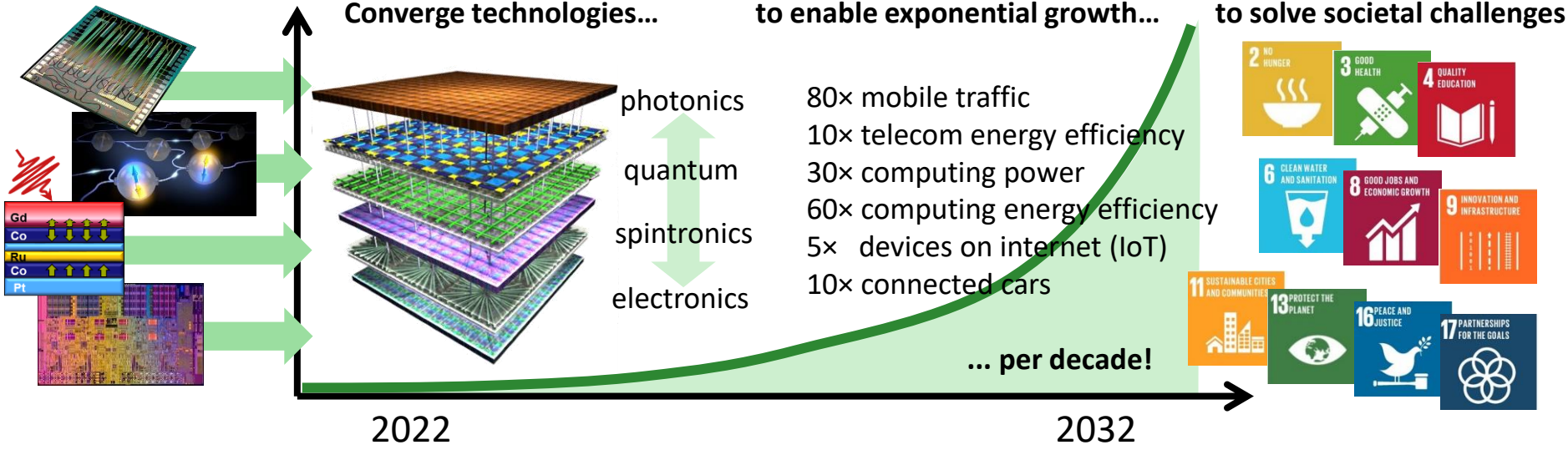
Photonic Integration for Space Applications

September 14. 2022, EPIC Meeting on Photonics at the Final Frontier at European Space Agency (ESA)

Martijn J. R. Heck

Eindhoven Hendrik Casimir Institute

Heterogeneous systems, based on new paradigms in computing, communication and sensing, will become the key enabler of our sustainable information society, thereby addressing our global societal challenges



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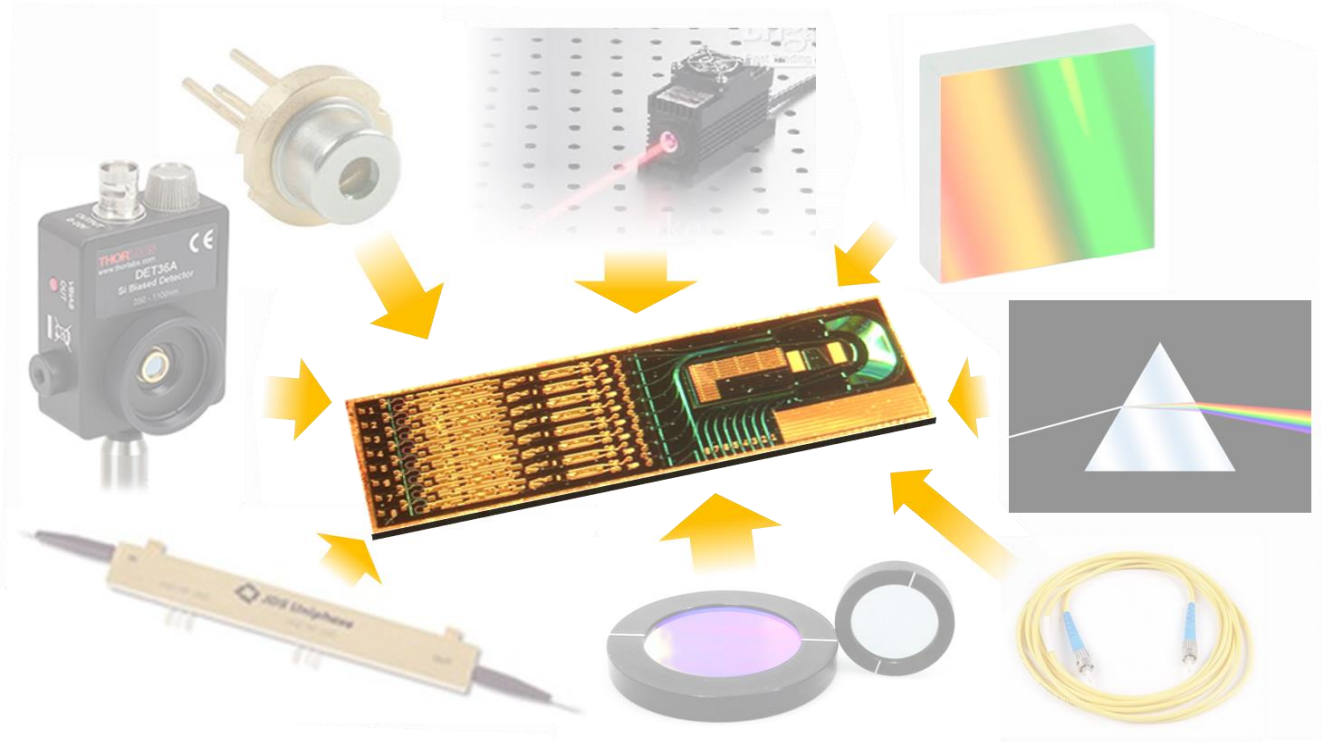
Photonic integration: optical chips



Advantages of photonic integration

increased performance

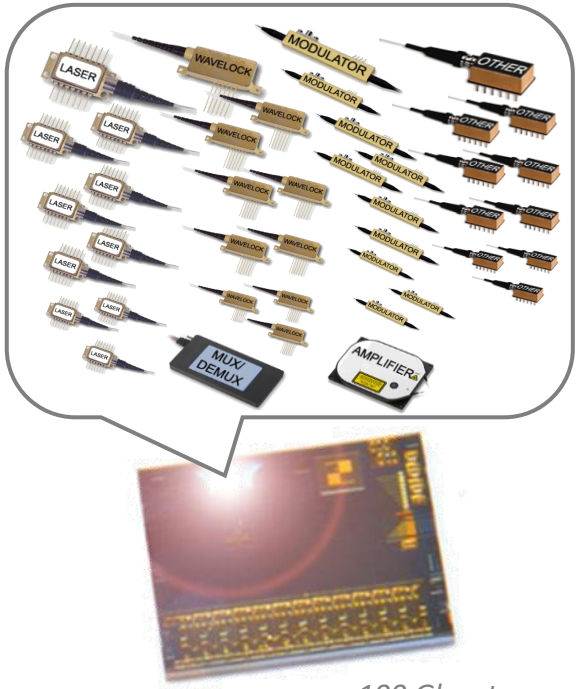
in terms of stability, speed and sensitivity, improves electronics performance;

decreased size, weight and power (SWaP)

for use in, e.g., drones, space and aircraft, handheld and wearable devices;

decreased cost

at high volumes due to wafer-scale manufacturing.



100 Gbps transmitter
R. Nagarajan, Infinera, 2006

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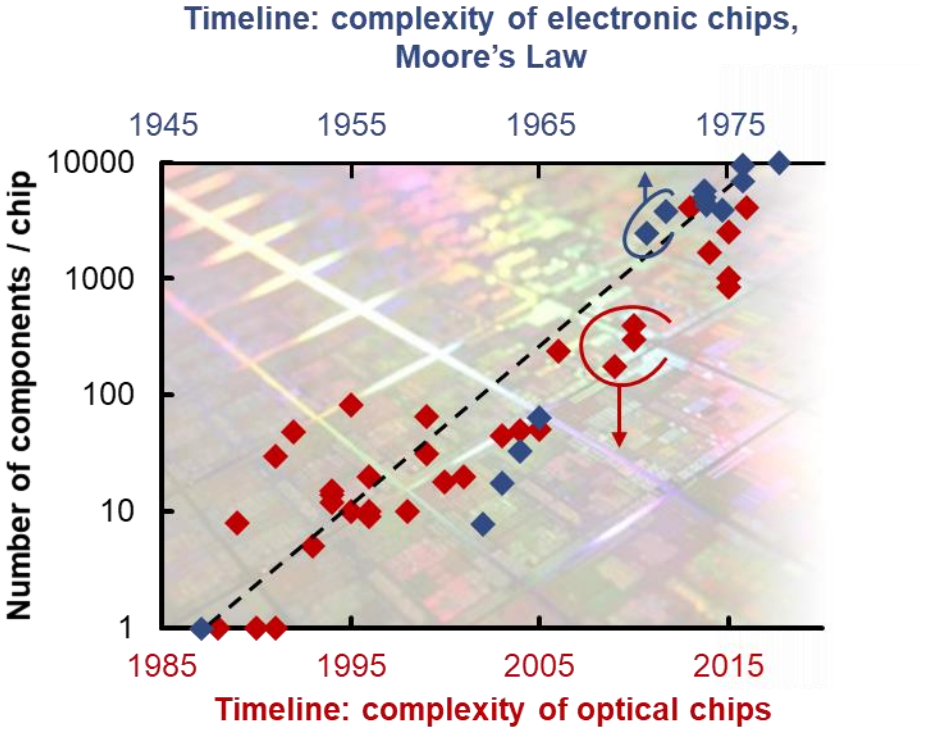
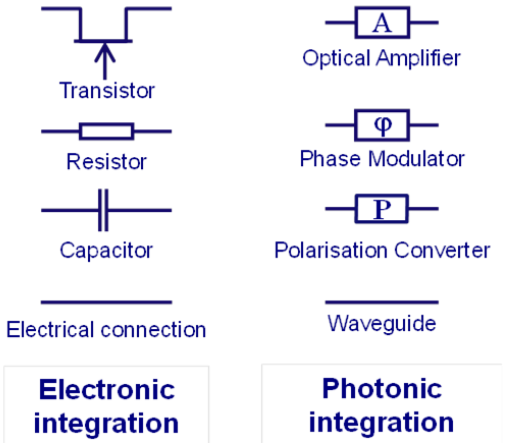
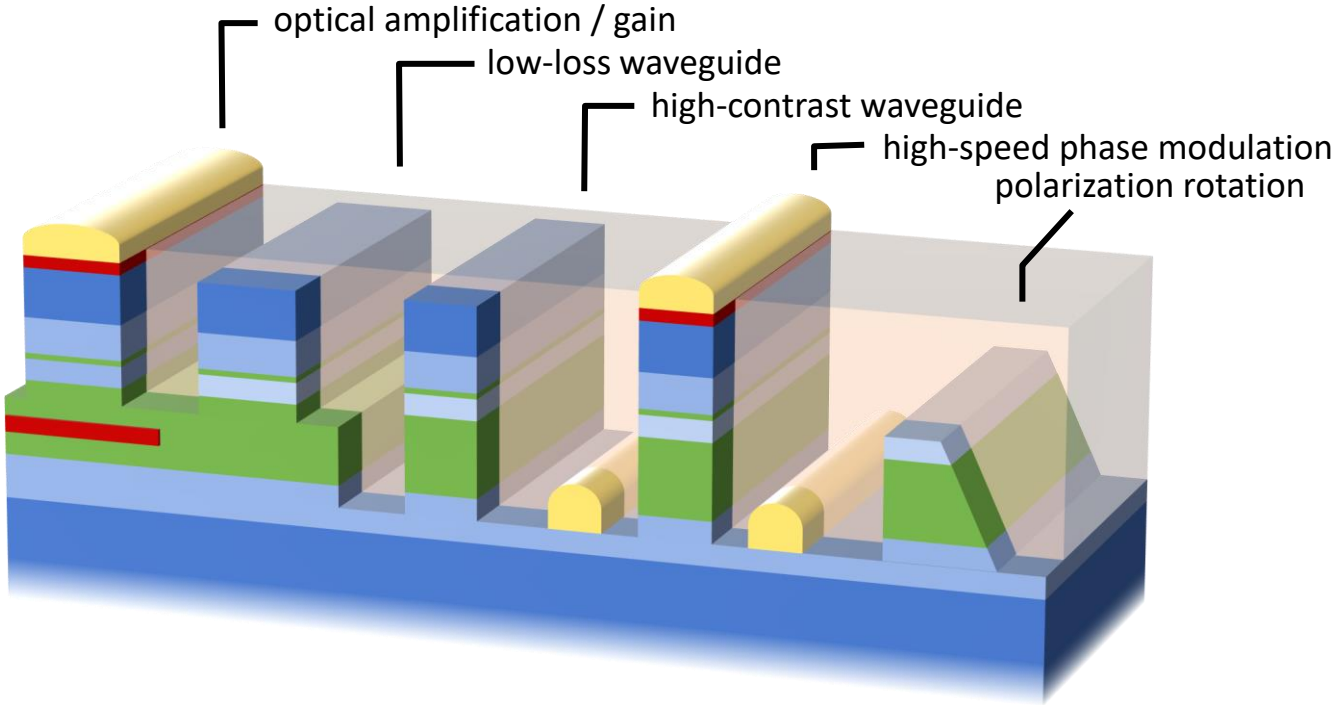
“Moore’s Law” of Photonics

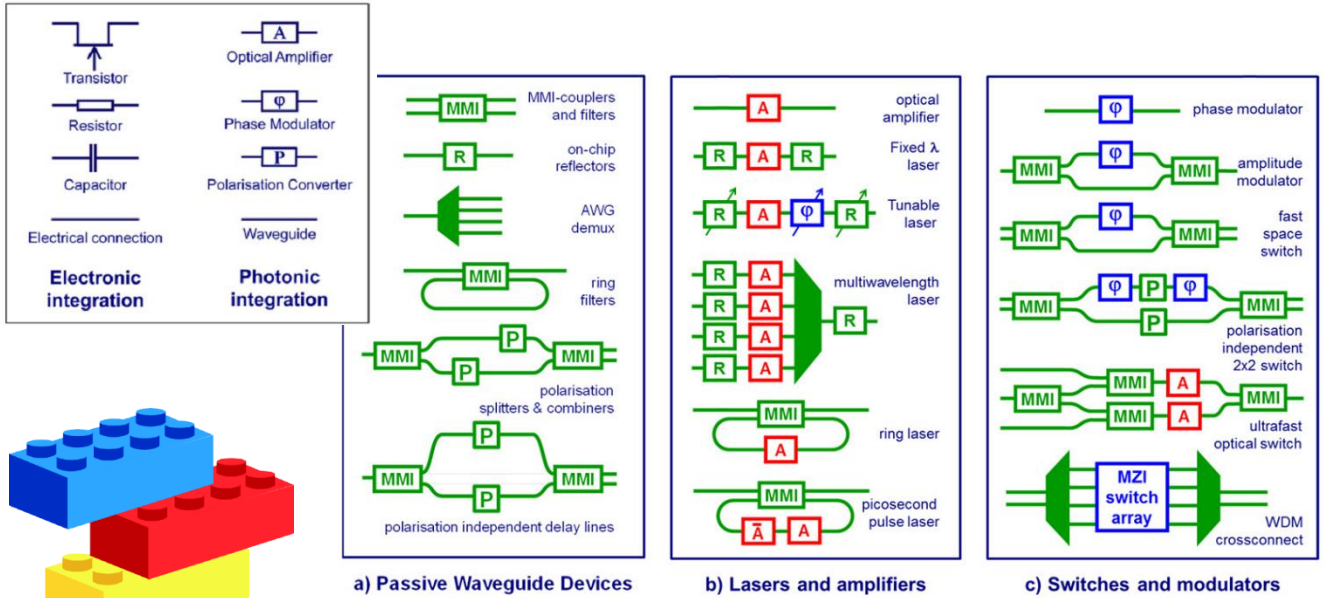


More in detail: InP PICs



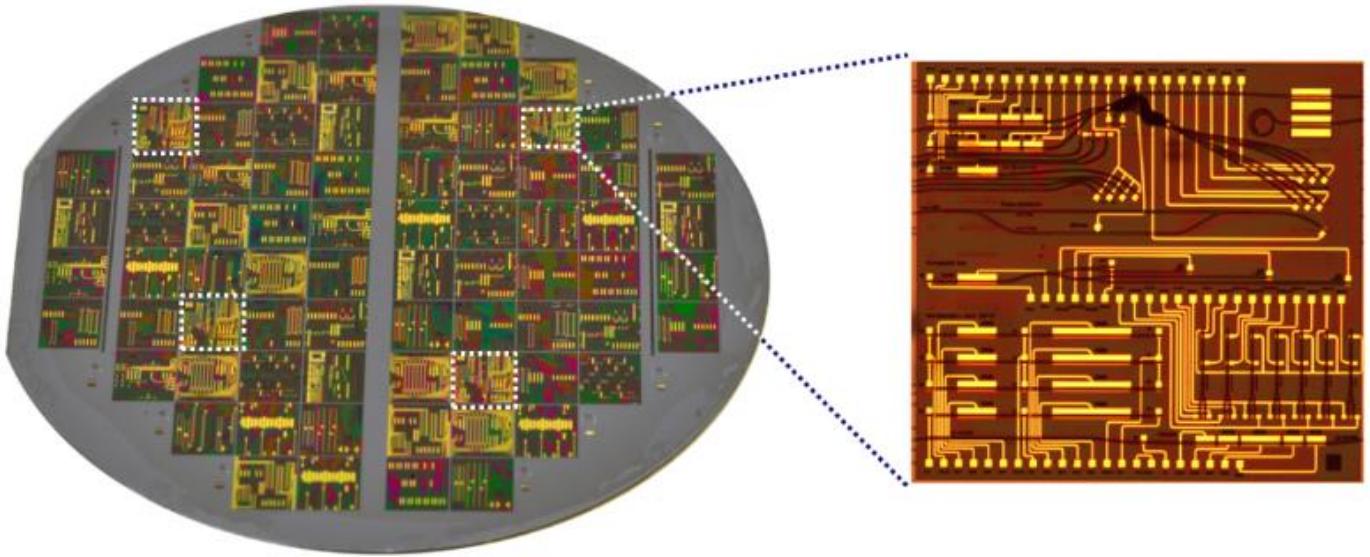


Building blocks to make a circuit



Smit et al., Semiconductor Science and Technology 29, 8 (2014)

Wafers with many circuits



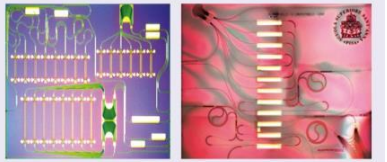
The ecosystem

JePPIX Knowledge JePPIX MPW Services JePPIX Pilot Line

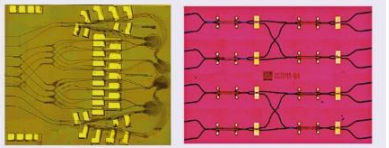
Over 500 PIC designs realised in JePPIX foundries

THz and RF circuits

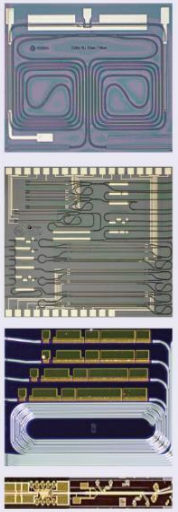
Optical data handling



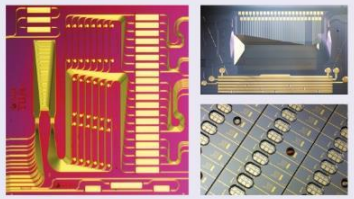
Optical switching



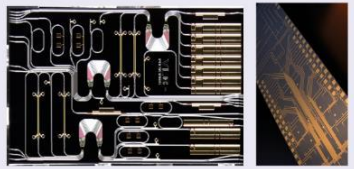
Variety of Lasers



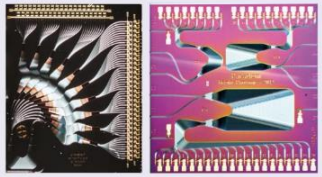
Medical and bio-imaging



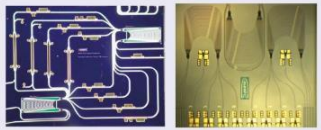
Microwave photonics beam-former



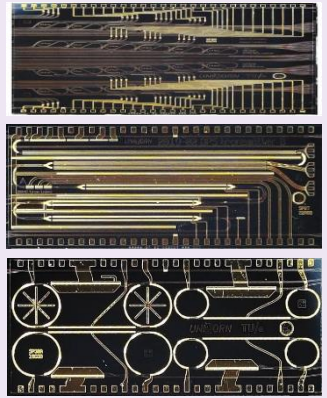
Sensor readout units



Fibre to the home



QKD transceivers



New **pilot line services** launched with manufacturing-grade PDKs and test automation

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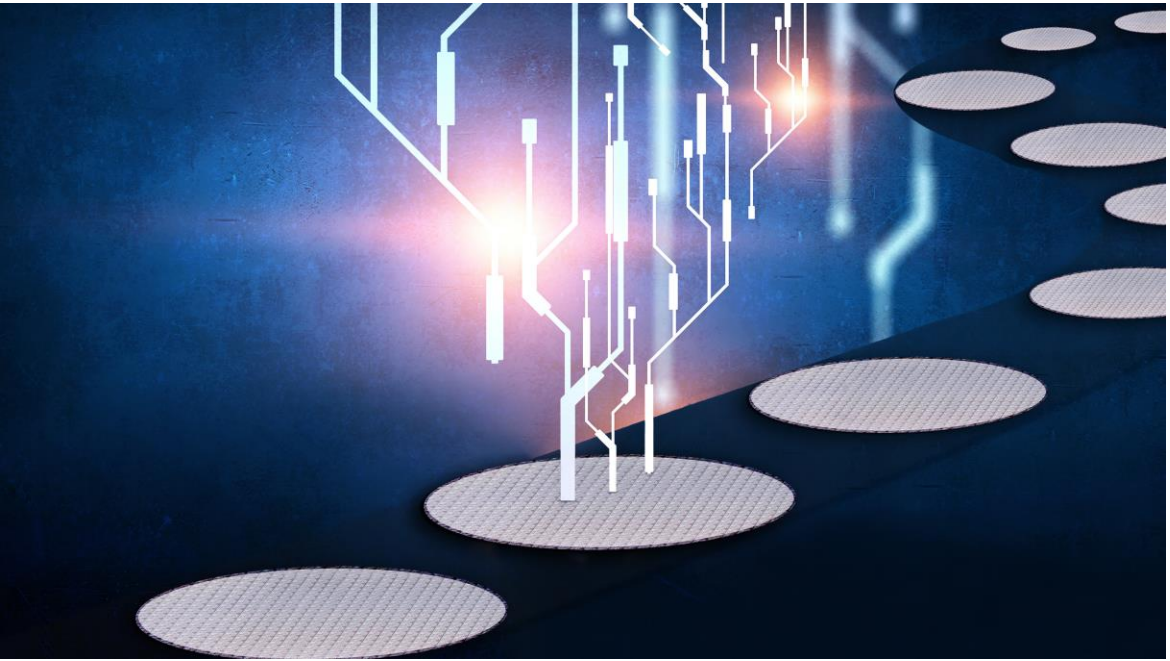
JePPIX Pilot Line



Photonic integrated circuit foundry **to your design** with 15-year track record

Trusted supply chain with foundry-calibrated design

Turn-key solutions for design, mass-manufacture, and automated test

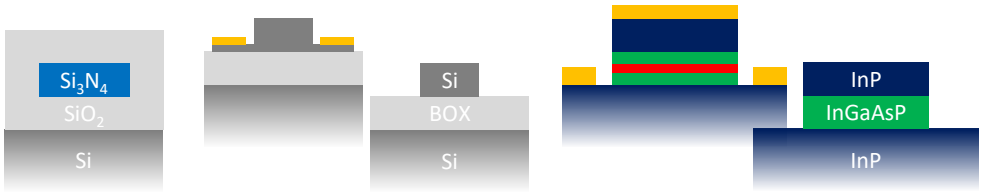
Accelerated development programs with integrated design loops

Comprehensive components including **lasers and amplifiers**

Seamlessly from idea to small series and mass production

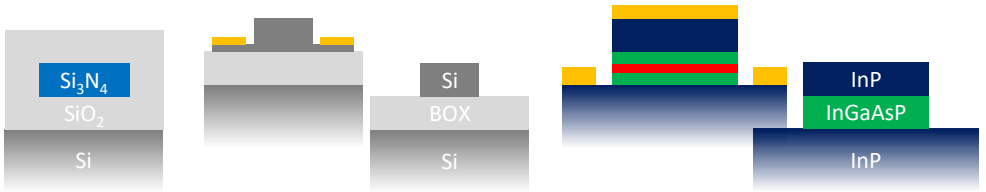
jeppix.eu/pilotline pilotline@jeppix.eu

Converge on three major integration platforms



	silica / silicon nitride	silicon-on-insulator	indium phosphide
wavelength range	0.3 µm – 3 µm	1.1 µm – 4.5 µm	1.3 µm – 1.6 µm
lasers, amplifers	NA	NA	+++
photodetectors	NA	++	+++
modulators	NA	+	++
passive devices	+++	++	+
wafer level packaging	+++	+++	NA
electronic SoC and SiP integration	+++	+++	NA

Converge on three major integration platforms



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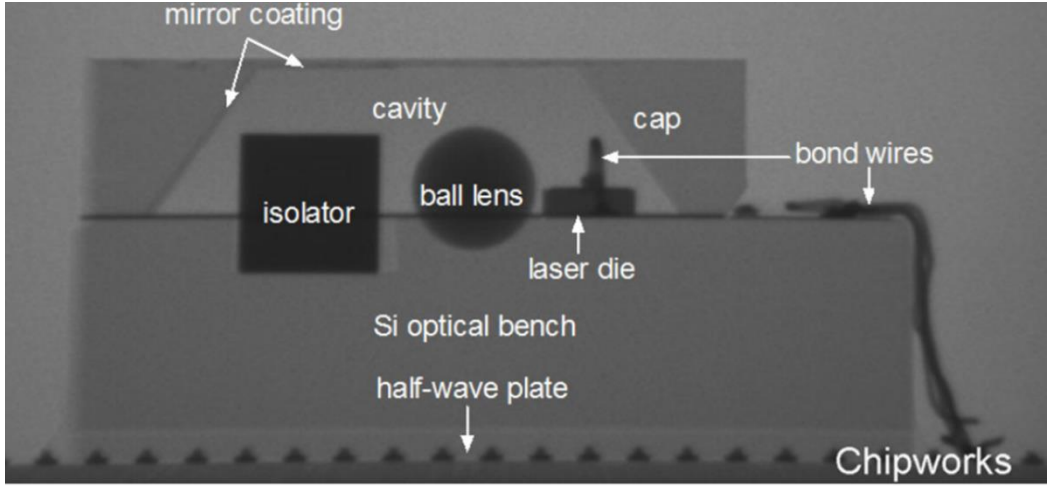
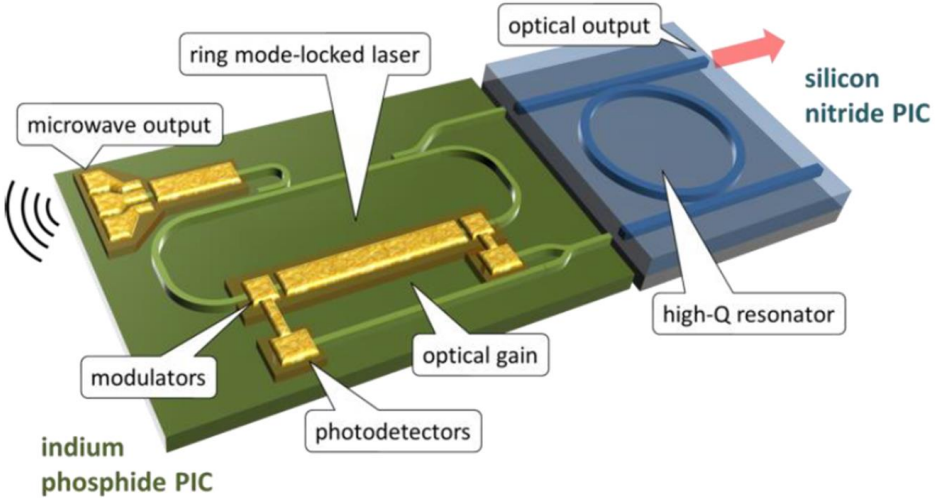
modulators	NA	+	++
passive devices	+++	++	+
wafer level packaging	+++	+++	NA
electronic SoC and SiP integration	+++	+++	NA

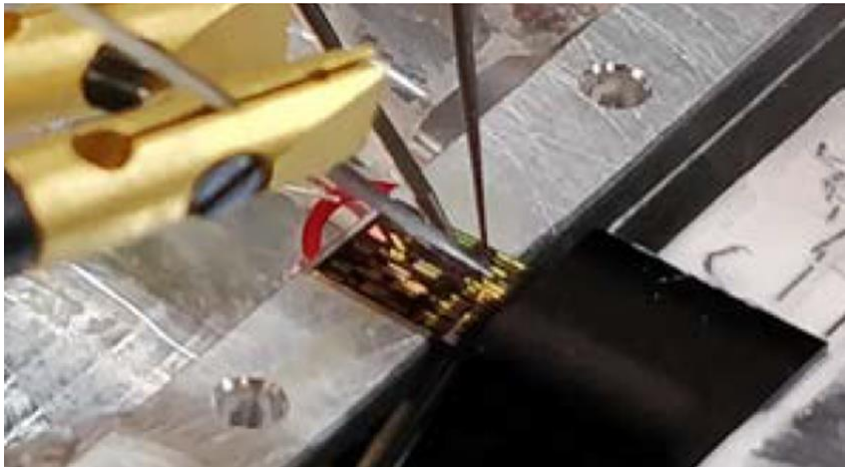
Combine – laser micro-package



credits: Chipworks

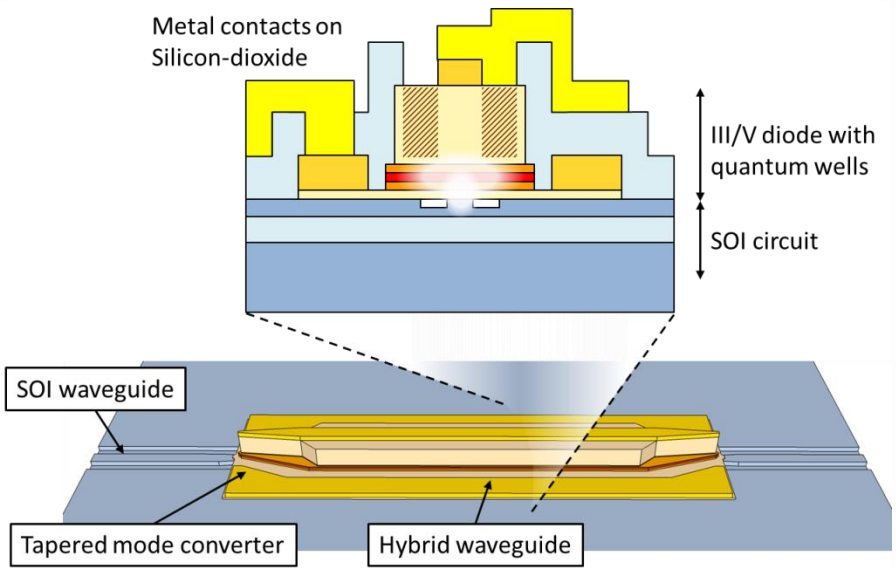
Combine – hybrid integration





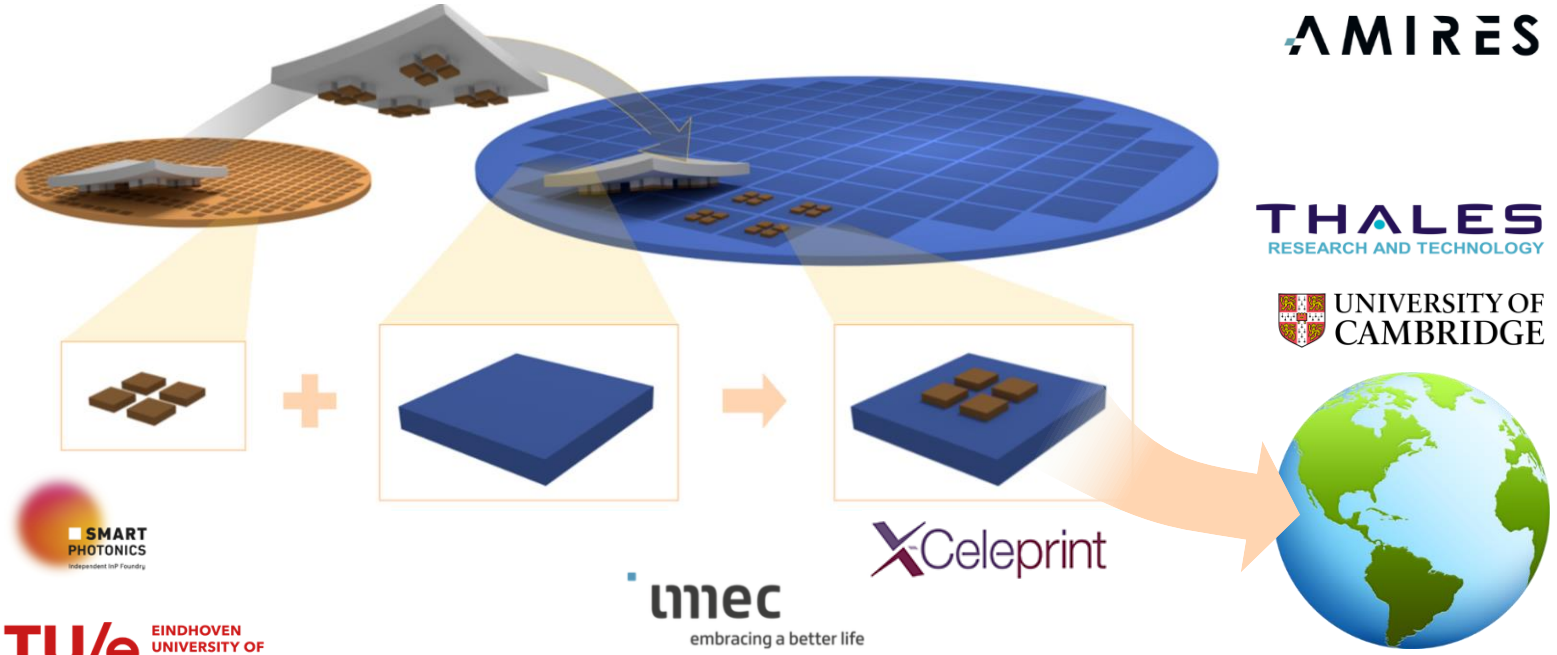
Far-Brusatori at al., OL 2022

Combine – heterogeneous integration



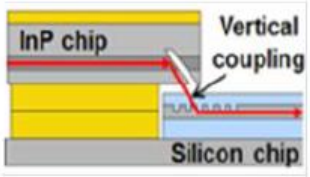
- III/V wafer or die bonded to processed silicon → no alignment;
- Back-end process on silicon substrates → CMOS infrastructure compatible;
- Mode couples to III/V → optical gain, detection or modulation.

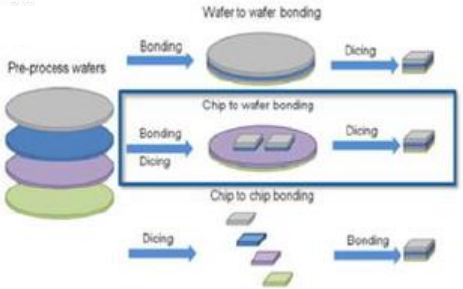
Combine – micro-transfer printing

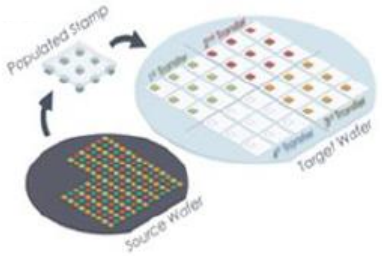


credits: INSPIRE – H2020

Hybrid and heterogeneous integration

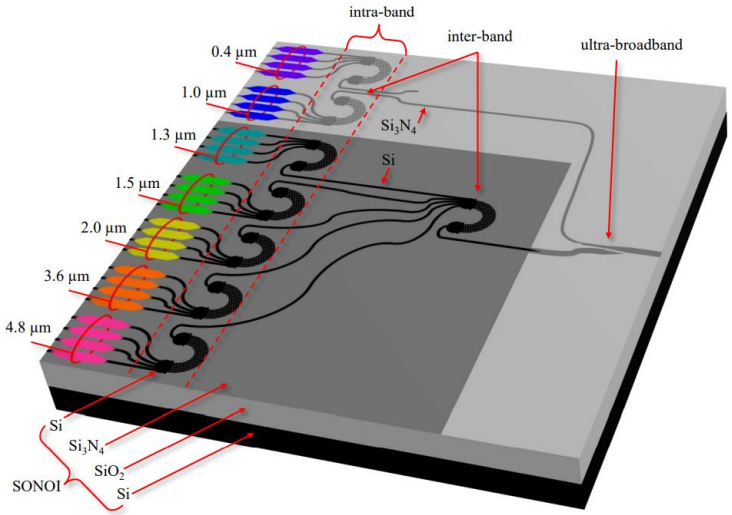






	LaMP	Flip-chip	Wafer-bond	Micro-TP
InP PIC maturity	✓	✓	On target wafer	✓
Optical coupling efficiency	✓	✓	✓	✓
Waveguide in-out devices	None	✓	✓	✓
Wafer level test and assembly	✓	✓	On target wafer	✓
Burn in	✓	✓	On target wafer	✓
Population of InP devices	Sequential	Sequential	✓	✓
Laser performance	✓	✓	✓	✓
Back end process integration	✓	✓	Substrate removal	✓
Density and volume	Micro-optics	Solder pad limit	✓	✓
Reduced barriers for new PICs	✓	✓	✓	✓

Additional flavors – other wavelengths



1.0 µm GaAs on SiN laser

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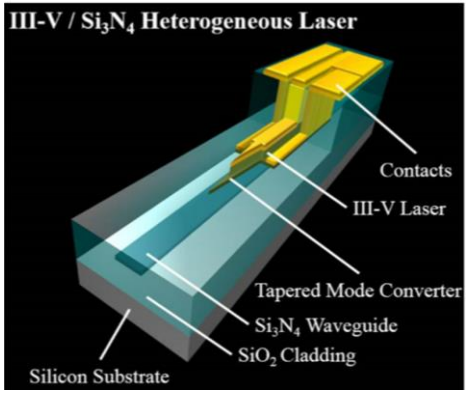
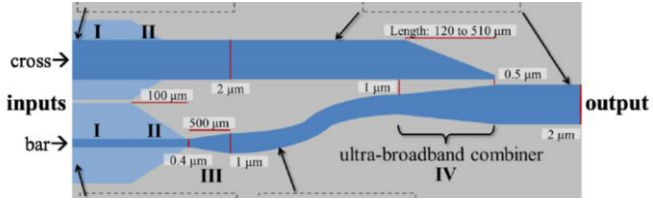
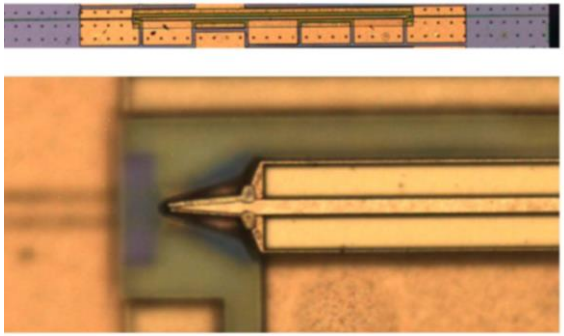




multi-octave spectral beam combiner



2.0 µm inP on Si laser

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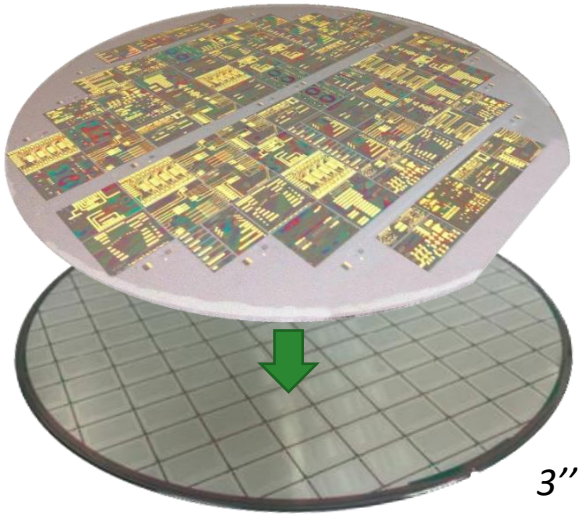
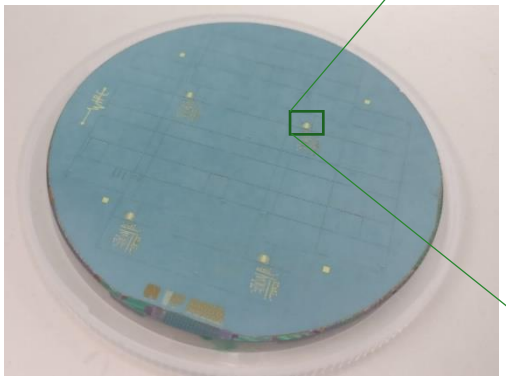
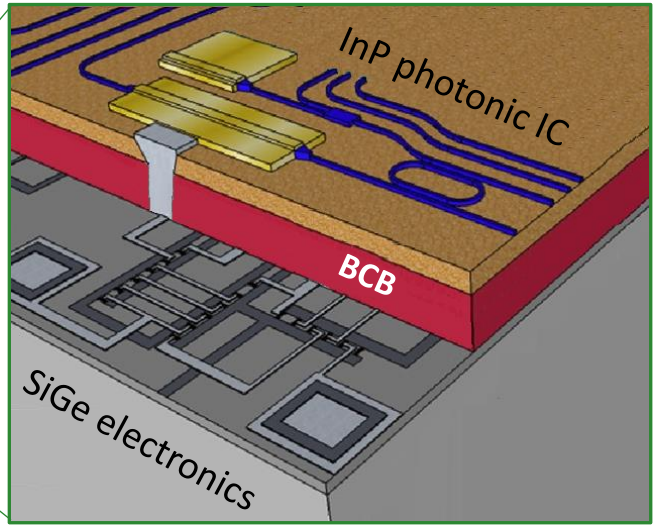
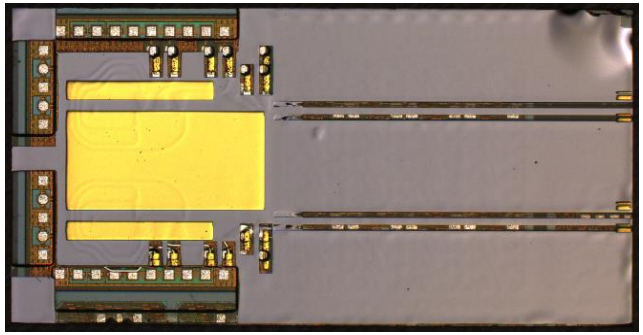
Additional flavors – electronics









3'' InP PIC wafer from HHI bonded to laser-sawn BiCMOS wafer from NXP

Intimate co-design to remove components and parasitics

Systematically improve efficiency, speed, and information density

Using wafer scale processes

PHOTONICS 21

PHOTONICS PUBLIC PRIVATE PARTNERSHIP

http://wipe.jeppix.eu

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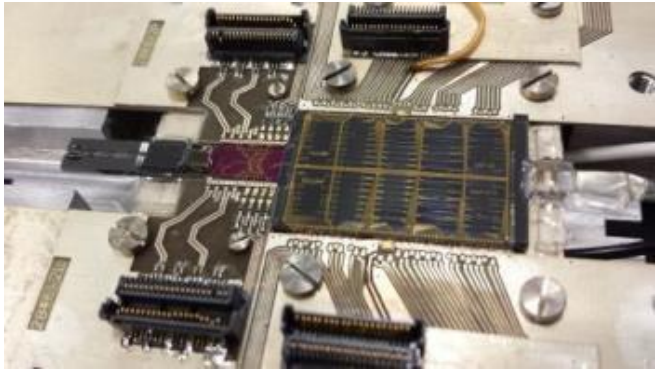
Applications in space

- wireless and optical communication;
- optical atomic clock;
- gyroscope;
- fiber sensors (temperature, integrity);
- optical frequency combs;
- microwave photonics – oscillators, signal processing, ...
- ... and many more!

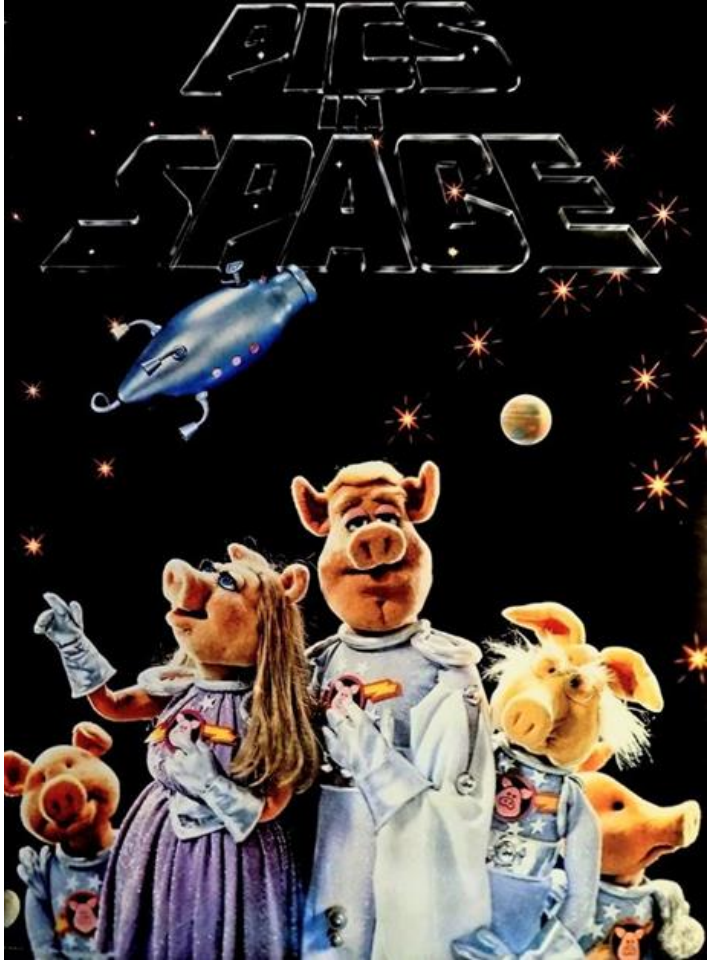


Photonics-based beamforming antenna system for broadband satellite communication, LioniX International.

Conclusion

- monolithic PIC platforms mature and accessible;
- hybrid/heterogeneous integration, assembly and packaging on the rise;
- more opportunities coming up by integration with electronics and other III-Vs (UV, visible, near-IR, mid-IR, THz, RF, ...)

Technology ecosystem ready for “PICs in space”... but design is another story...



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https://www.tue.nl/en/research/institutes/eindhoven-hendrik-casimir-institute/

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Optical chips miniaturize optical systems

https://www.photonfirst.com/

The engineering vs. physics trade-off