SiNANO-ICOS-INPACE Workshop

"Emerging technologies in Advanced Computation, Advanced Functionalities, Ground-breaking Technologies: Impact on International Cooperation"

Scaling semiconductor photonics
The trends and the challenges

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Bruges, September 9, 2024

ePIXfab - The European Silicon Photonics Alliance

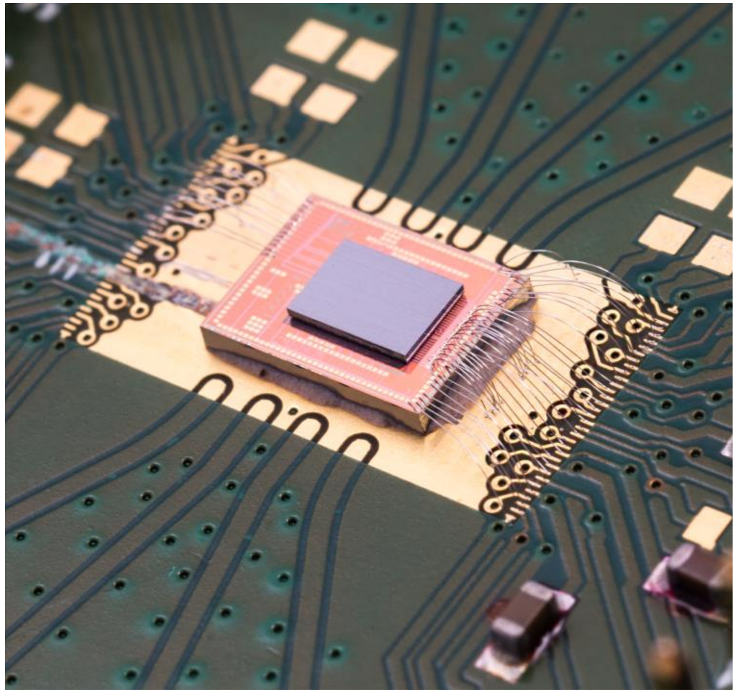
ePIXfab's mission is to act as a catalyst for European academia and industry to strengthen the worldwide silicon photonics ecosystem.

Advocate	Represent	Train	Consult	Roadmap
Innovation opportunities enabled by SiPh	European silicon photonics community	Lift the workforce	About the ecosystem and supply chain	About the technological trends and evolution

ePIXfab
The European
Silicon Photonics Alliance

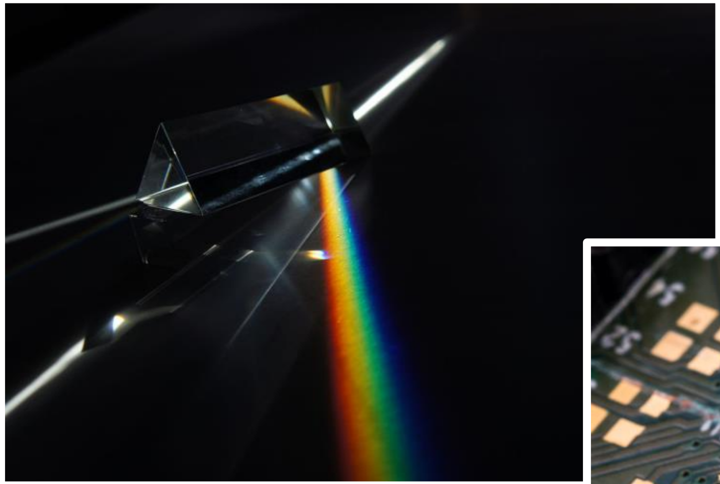
Outline

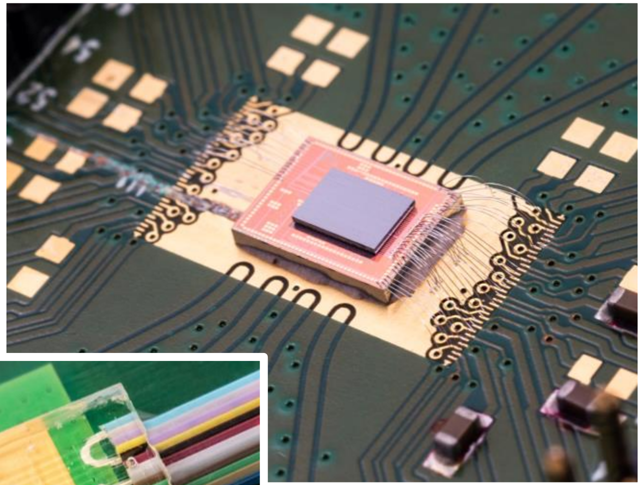
- What do we mean with "Photonics"?
- Where do we find photonics today?
- Where do we want photonics tomorrow?
- Challenges between today and tomorrow…



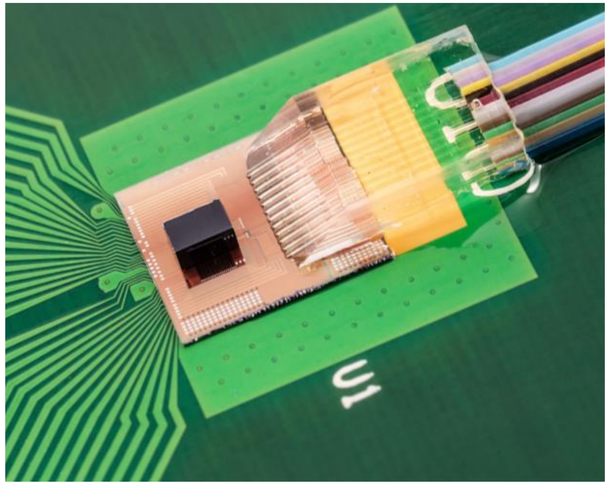
Photonics: What's in a name?

- Manipulating light
  on a microscopic scale





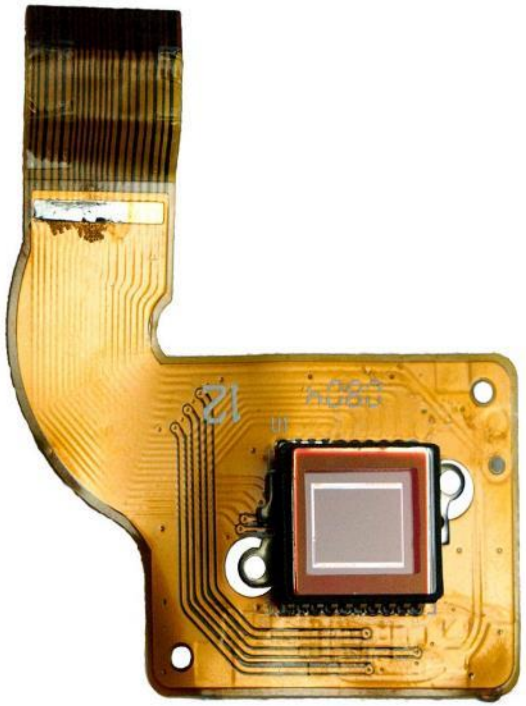
- Fiber-optic communication
- Sensing
- Quantum-optics
- …



- Often using semiconductor technology

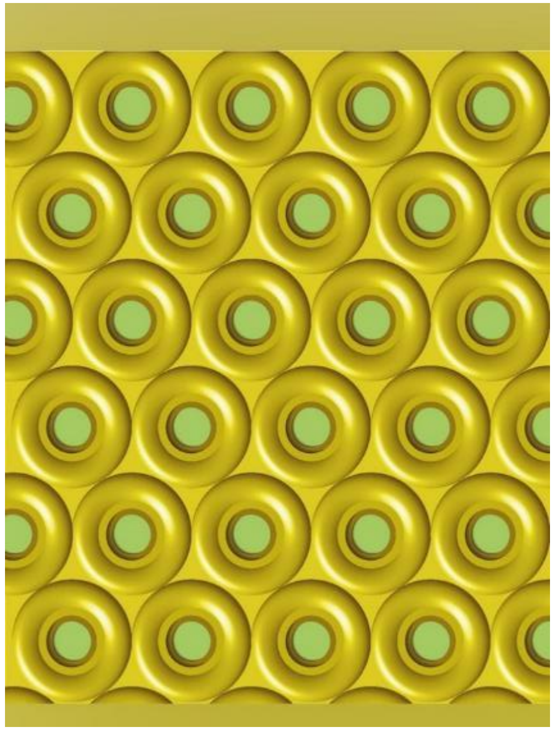
Semiconductor Photonics

Different classes of devices



CMOS Imagers

LEDs

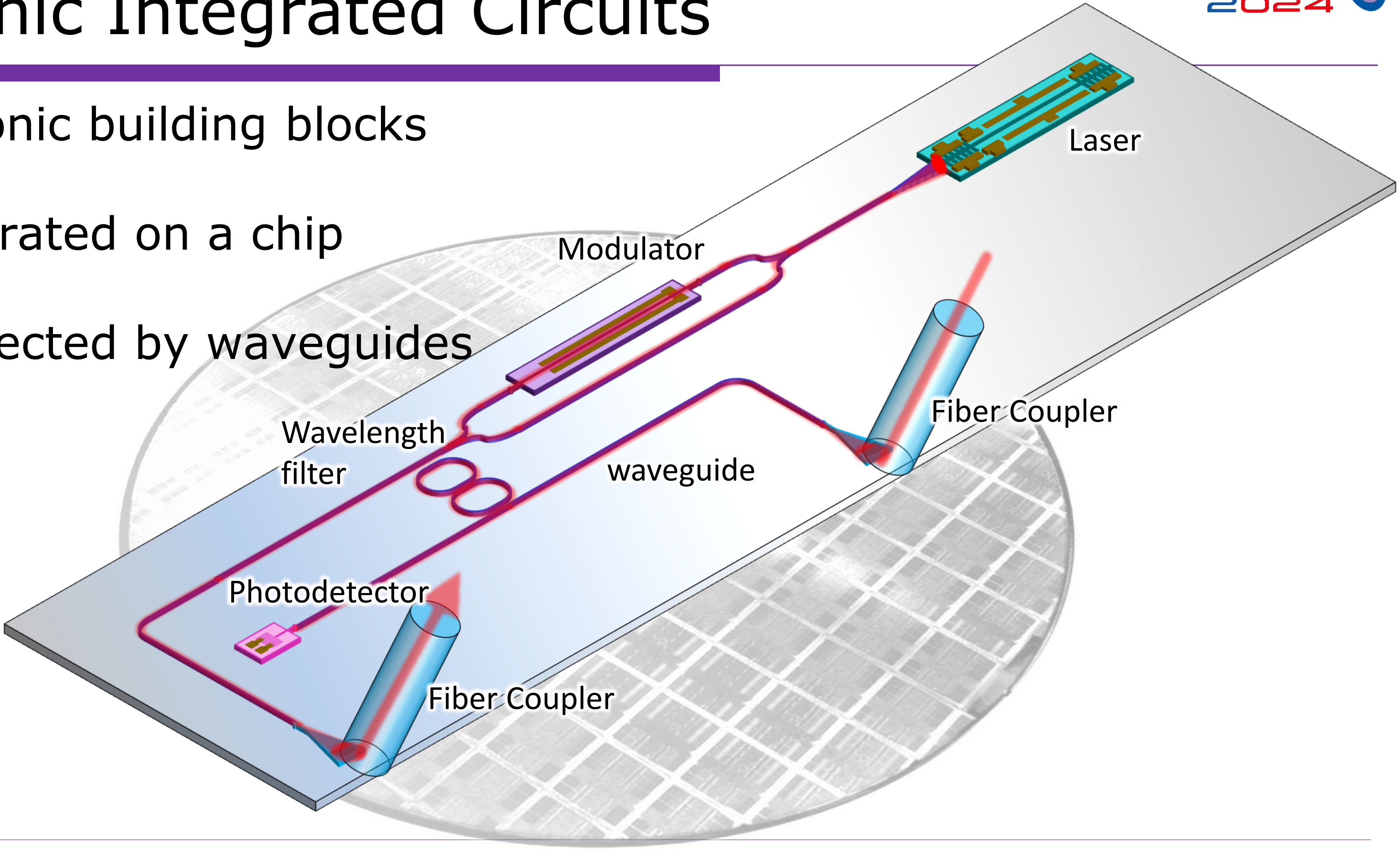


VCSELs

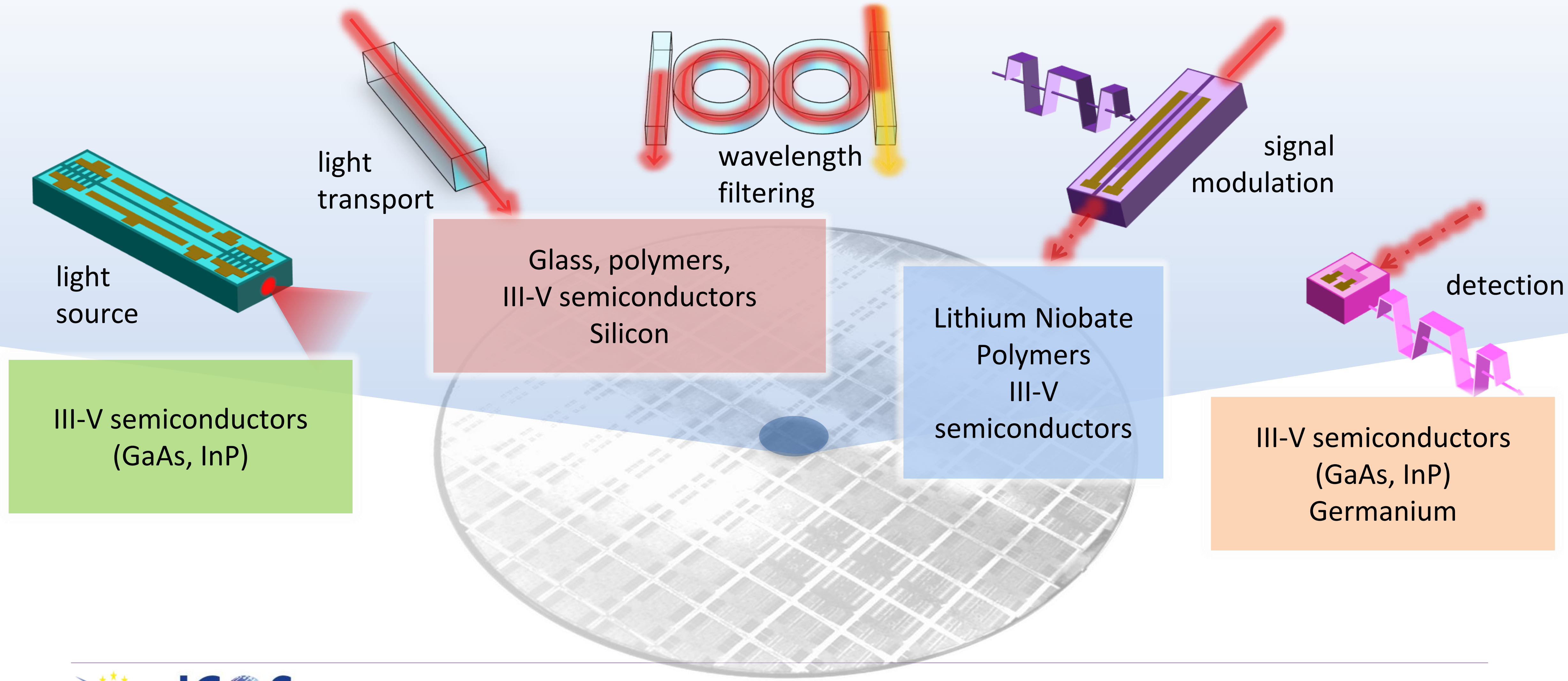
Photonic ICs

Photonic Integrated Circuits

- Photonic building blocks
- Integrated on a chip
- Connected by waveguides

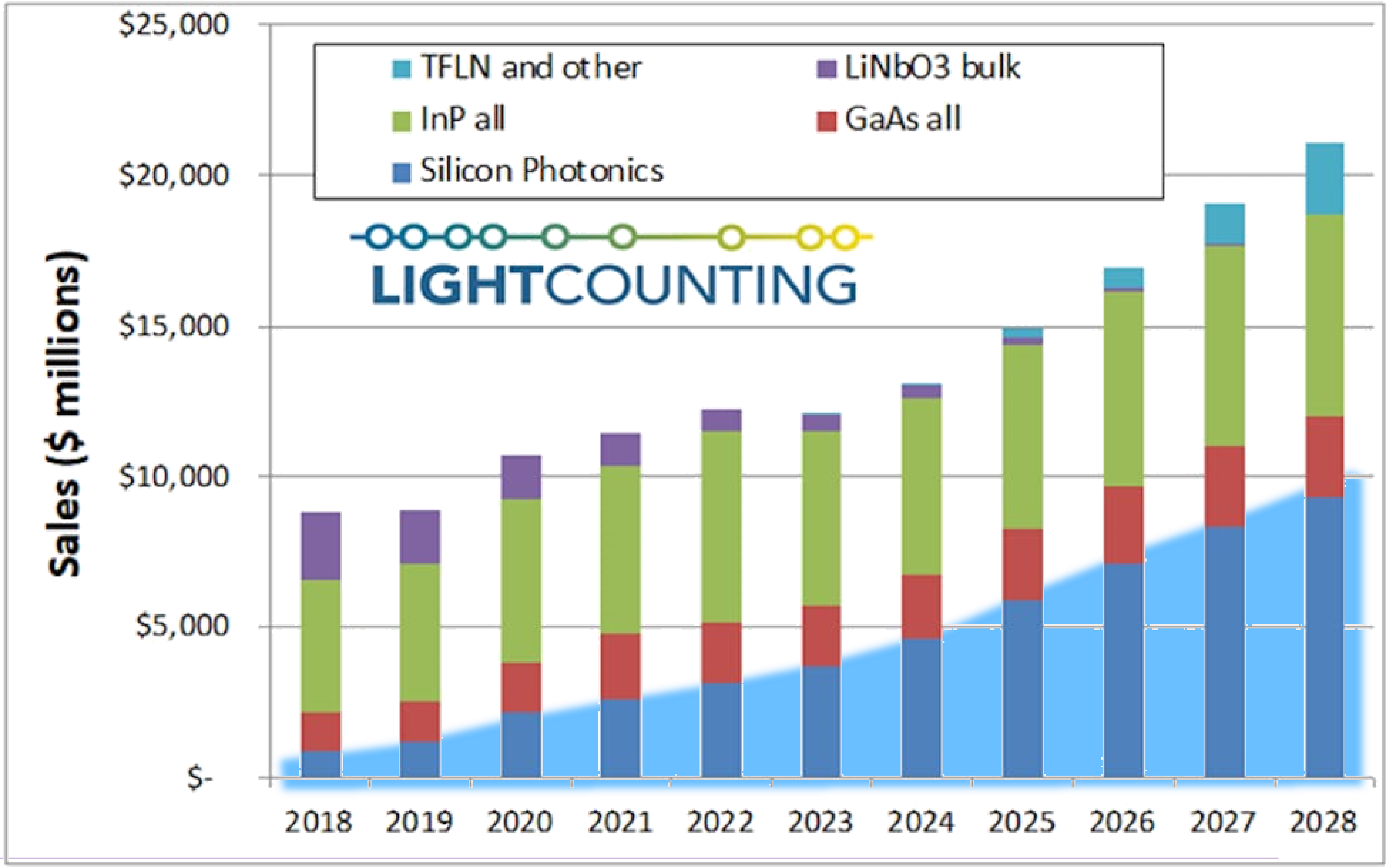


Photonic Integrated Circuits

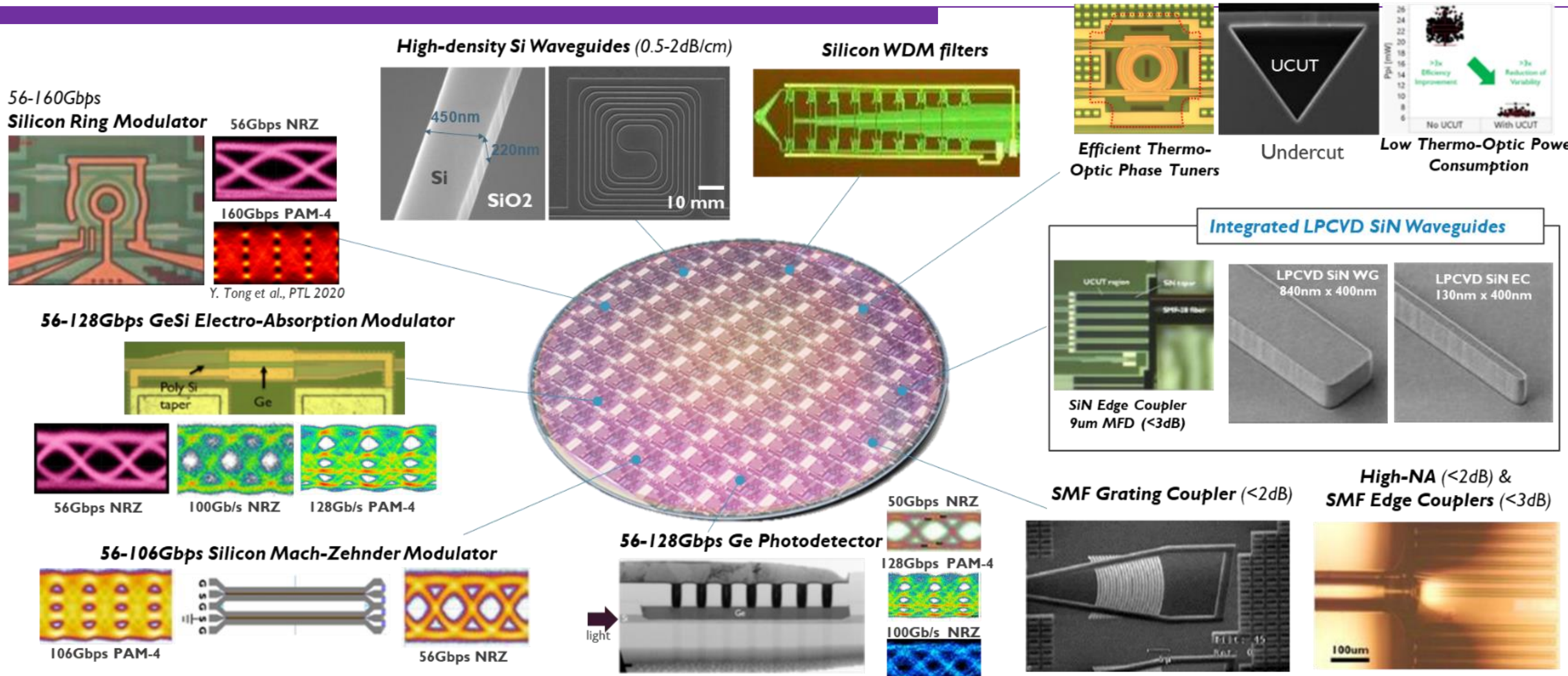


Building on Semiconductor Technology

- Diverse platforms
- III-V compound is still dominant
- Silicon is growing fast



Example: IMEC's iSiPP200 silicon photonics platform



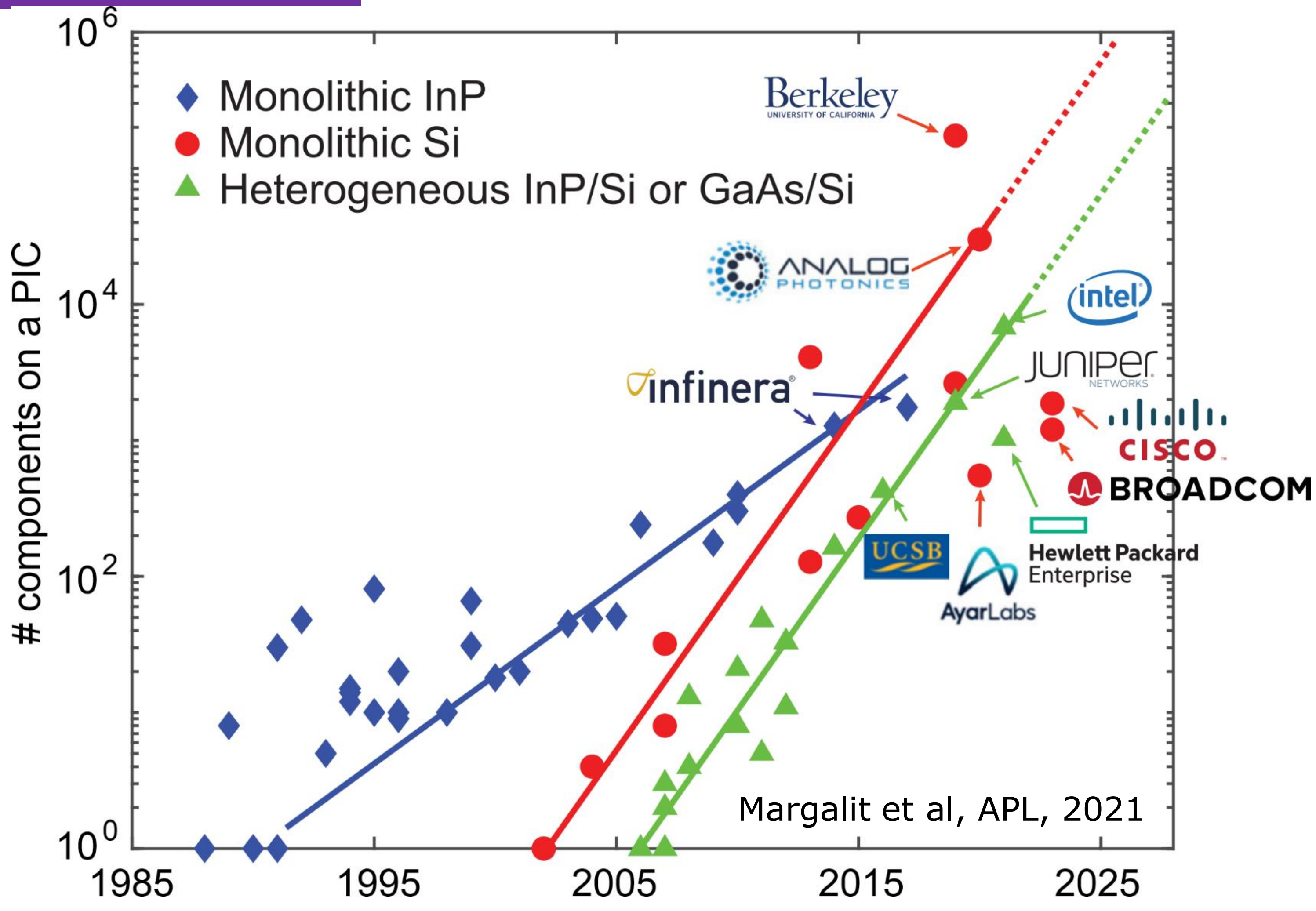
Fully Integrated Silicon Photonics Platform for 1310nm/1550nm Wavelengths

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

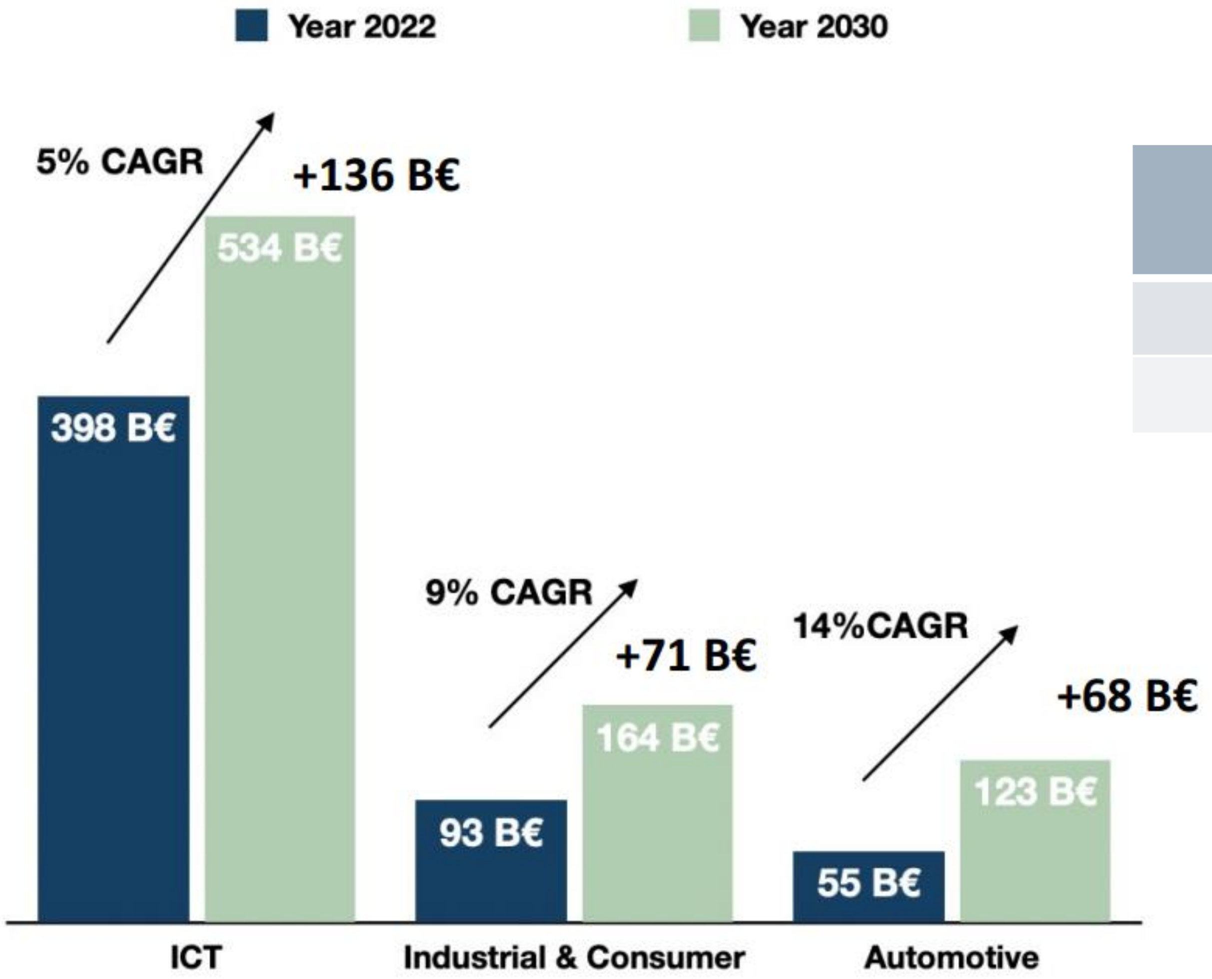
Steady scaling in complexity

Scaling depends on

- ☐ Material parameters
- ☐ Fabrication quality
- ☐ Design capabilities
- ☐ Electronic control

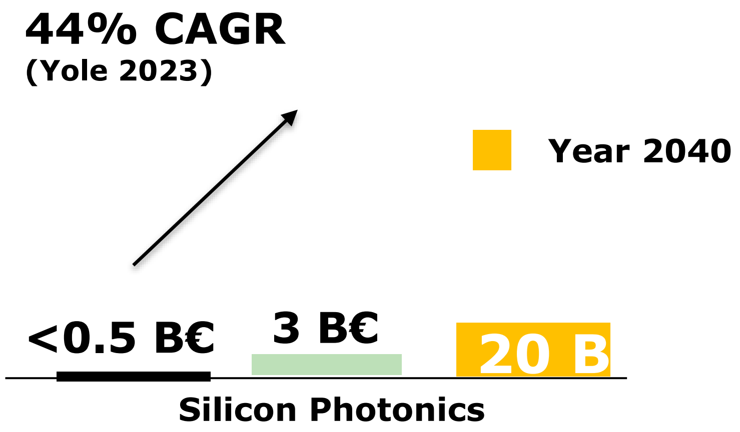


Growth in Photonic Chips



Source: DECISION Etudes & Conseil, Mc Kinsey, WSTS

Silicon Photonics Market ÷ Semiconductor Market	
2023	< 0.1%
2040	> 1%



Source: Yole market studies; Roel Baets

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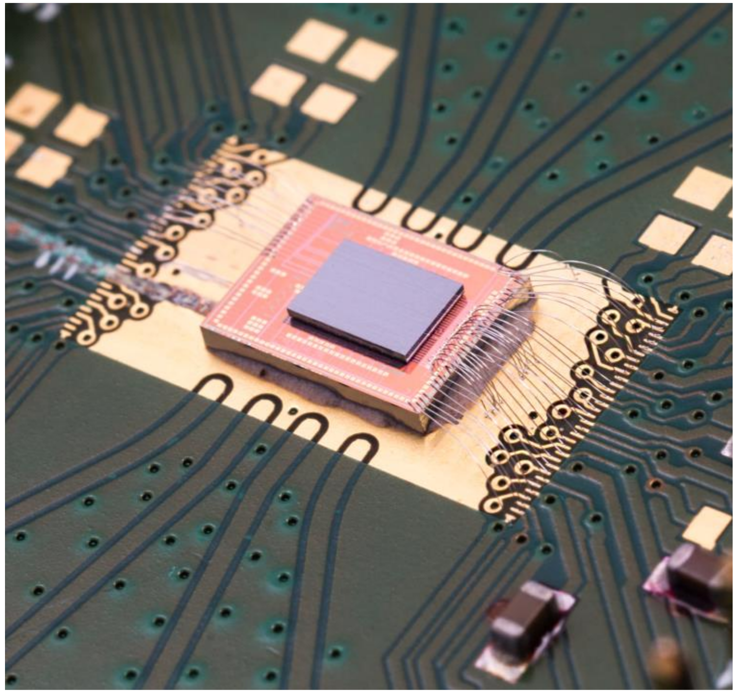
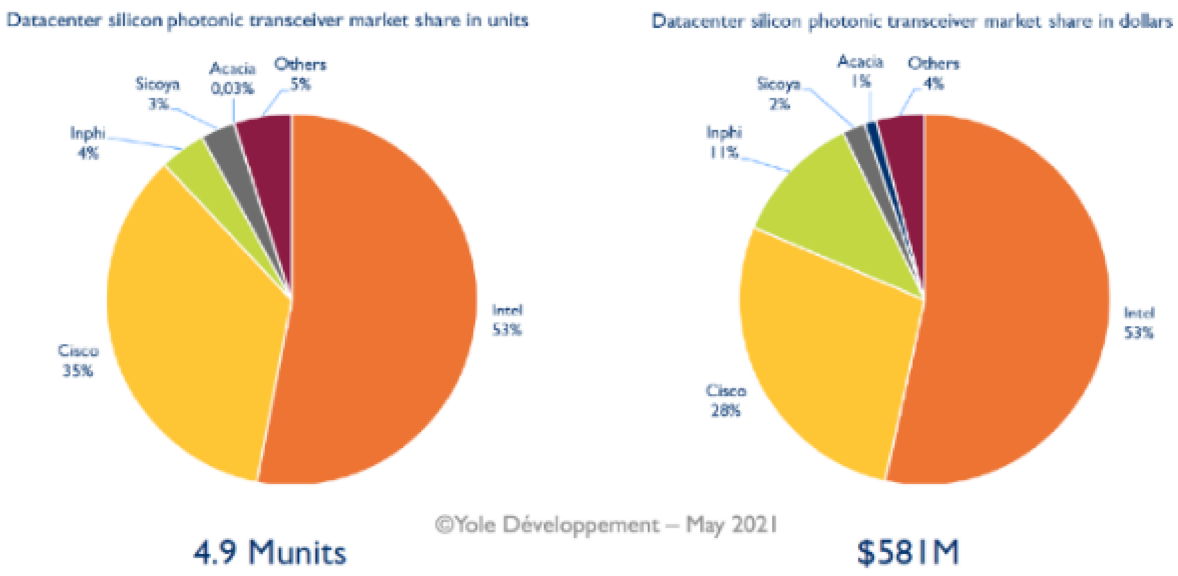


Applications Today: Transceivers

- Typical data rate: 100-400 Gb/s
- Typical symbol rate: 25-50 GBaud
- PSM4 (4 parallel fibers)
- WDM (4 wavelengths)
- PAM4
- Polarisation multiplexing
- Coherent (QPSK, 16-QAM)



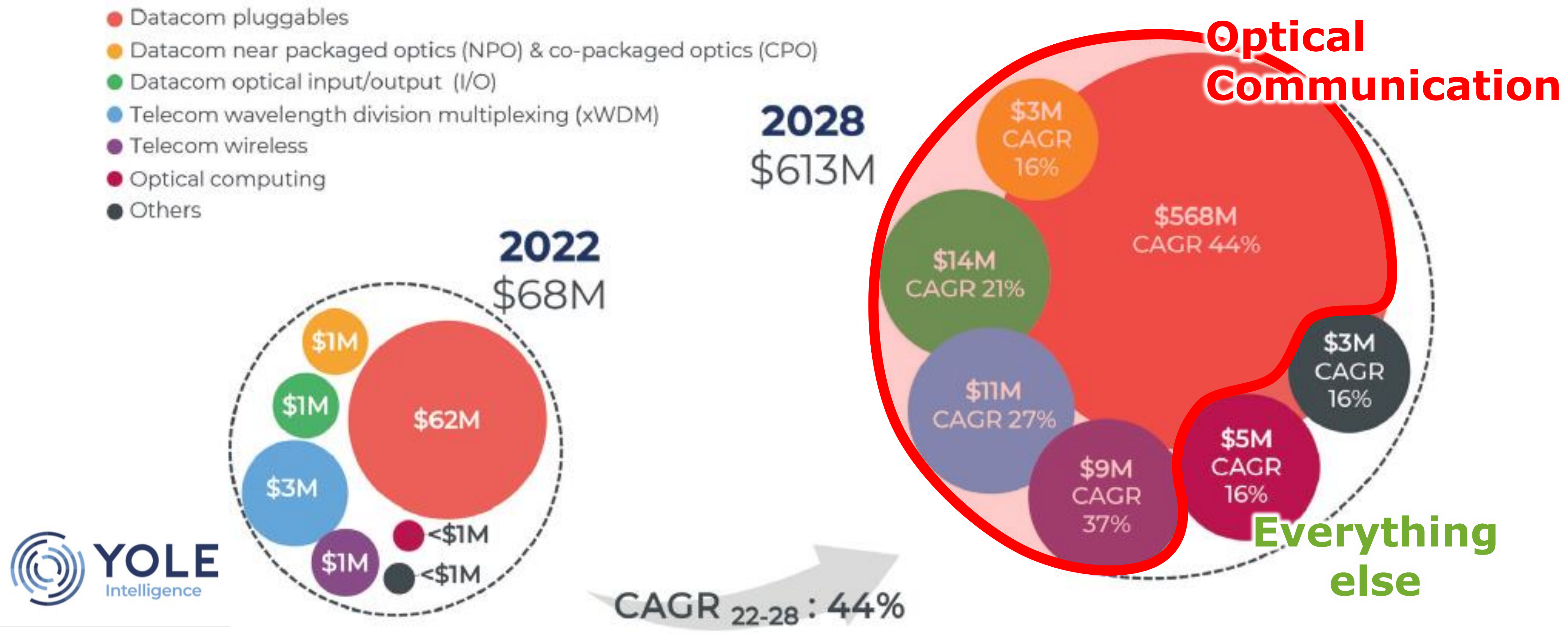
Under development + early deployment:

Data rate: >800 Gb/s

Symbol rate: 100 Gbaud

Evolution towards Co-packaged Optics

Growth in Photonic Chips

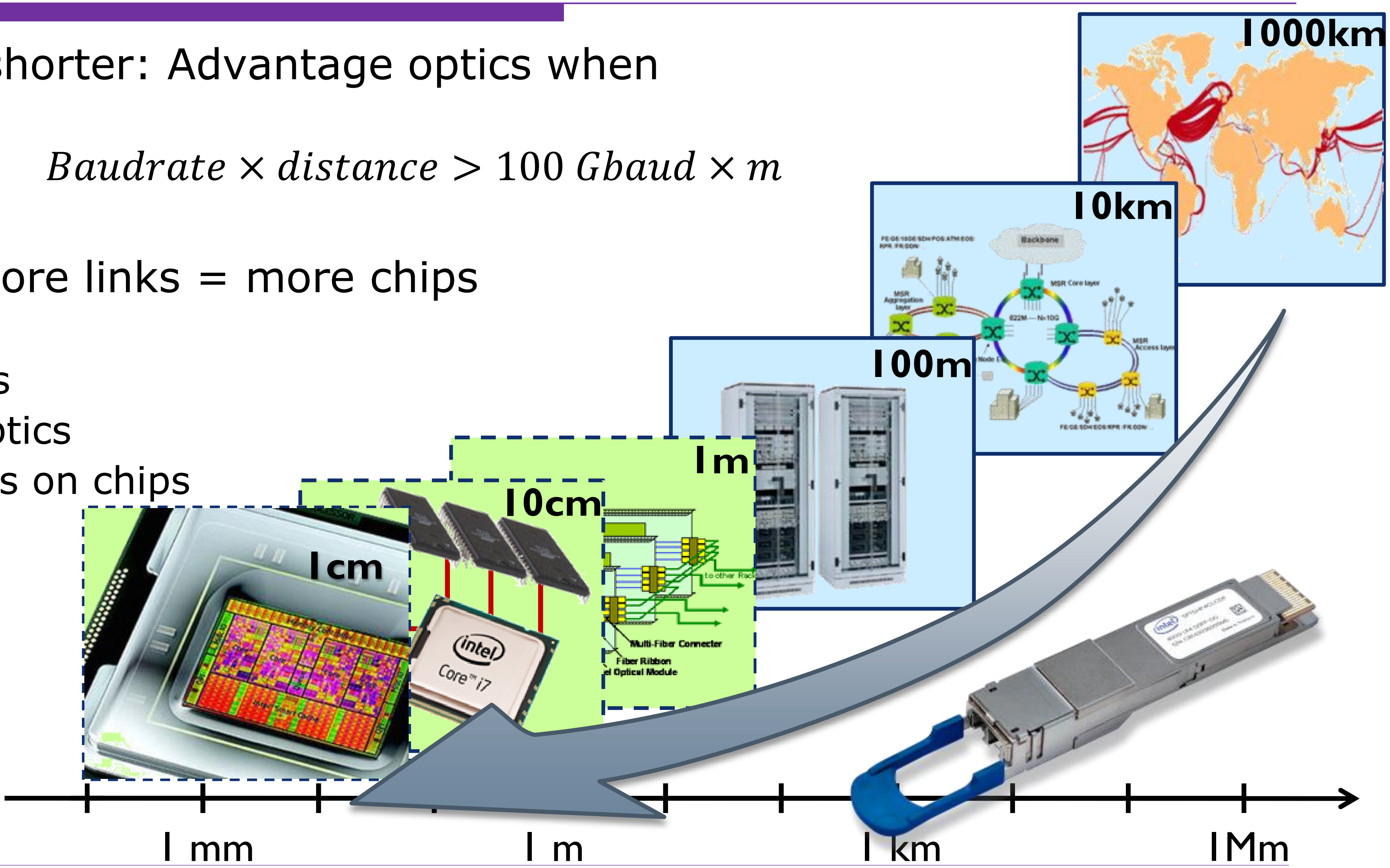


Growth paths: Optical Communications

- Optical links get shorter: Advantage optics when

$$Baudrate \times distance > 100\ Gbaud \times m$$

- Shorter links = more links = more chips
  - Pluggables
  - On-board Optics
  - Co-packaged optics
  - Optical networks on chips
- Fueled by AI

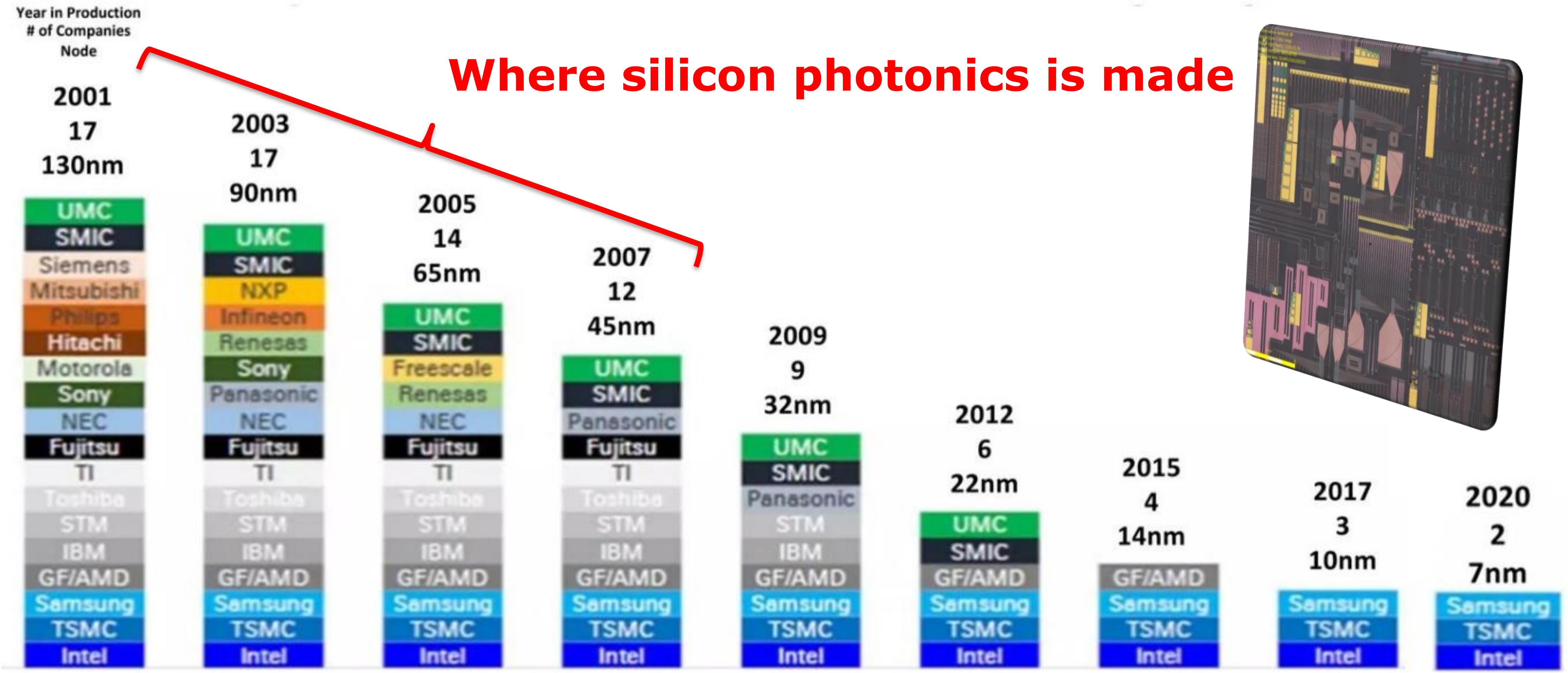


Photonic Chip Technology

- Today: Photonic chip technology is "adequate"
  - processes on 200mm or 300mm
  - low enough waveguide losses
  - decent modulators
  - very good detectors
  - basic laser integration

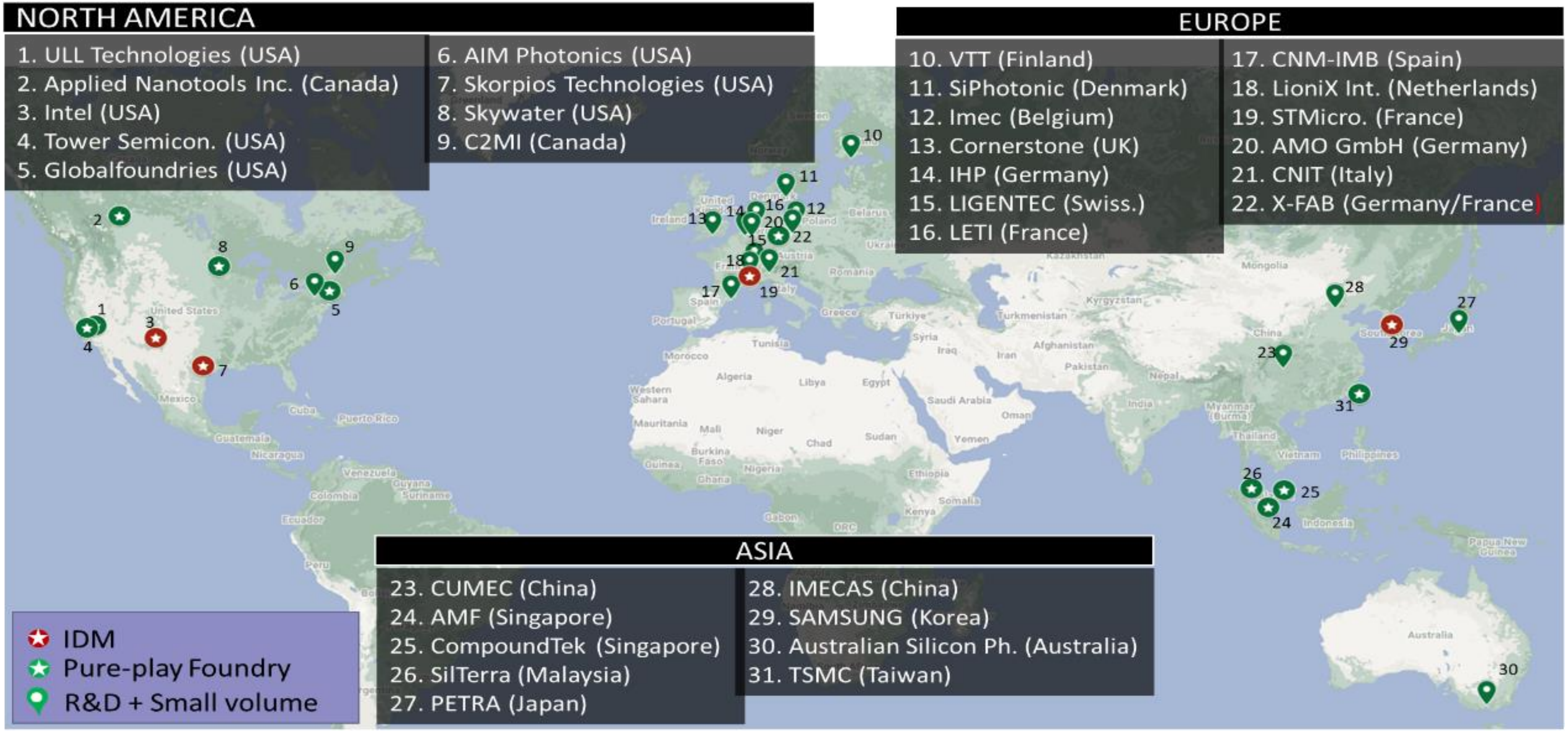
- But improvements are needed for future chip generations
  - Lower losses
  - higher-speed modulation
  - low-power tuning
  - many light sources
  - high optical power handling

Who can make Silicon Photonics?

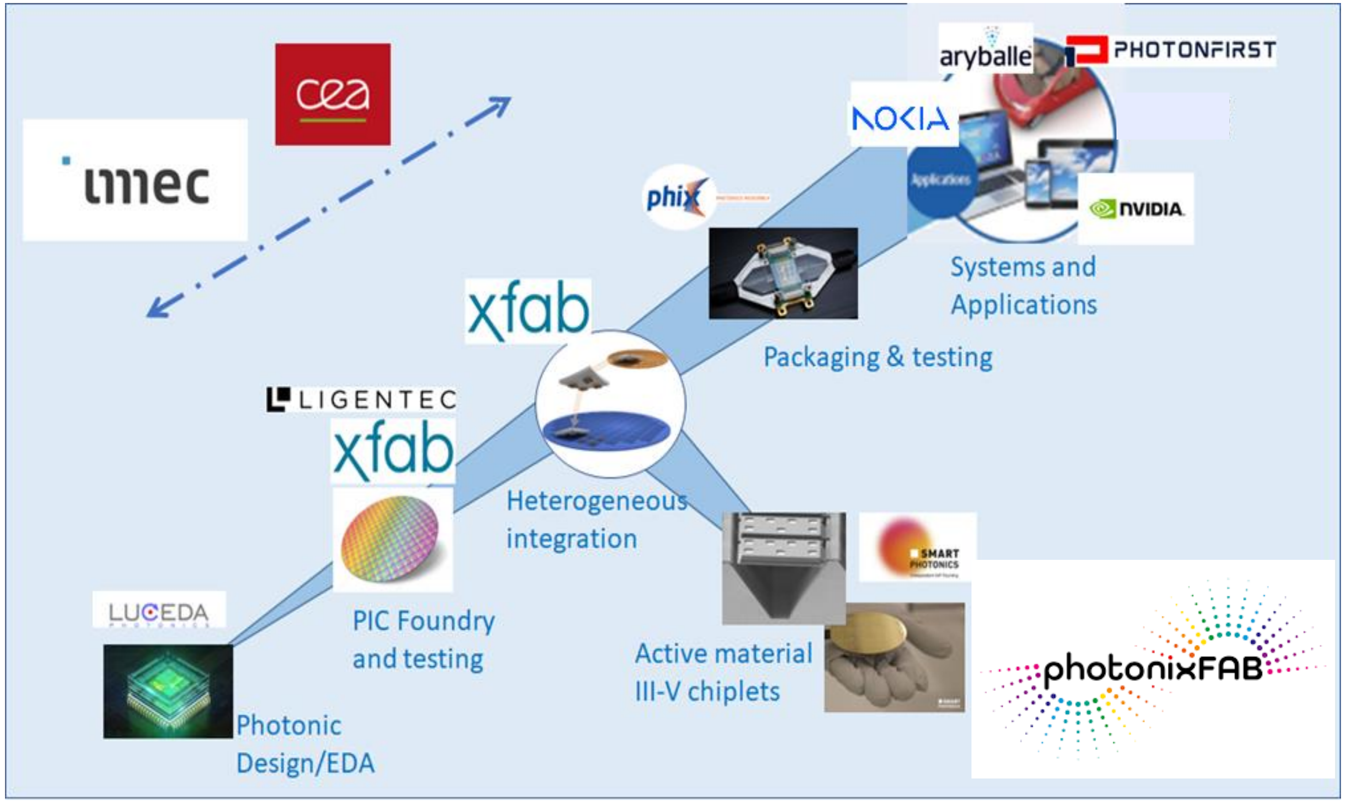


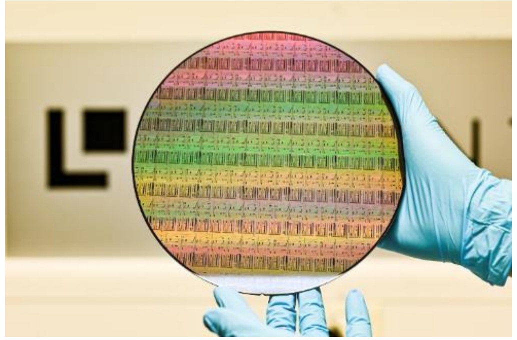
Bharat Jha, The Evolution of Semiconductor Nodes: A Journey of Innovation and Progress, LinkedIn

Who can make Silicon Photonics?

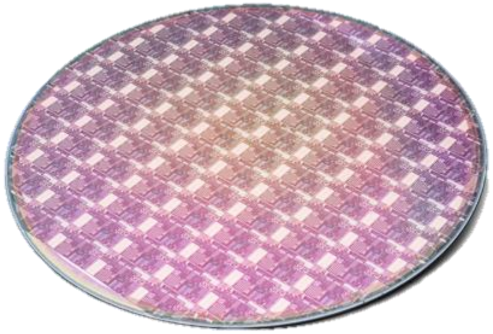


In Europe: PhotoniXFAB





- SiN platform
- X-FAB with Ligentec



- SOI-platform
- X-FAB with imec

European Commission

ChipsJU

SMART PHOTONICS
Independent InP Foundry

- Heterogeneous
- integration of InP

What to do with all this capacity?

- A lot of choice for photonics fabs
  - Multiple pure-play silicon photonics foundries
  - Foundries for specialized platforms (e.g. III-V)
  - Many R&D institutes to help with development (IMEC, LETI, CNSE, CUMEC, …)

- Is this economical?
  Current SiPh wafer volume:
  only ~100’000 wafers / year (300mm eqv)

- We need more applications

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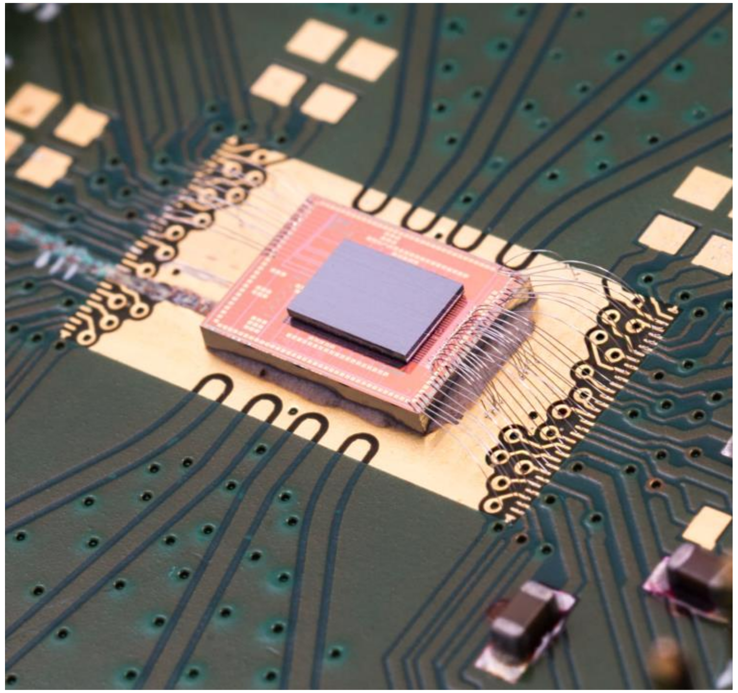


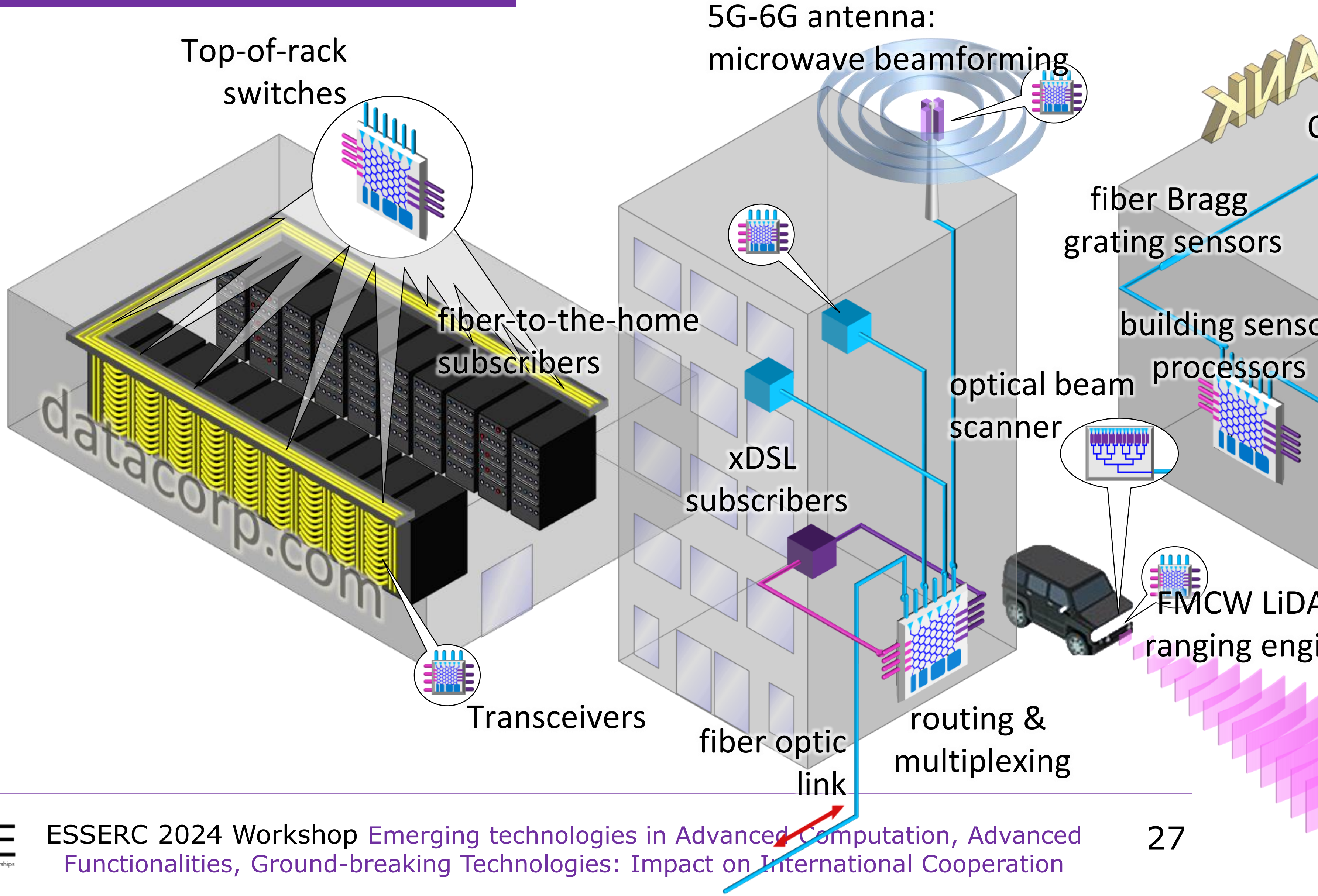
Only Optical Communications?

- Electronics is only for calculators?

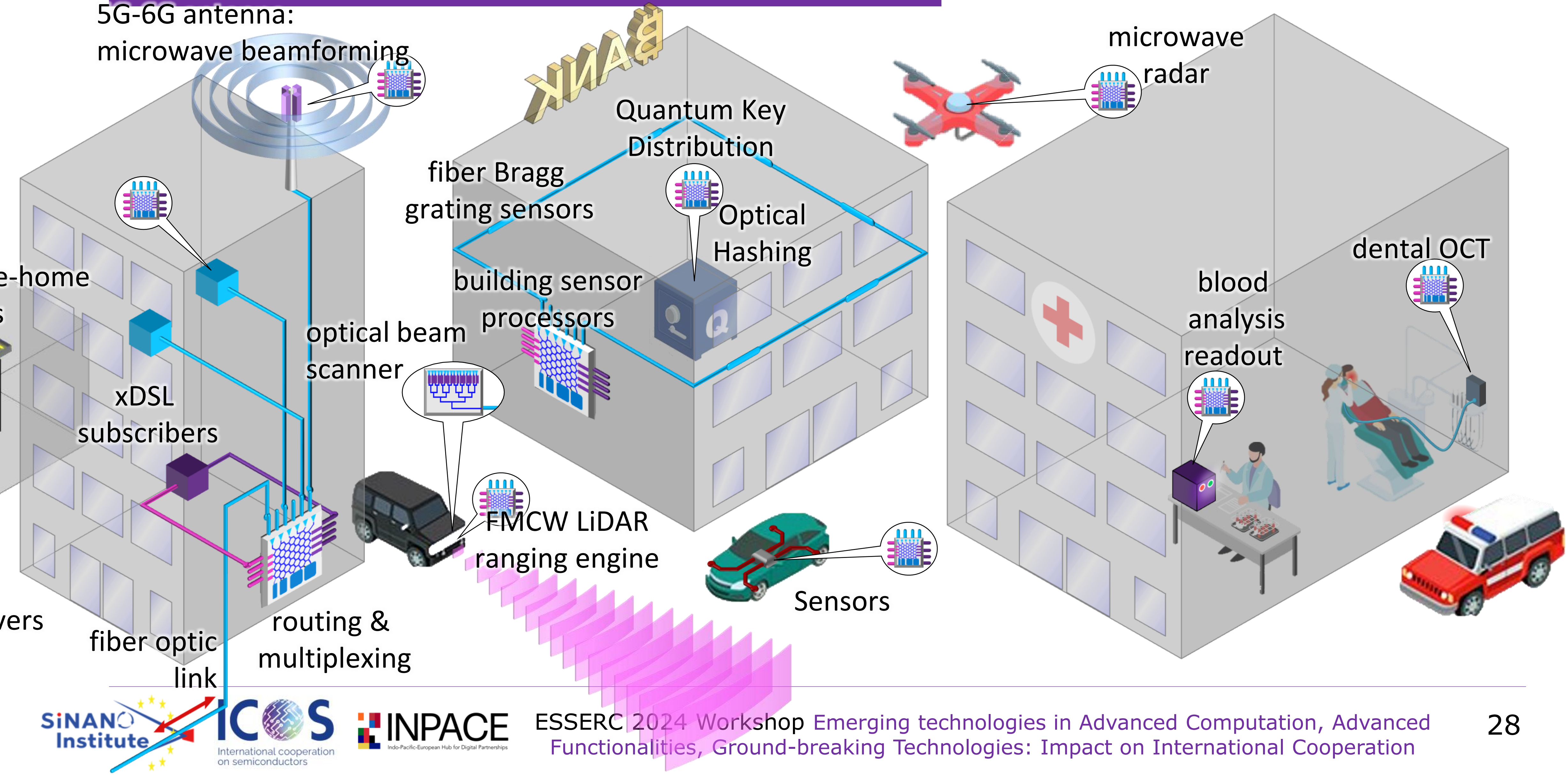
- Photonics is only for interconnects?

What else is there?

Photonic Chips can serve many applications

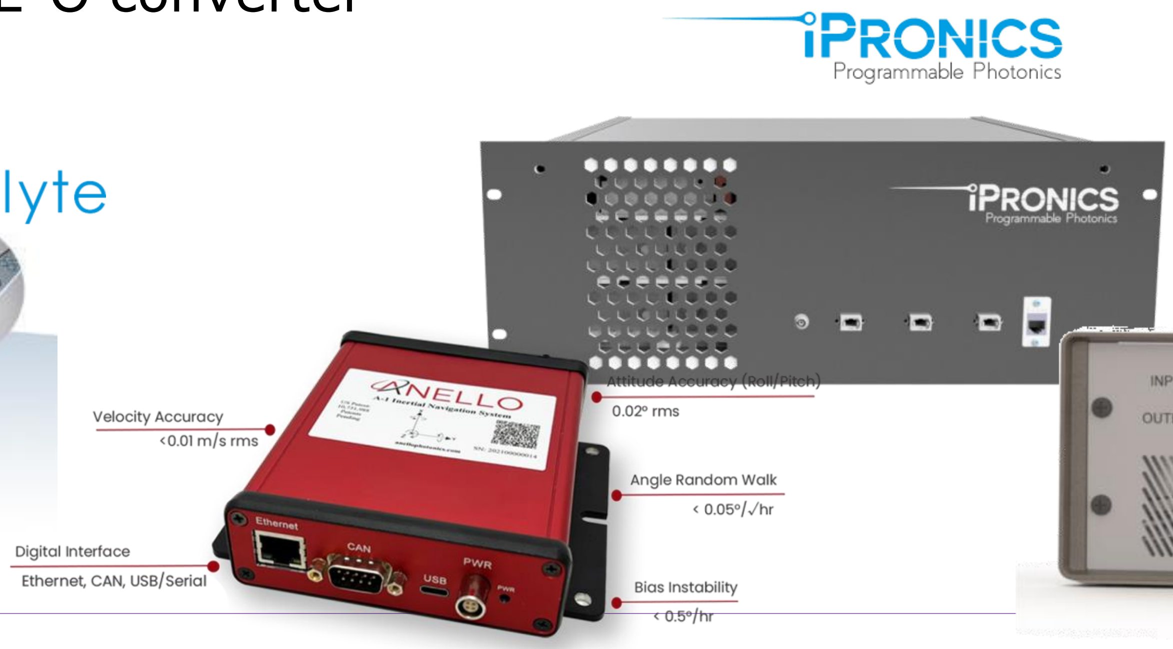


Photonic Chips can serve many applications



New Applications: Examples

- Biosensors (Genalyte)
- Quix quantum processor
- Sentea, PhotonFirst
- Anello Gyroscope evaluation kit
- iPronics photonic processor
- ThorLabs E-O converter



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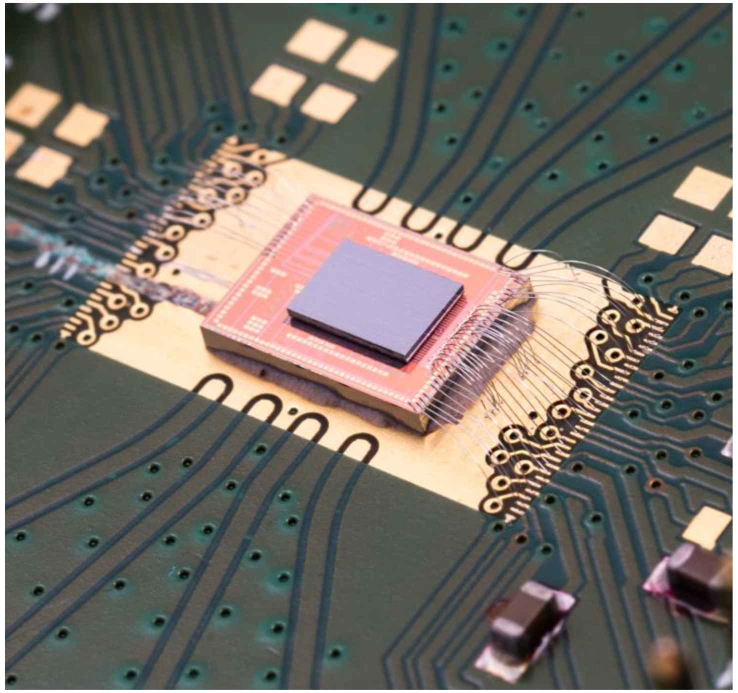
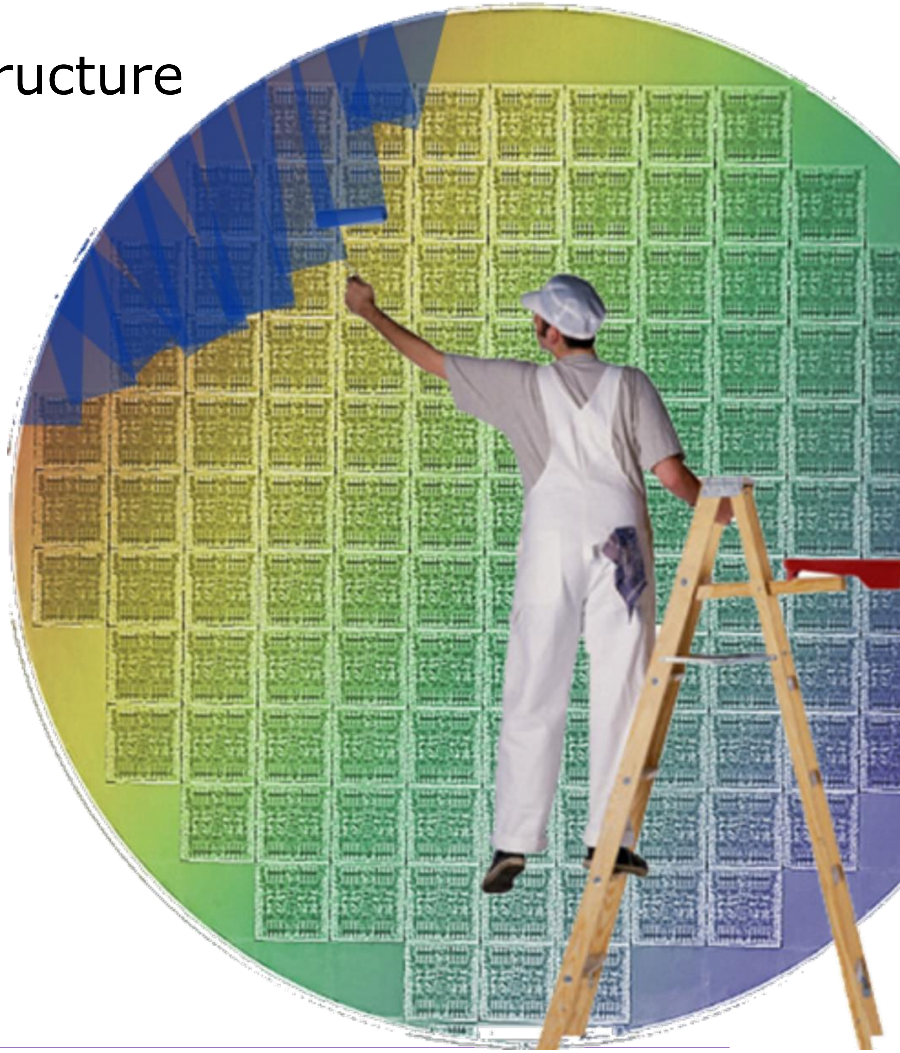


Challenges for the Photonics Ecosystem

- Low volume: need more applications
- Getting the best materials (Heterogeneous integration)
- Design and modelling (first-time-right capabilities)
- Rapid prototyping (bypass long chip iteration cycles)
- Packaging (optical, electrical, mechanical, thermal, RF)
- Combining photonics and electronics

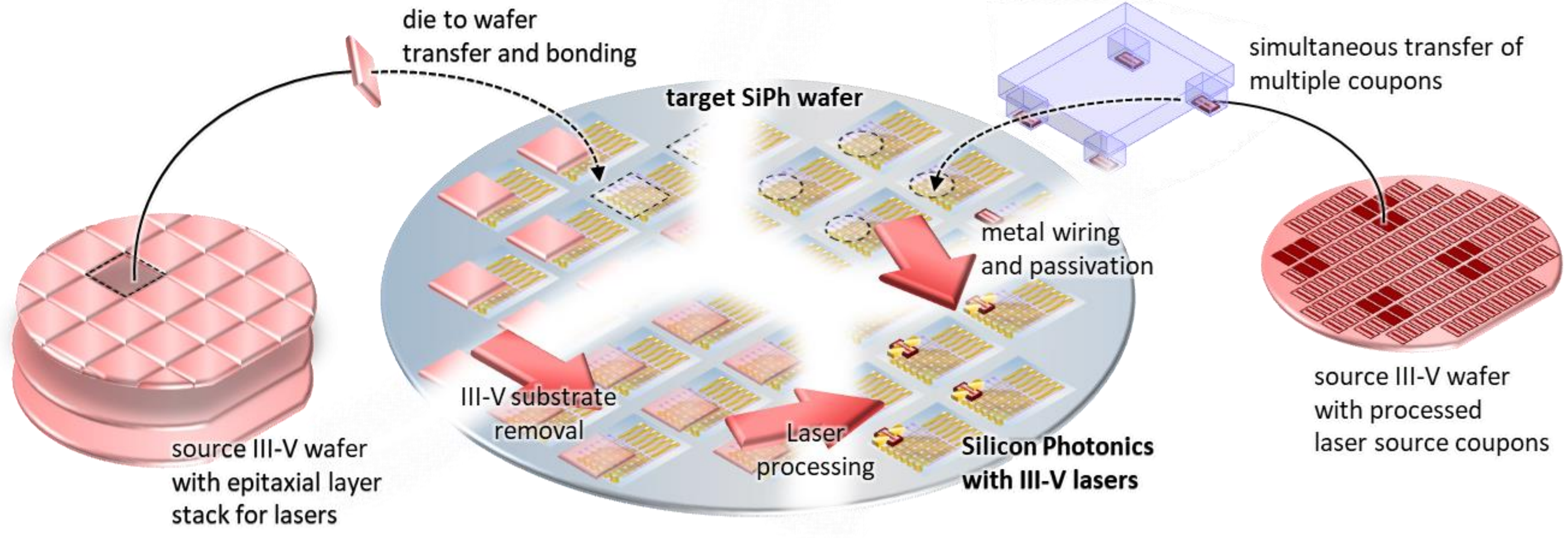
Heterogeneous Integration

- Silicon photonics provides the most scalable infrastructure
- But not the best material
  - no light emission
  - no electro-optic modulation
  - no high power handling
- Heterogeneous Integration: bring in new materials (at wafer scale, but at the end of the line)
  - Bonding
  - Transfer printing
  - 3D stacking
  - Inkjet printing



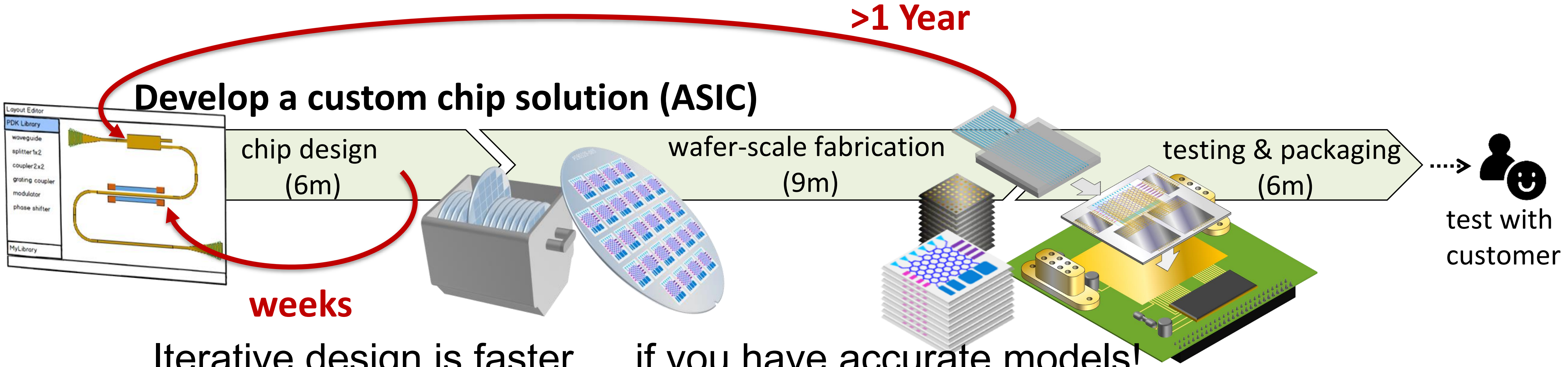
Heterogeneous Integration

Die-to-wafer bonding **Micro-Transfer Printing**



Design Challenges

The design – fabrication – test cycle is long and expensive

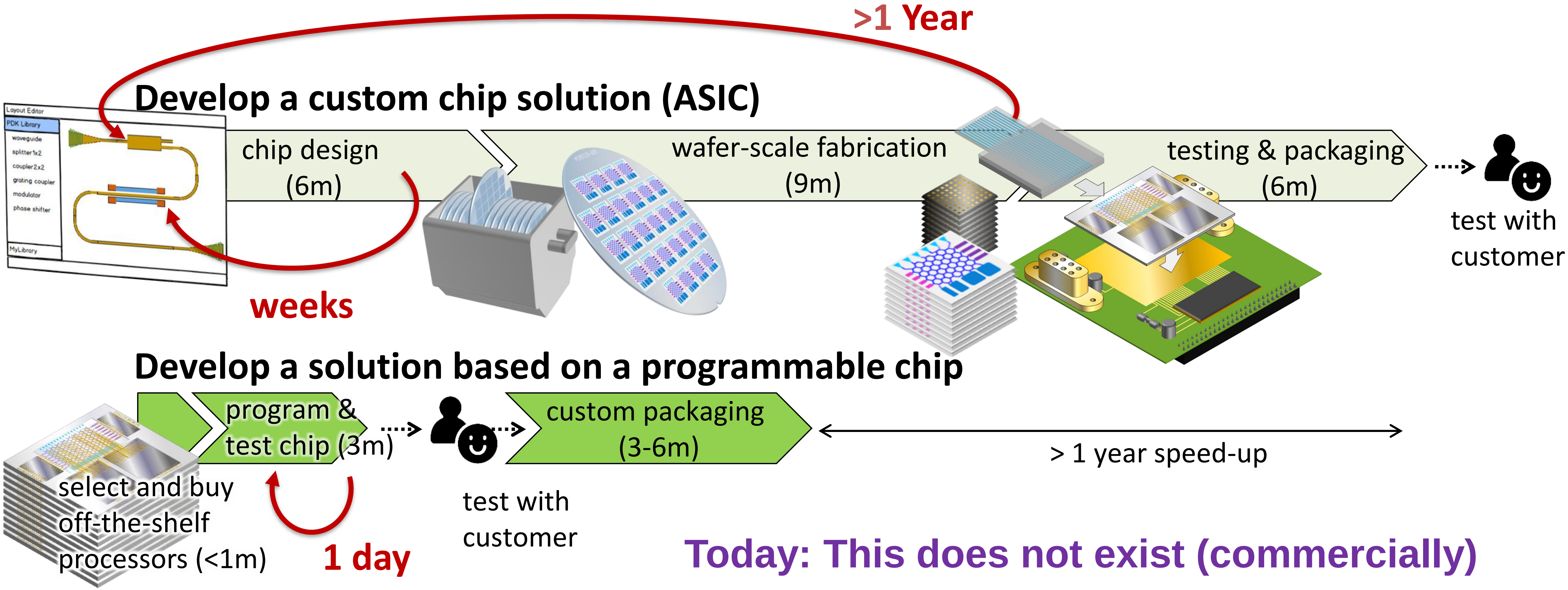


Iterative design is faster … if you have accurate models!

Today:

- no standardized circuit simulation formalism (like SPICE)
- no standardized photonics models with parameter extraction

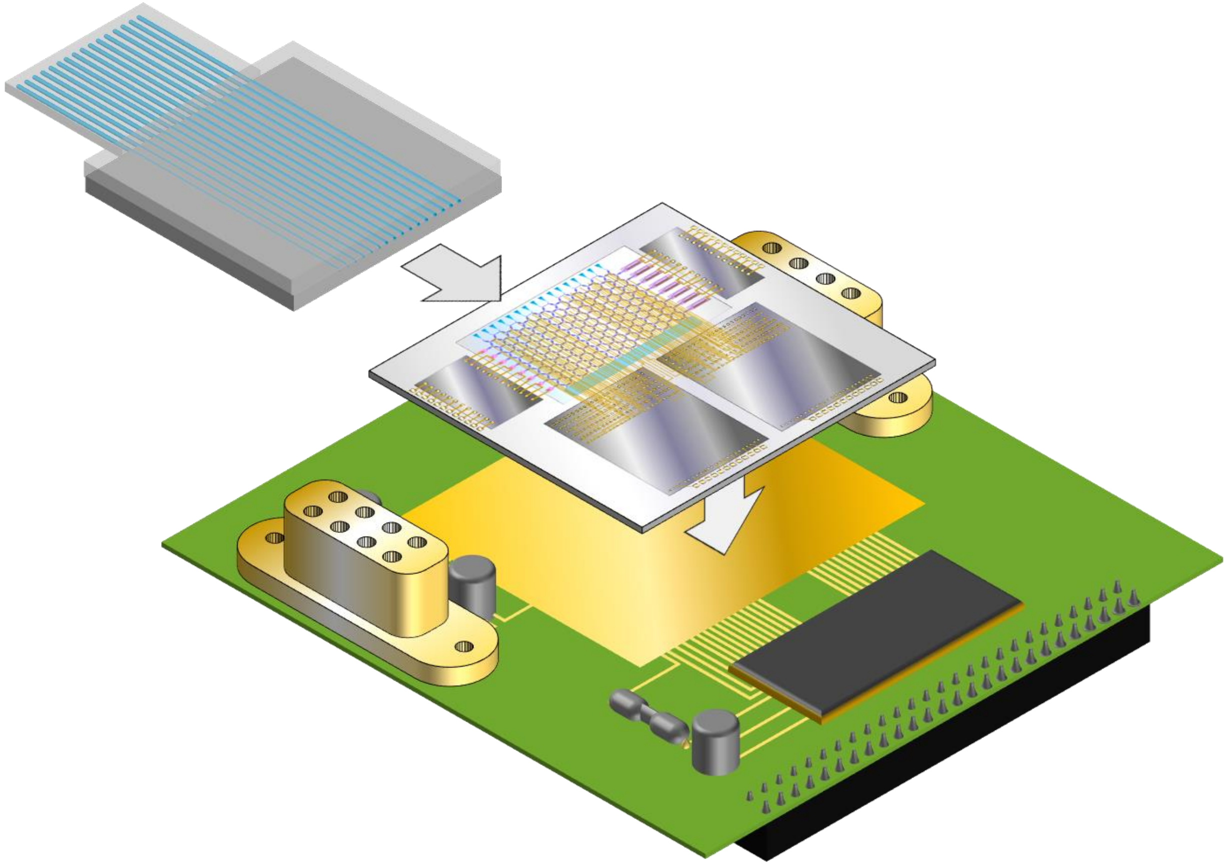
Rapid-Prototyping Challenges



Today: This does not exist (commercially)

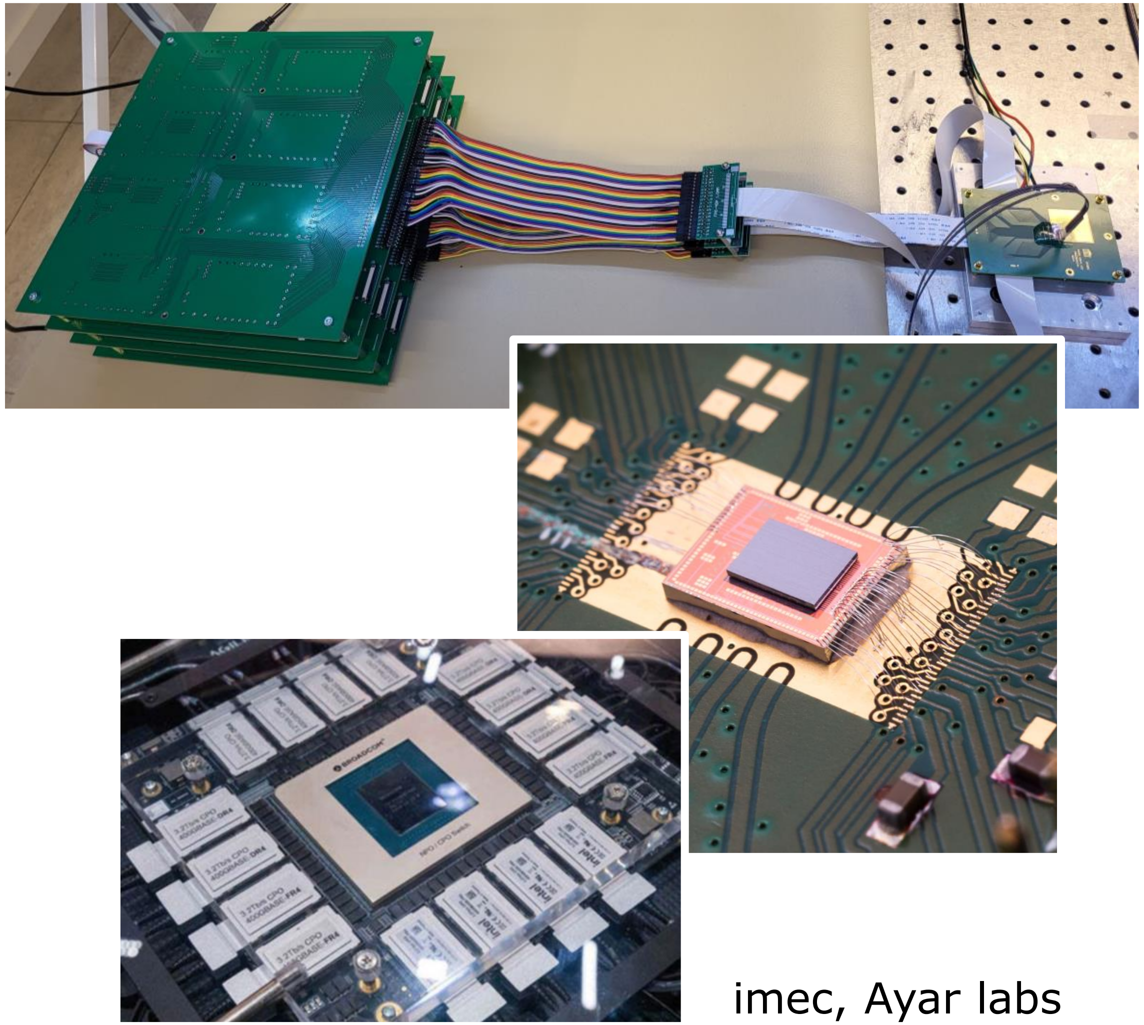
Packaging Challenges

- Packaging is >80% of the cost of photonic chip products
- Many considerations:
  - Optical
  - RF
  - electrical
  - thermal
  - mechanical
- Cost-effective fiber attach methods are under development
- A slow push for standard form factors



Photonic-Electronic integration

- Electronics needs photonics
  - for high-bandwidth interconnects
- Photonics needs electronics
  - for control and acquisition
- Many co-integration schemes
  - separate
  - wirebonding
  - flip-chipping
  - interposers, co-packaging (chiplets)
  - monolithic (o the same chip)
- Some standards would be welcome

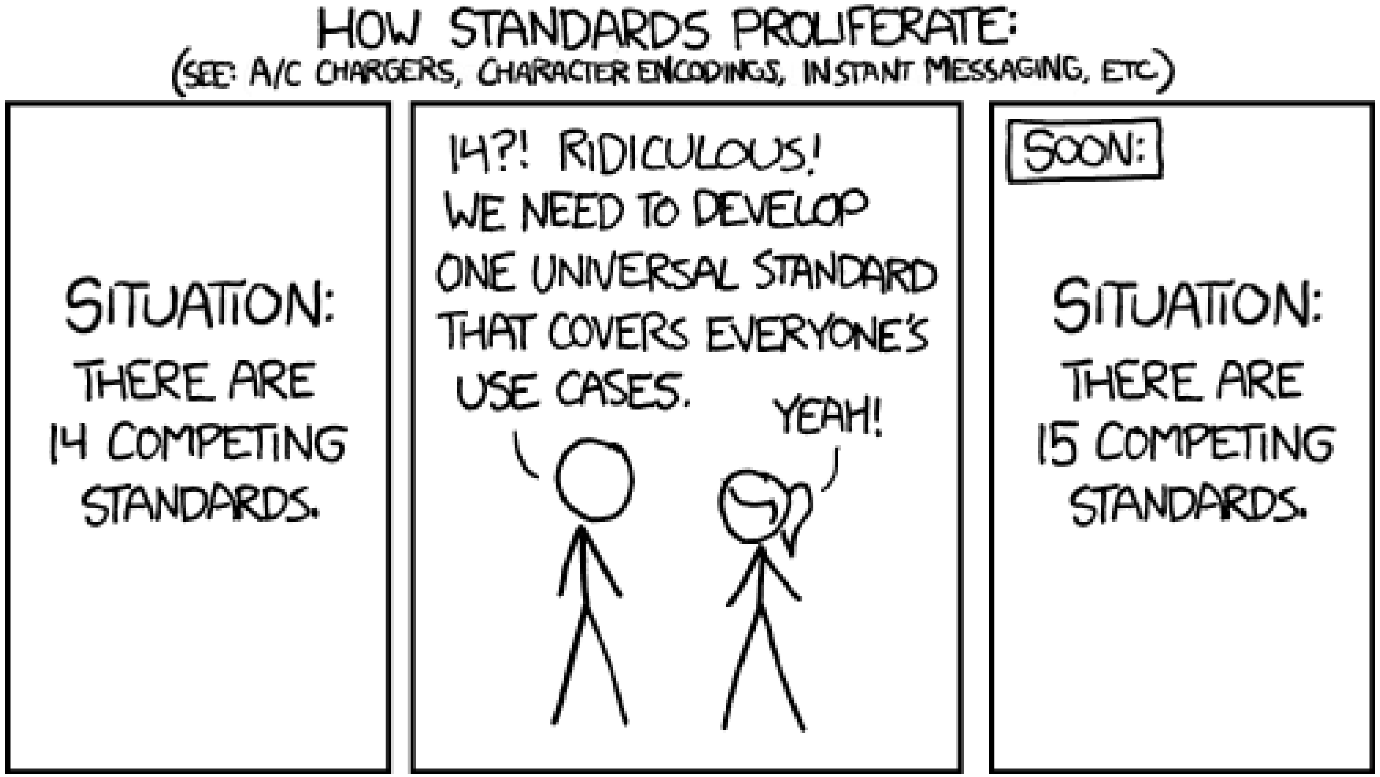


imec, Ayar labs

Standards in photonics

- There are standards for photonics
  - A legacy from telecom
  - pluggables for datacom

- But today…
  - time to market is more important than standardization
  - many competing solutions



xkcd

Integrated Photonics Systems Roadmap

BRUGES 9-12 SEPTEMBER ESSERC 2024

IPSR INTERNATIONAL

International initiative to create a technology roadmap for photonic chips (not just silicon photonics)

- Main initiative: PhotonDelta, AIM Photonics, ePIXfab
- Objective:
  - Identify the key future developments
  - Identify bottlenecks in performance and supply chain
  - With a projected timeline

=> Purple brick wall

	TECHNOLOGY/DEVICE LEVEL				
Year	**Wafer-scale light source integration**	**High-speed modulators**	**High-speed detectors**	**Waveguides**	**Optical isolator/circulator**
2024	• Only limited number of suppliers offering wafer-scale light source integration. • Maturing reliability and yield for all heterogenous integration processes.	Cranking up modulator performance (bandwidth, energy, …) through novel materials (LN, BTO, polymers…) on SOI SiPh or as dedicated thin-film technology on silicon	Germanium photodetectors with high-speed and low dark currents addressing today's market needs	• Waveguide geometry accurate and uniform down to a few nm-scale (and better for fabs using immersion lithography). • Only limited usage of OPC, in particular for curvilinear designs (lack of OPC-tools)	• Moderately good results at research level • No industrial platforms with integrated isolators.
2025	Solutions addressing application-specific needs	Even higher bandwidh demands with even higher energy efficiency		Techno-economics barrier (lithography costs and mask costs)	
>2030	Scale-up challenges for industrial-grade heterogenous or monolithic integration approaches for light sources, especially at non-telecom wavelengths	New uncharted methods for driver-modulator architectures and associated technologies.	• Moving bandwidths beyond 150 GHz • Process flows with new materials for other spectral bands	Order of magnitude better pattern fidelity (OPC, process control…) for passive waveguide structures.	Techno-economic barriers
>2035	Established supply chains for wafer-scale light source integration for all relevant spectral bands (monolithic or heterogeneous)		Established supply chains for wafer-scale detector integration for all relevant spectral bands (monolithic or heterogeneous)		Established integrated isolators with good performance in industrial platforms.

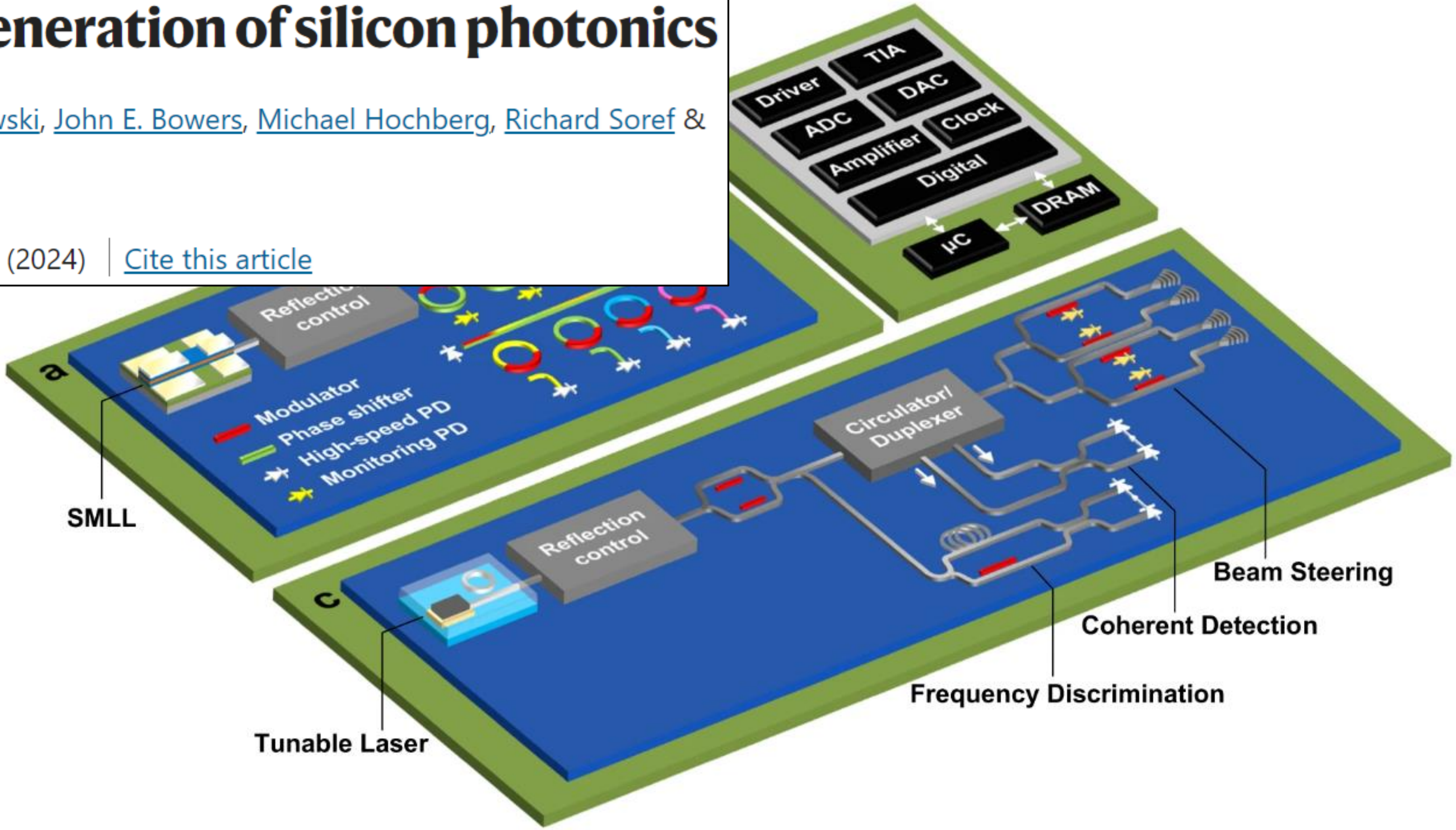
What is coming?

Perspective | Open access | Published: 25 January 2024

Roadmapping the next generation of silicon photonics

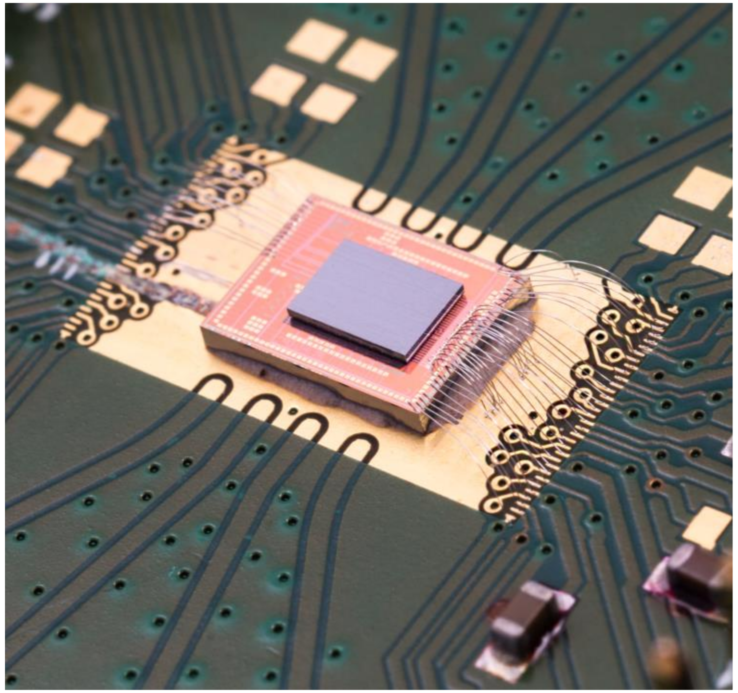
Sudip Shekhar, Wim Bogaerts, Lukas Chrostowski, John E. Bowers, Michael Hochberg, Richard Soref & Bhavin J. Shastri

Nature Communications 15, Article number: 751 (2024) | Cite this article



Summary

- Photonics is already enabling our information society
  - Telecom
  - Optical interconnects
  - AI
- There are already established foundries
  - For silicon and other platforms
  - With ample capacity (and more being deployed)
  - Driving steady improvement in performance
  - Establishing regional foundries
- It can enable many more applications (but this is a slow process)
  - Need mechanism to speed this up (design, rapid prototyping, …)
  - Some standards would help



Thanks …