SENSITIVITY

Consumer



1D RANGE FINDER

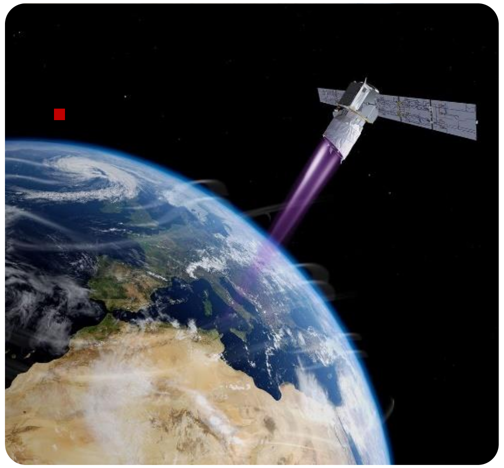
LOW COST

Engineering

3D MAPPING

ACCURACY

Space/Science



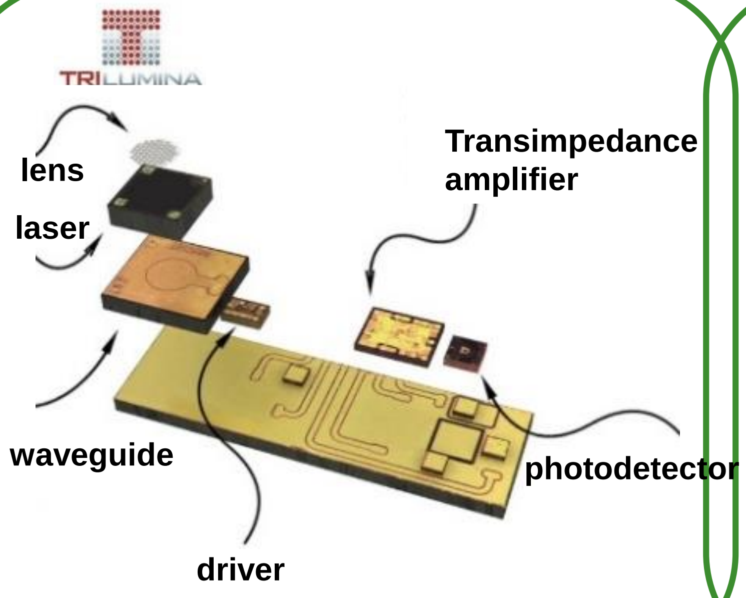
REMOTE SENSING

PERFORMANCE

SMART MINIATURIZED LIDAR – CURRENT TRENDS

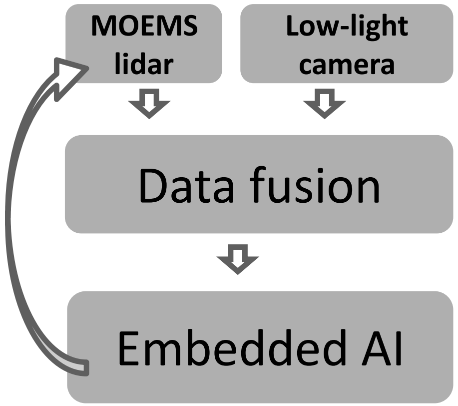
- PHOTONICS
- ELECTRONICS
- SOFTWARE

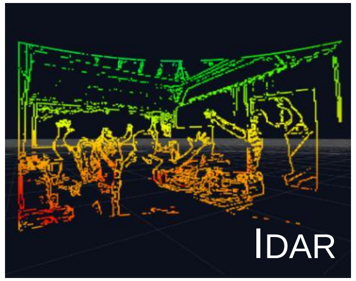
Mechanics | Electro-Mechanics | Solid-State



AEYE

MIMICKING HUMAN'S VISUAL CORTEX





LOW COST TECHNOLOGIES & INTEGRATED ON CHIP

HETEROGENEOUS INTEGRATION & 3D ASSEMBLY WITH ELECTRONICS

OPERATION DERIVED FROM DATA FUSION & AI

SILICON PHOTONICS FOR LIDAR

CEA-LETI building blocks for LIDAR integration strategy

TECHNOLOGIES — SYSTEM — One enabling technology

TECHNOLOGIES

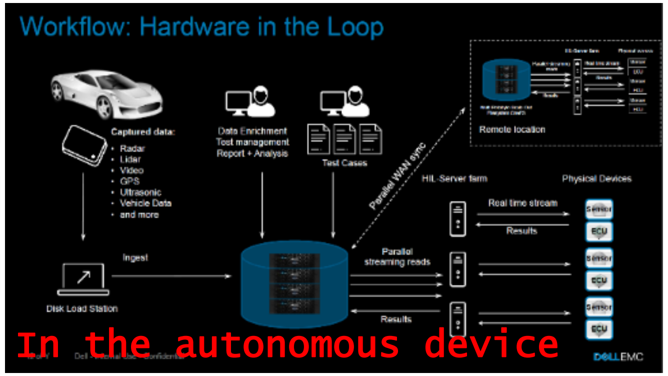
- VCSEL | Laser diode | Fiber laser
- Rotating mirror | Optical phased array | MEMs mirror
- Lens | MEMs mirror
- SPADs -Gm | PiN | APDs | SiPM
- Si | SiGe / Ge | InGaAs | HgCdTe
- Analog IC | Time to Digital C | Pulse averaging | Heterodyne detection
- Sigma fusion | Sensor fusion | Feedback loops | Embedded AI

SYSTEM

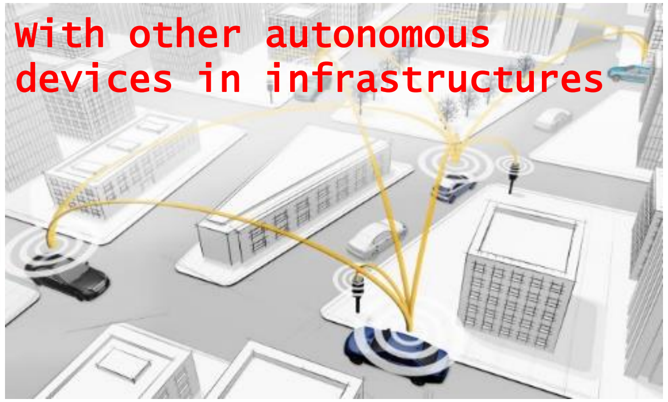
- Optical source
- Beam steering
- Optics (Tx, Rx)
- 3D Sensor
- ↕ System integration ↕
- Data processing

One enabling technology

- AI
- RF
- SLAM



- V2I
- V2V
- …

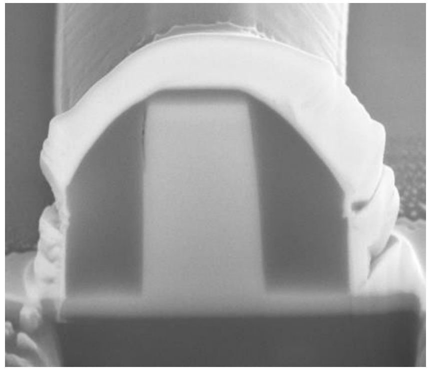


SILICON PHOTONICS FOR LIDAR

SILICON PHOTONICS EMITTER

OPTICAL SOURCE

CMOS-COMPATIBLE HYBRID III-V ON SI LASER

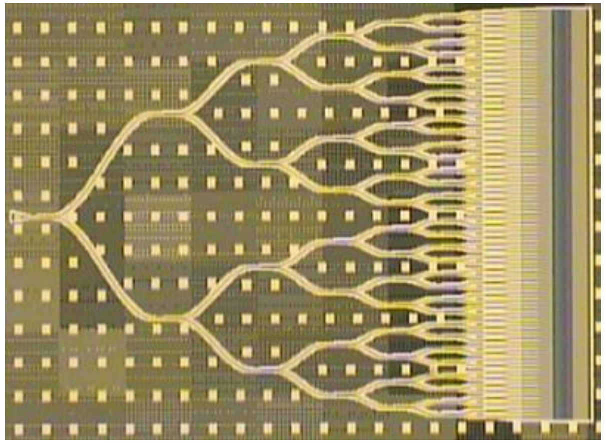


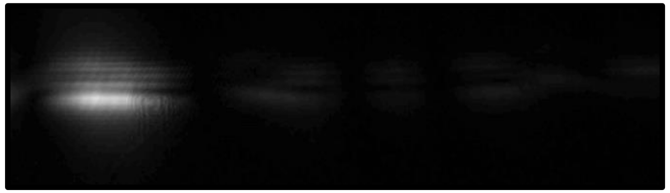
- CW Narrow linewidth for coherent FMCW Lidar
- Pulsed Narrow linewidth for pulsed coherent Lidar
- Pulsed for direct detection Time of Flight (TOF) Lidar

+

BEAM STEERING

OPTICAL PHASED ARRAYS





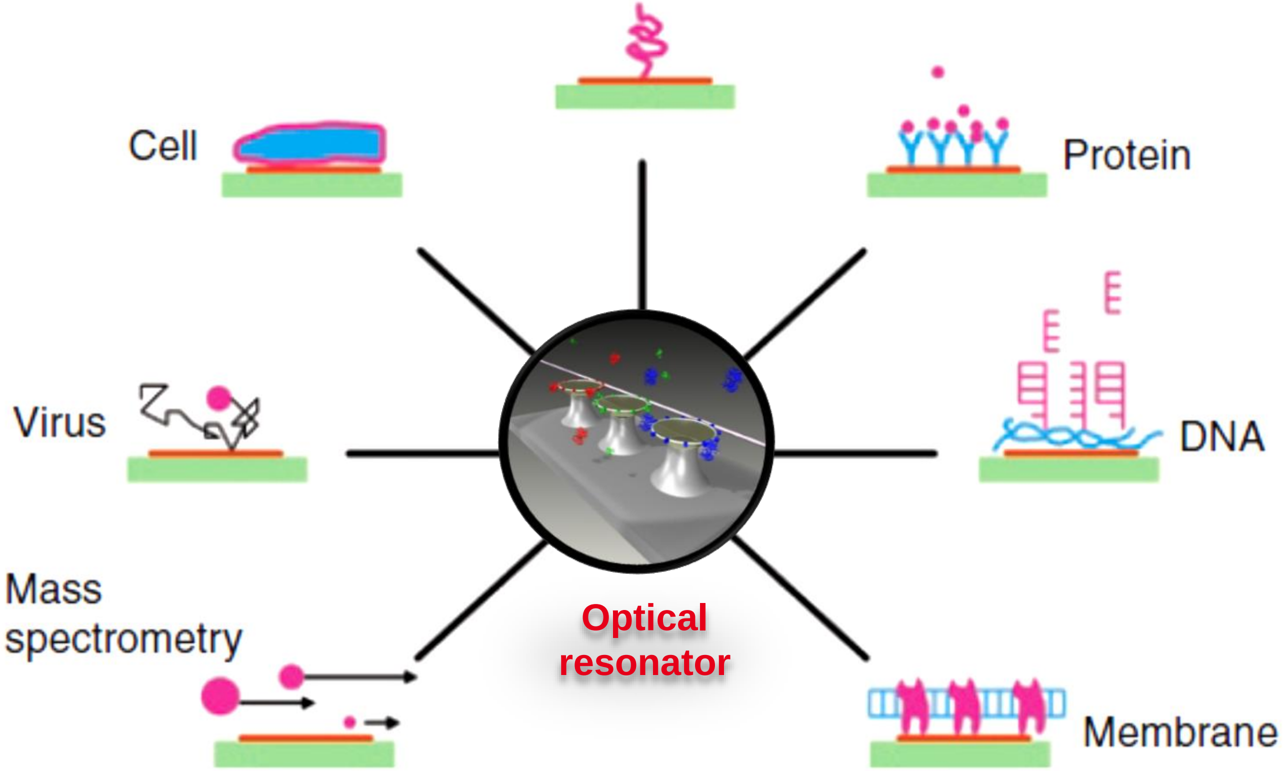
- Emit low divergence laser beam
- Steered non-mechanically

Demonstration of 1D and 2D LIDAR EMITTER @ CEA-Leti

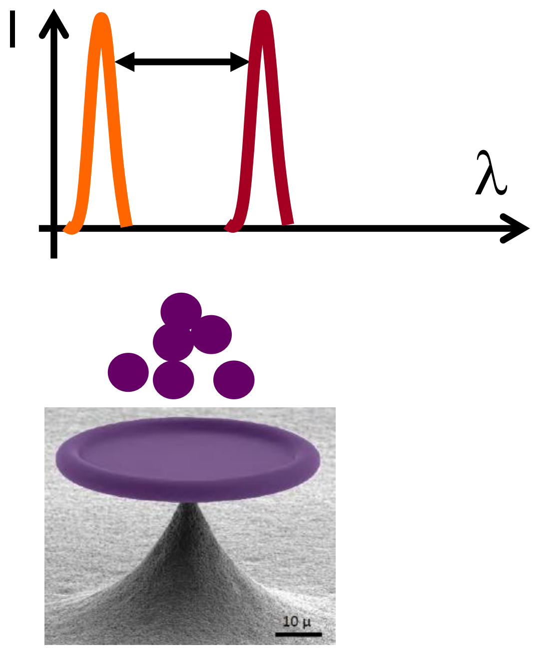
1D ±10° BEAM STEERING AT 900NM USING INTEGRATED SIN OPA

SILICON PHOTONICS FOR MULTIGAS SENSORS

MOLECULAR IMPRINT PRINCIPLE



$$\frac{\delta\lambda}{\lambda} \approx \frac{\alpha_{ex}\sigma_s}{\epsilon_0(n_1^2 - n_2^2)R}$$

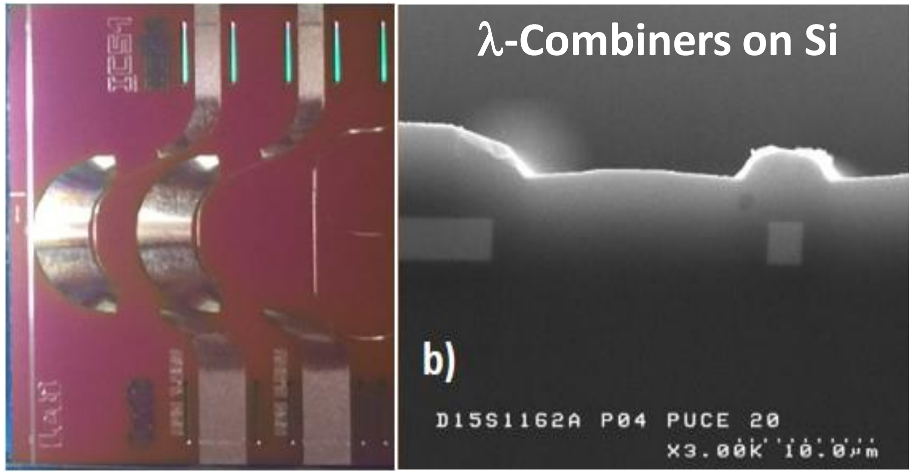


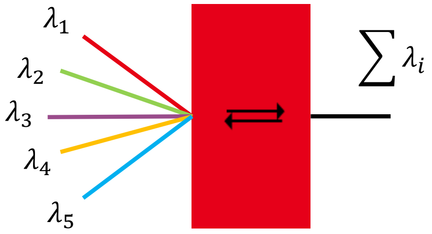
Modified from Frank Vollmer & Stephen Arnold, Nature methods 5 (2008), 591-596

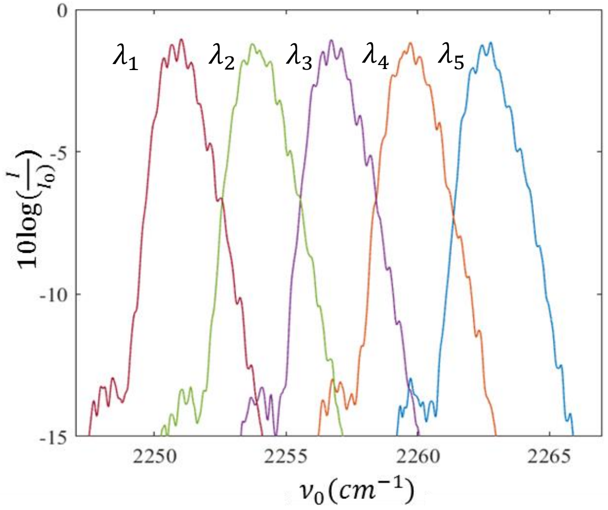
L Duraffourg, J Arcamone, NEMS, Wiley 2015

SILICON PHOTONICS FOR MULTIGAS SENSORS

SIGE & GE PLATFORMS (MIR)





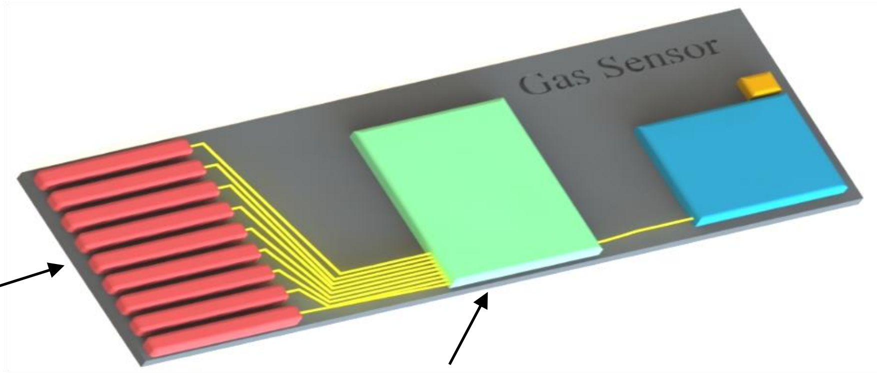


- Mid-IR photonics circuit based on $Si_{60}Ge_{40}/Si$
  - Wavelength range: **3µm – 8µm**
  - Propagation loss: 0.3 dB/cm (@4.5µm)
    - Combiner 35 inputs with low insertion loss (-1.6 dB)
    - Cross talk < -12 dB

- Mid-IR photonics circuit based on Ge/SiGe
  - Wavelength range: **3µm – 12µm**
  - Propagation loss: 2 dB/cm (@4.5µm)

SILICON PHOTONICS FOR MULTIGAS SENSORS

CONCEPT OF INTEGRATED MULTIGAS SENSOR ON SI



Gas sensing cell – PhotoAcoustic detector with MEMS µPhone

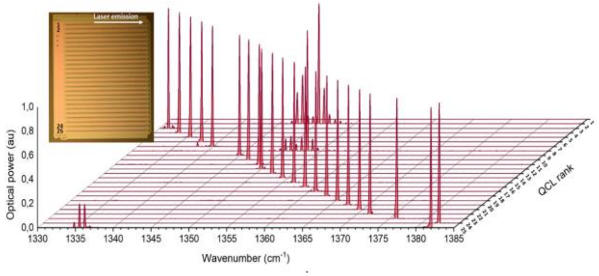
Photonics Integrated Circuit Beam Combiner

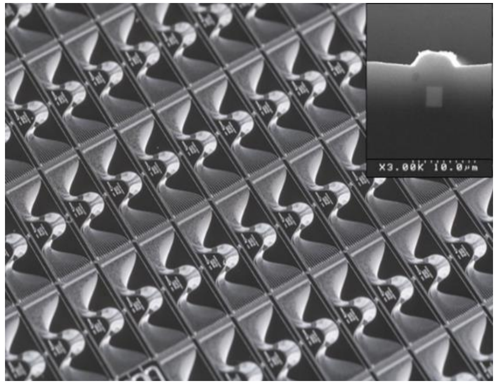
Array Quantum Cascade Lasers on Si

Replace bulky multipass cells

Replace costly and fragile discrete optics

Multigas detection enabler

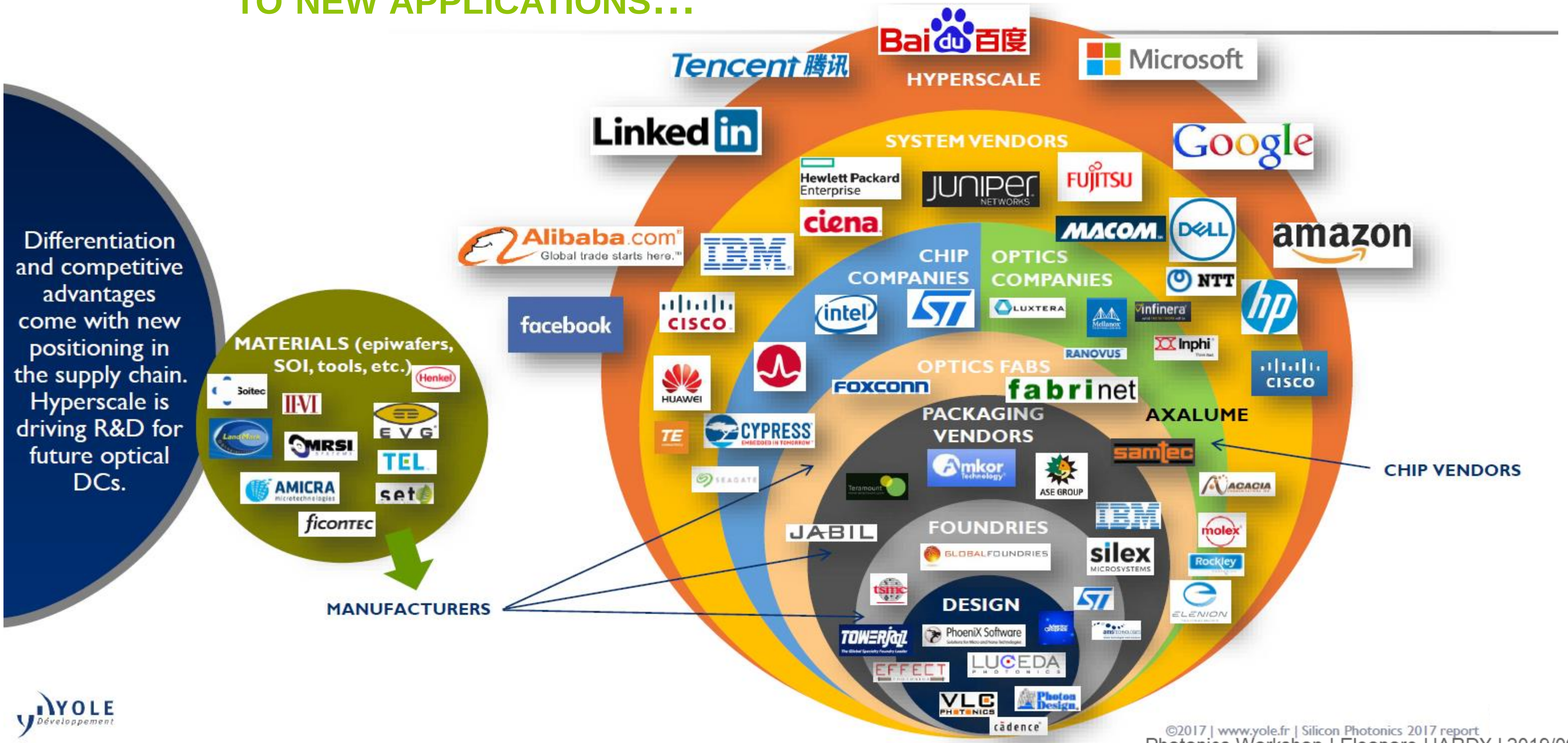




REDFINCH MIRPHAB CHEMICAL SENSING AND SPECTROSCOPY

SILICON PHOTONICS VALUE CHAIN

DYNAMIC VALUE CHAIN FROM COMMUNICATION SECTOR TO NEW APPLICATIONS…



谢谢

Eleonore HARDY
Business Developer, Silicon Photonics
CEA-LETI, Grenoble, FRANCE
eleonore.hardy@cea.fr