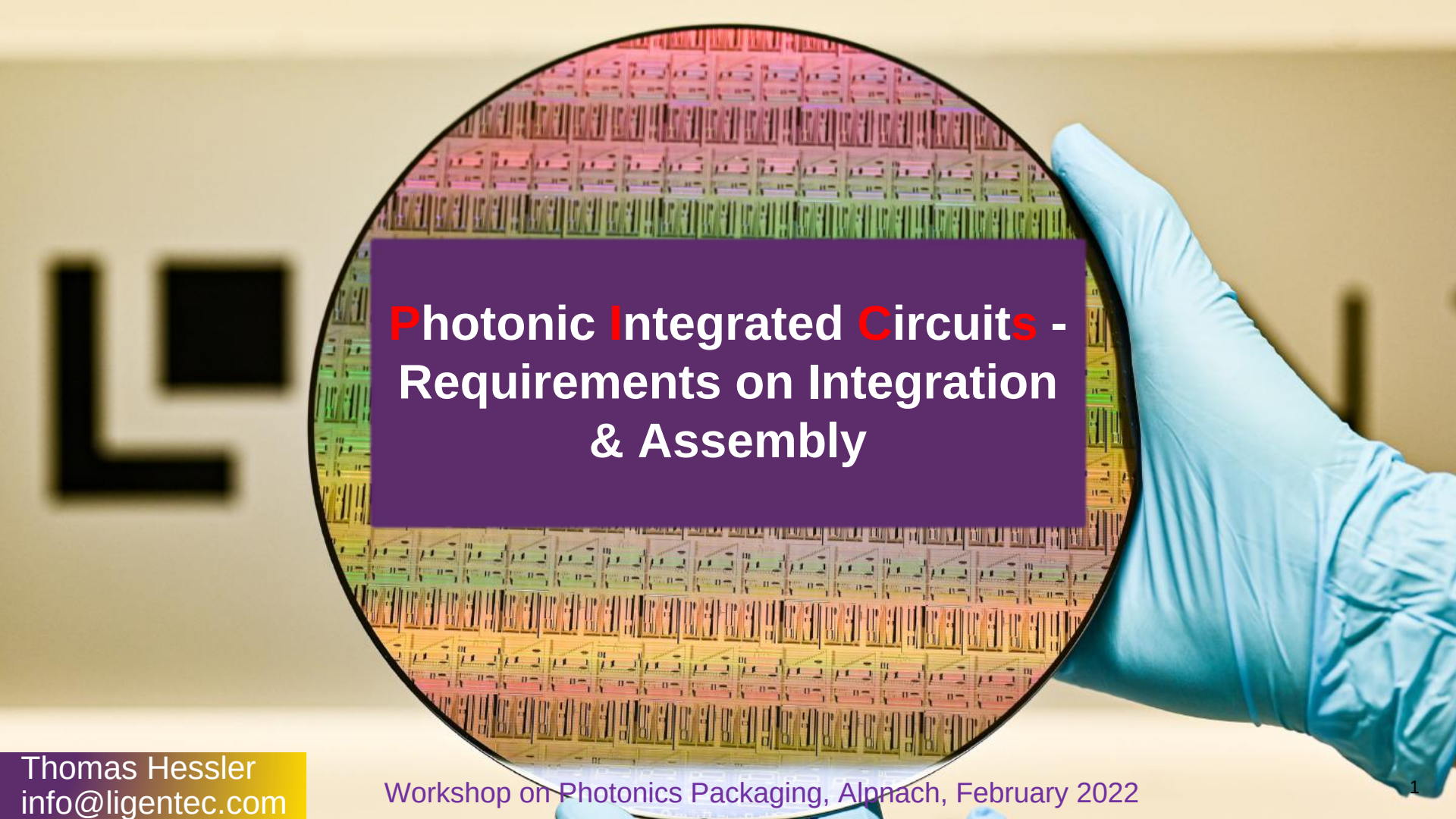
Photonic Integrated Circuits - Requirements on Integration & Assembly



Thomas Hessler
info@ligentec.com

LIGENTEC

Leader in low loss Silicon Nitride Integrated Photonics

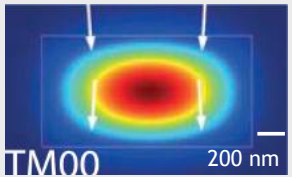
European PIC Company

Headquarters in Lausanne (CH)

Originating from EPFL (Kippenberg Lab)

LIGENTEC Snapshot

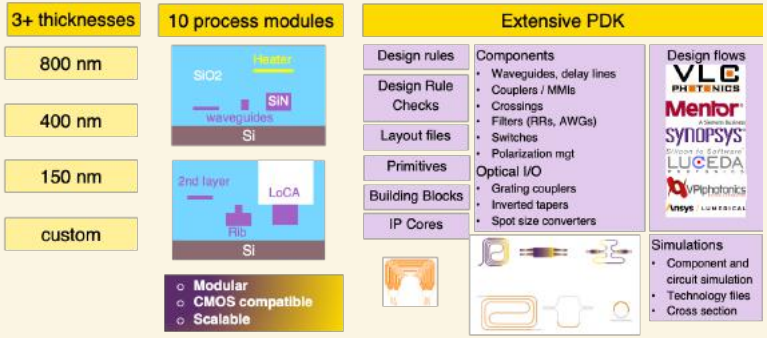
Thick SiN – the game changer



90% of the light is confined
- Low propagation loss
- Small chip size
- Non-linear optics
- High Power, VIS to IR

All Nitride Core Technology: combining the benefits of
- **Silicon Nitride** (VIS-IR, low loss, high power) with
- **Silicon Photonics** (small chip size, scalability)

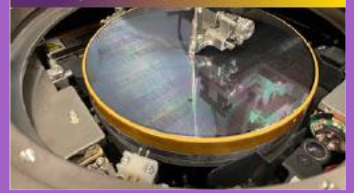
Versatile PIC Platform



Commercial Offering

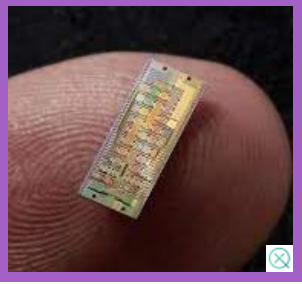
R&D and Prototyping
Open access, low barrier

Custom PIC Developments
High flexibility & competence



Manufacturing
Niche to high volumes

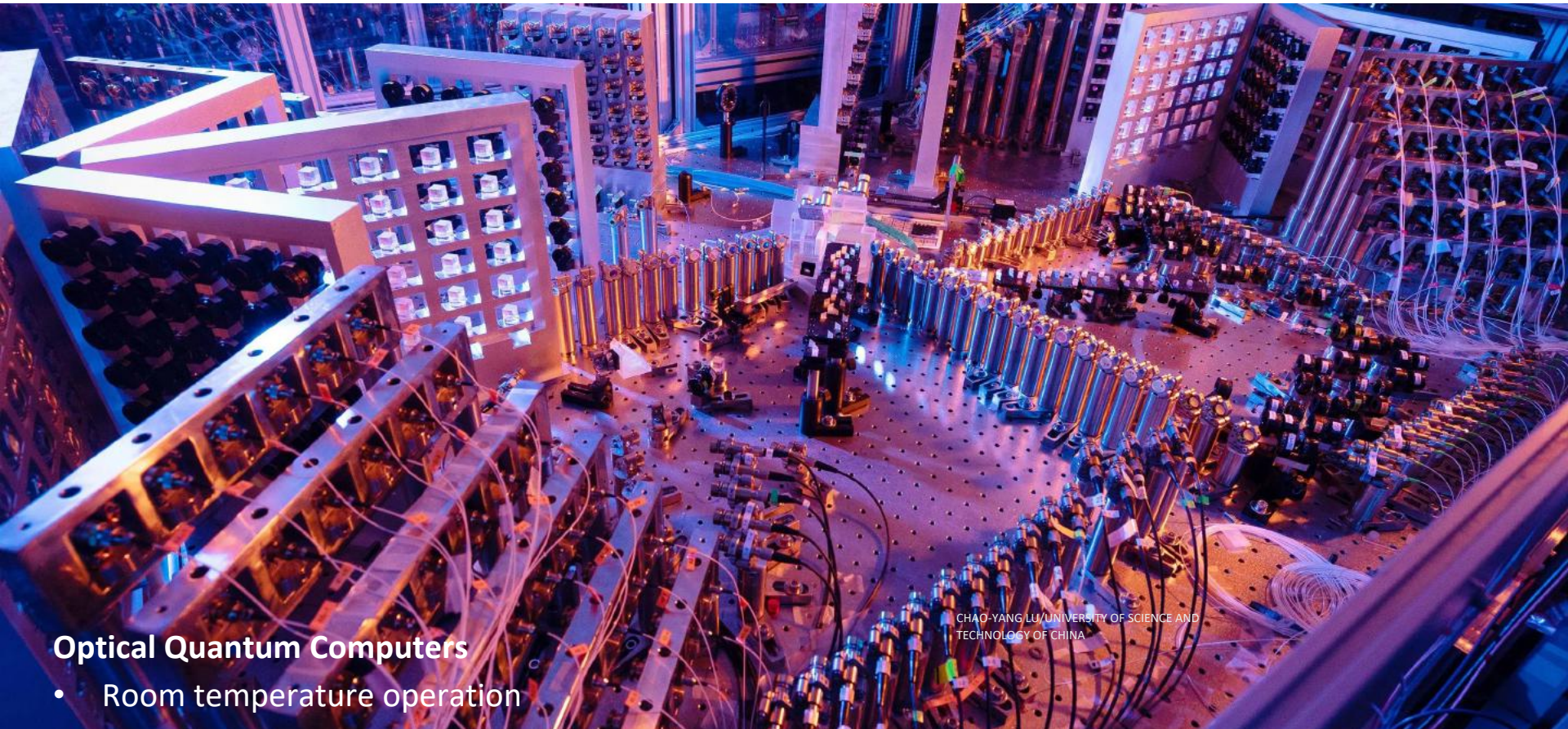
We deliver PICs



Do we really need Photonic Integration?

Use case: Quantum Computing

LIGENTEC



CHAO-YANG LU/UNIVERSITY OF SCIENCE AND TECHNOLOGY OF CHINA

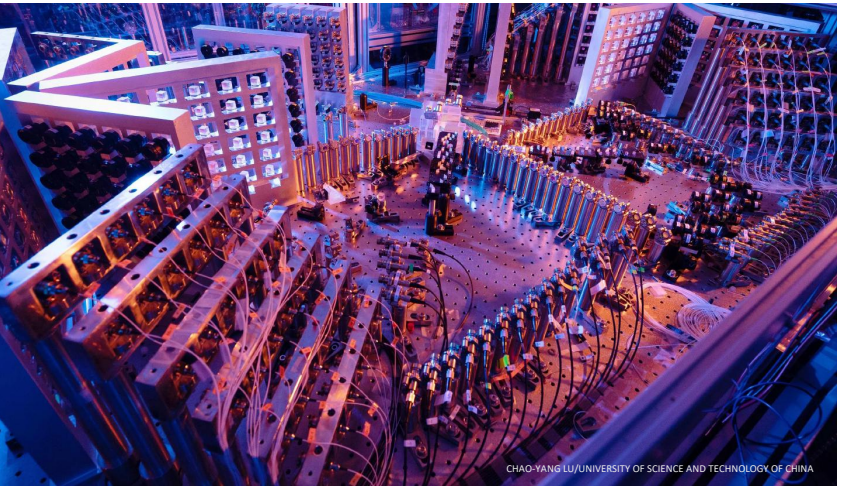
Optical Quantum Computers

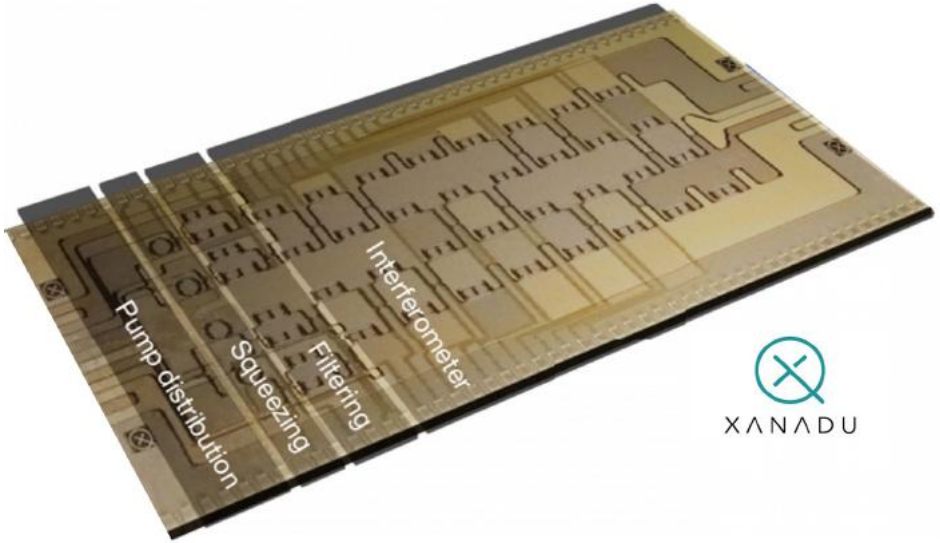
- Room temperature operation

Do we really need Photonic Integration?

Use case: Quantum Computing

LIGENTEC





Optical Quantum Computers

- Room temperature operation
- **Not scalable with discrete optics!**

PIC based Photonic Quantum Computers

- Scalable with existing, semiconductor like manufacturing technologies

Photonic Integrated Circuits (PICs) …

LIGENTEC

… have a huge potential

Disruptive PICs:

Size: 100x smaller

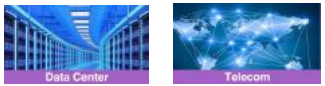
Weight: 100x lighter

Power: 1/10th of energy consumption

Cost: 1/100th of cost

To repeat the electronic IC revolution.

... and have become technology of choice in selected markets,



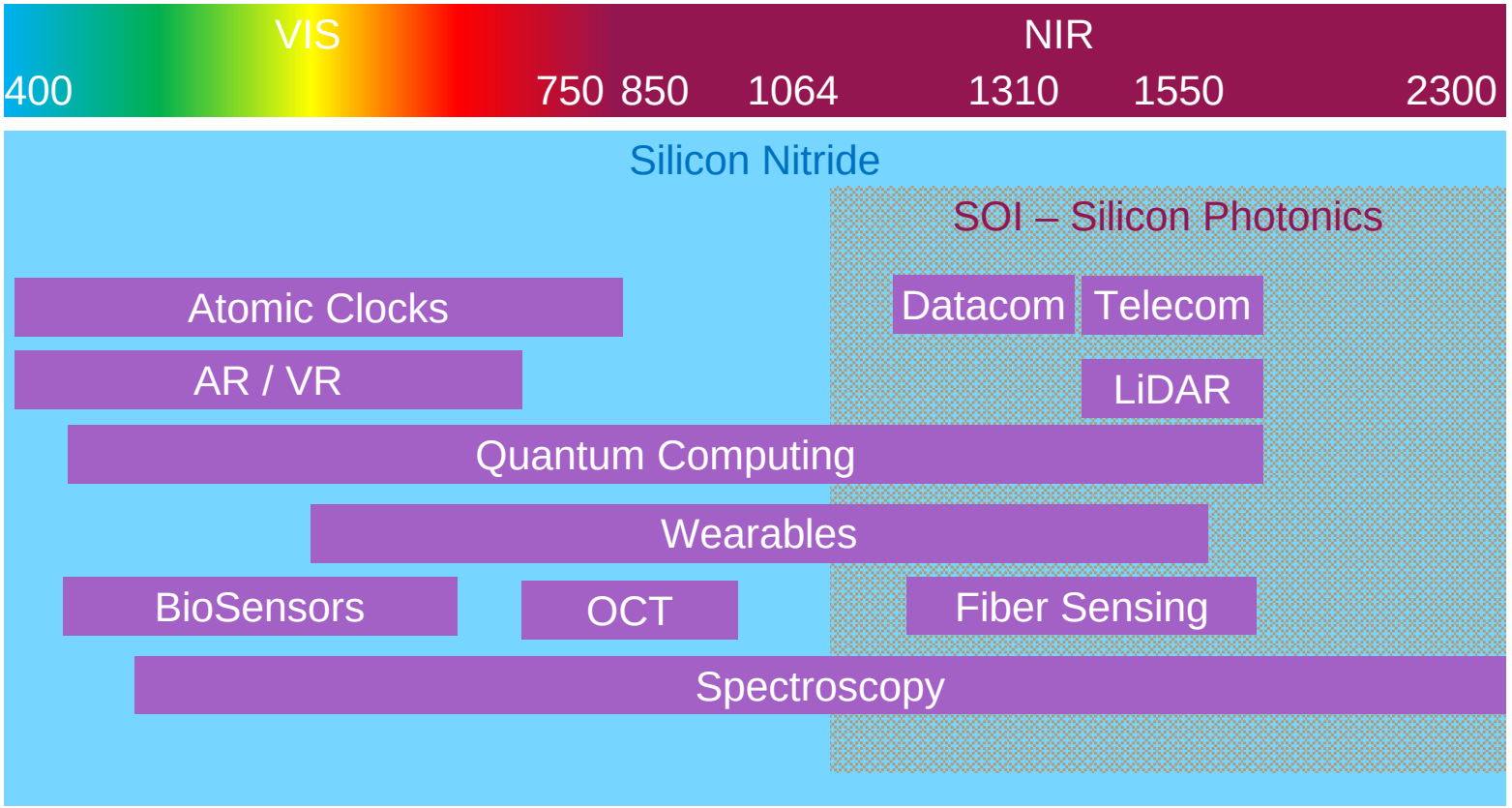
but larger scale adoption

is still challenged by:

- ❑ **On chip and in/out coupling losses**
- ❑ **Long & expensive R&D cycles**
- ❑ **No one fits all solution**

Material Platforms

Application requirement diversity: wavelength



Challenge application diversity

Combine the best

LIGENTEC

Application Challenges

Wavelength | Non-linear effects | Phase noise | Integration Density | Bandwidth

Propagation Loss | Power | T Stability | Radiation hardness | Optical power | Uniformity

Linearity | Size | Voltage | Cost | Opt. I/O | Back reflection | Scalability | Crosstalk

	InP	Silicon	SiN	Silica
Wavelength	NIR upwards	NIR to MIR	VIS to MIR	VIS to MIR
Passives		Moderate loss, TPA, T sensitive	Very low loss, high power	Very low loss
Lasers			Heterogeneous integration	External / hybrid
Modulators	Monolithic			NA
Photodetectors	Monolithic	Monolithic		External / hybrid
Compactness / index contrast	low	high		
Cost				
Maturity	high	high	emerging	high

There is no one fits all technology

High application diversity, no one fits all solution,

Optimizing for a single application only possible high-volume applications

Approach:

Best and scalable base platform for circuitry with standard I/Os and PDK

+

Application specific choices of integration

⇒ Combine the best to lower adoption barriers

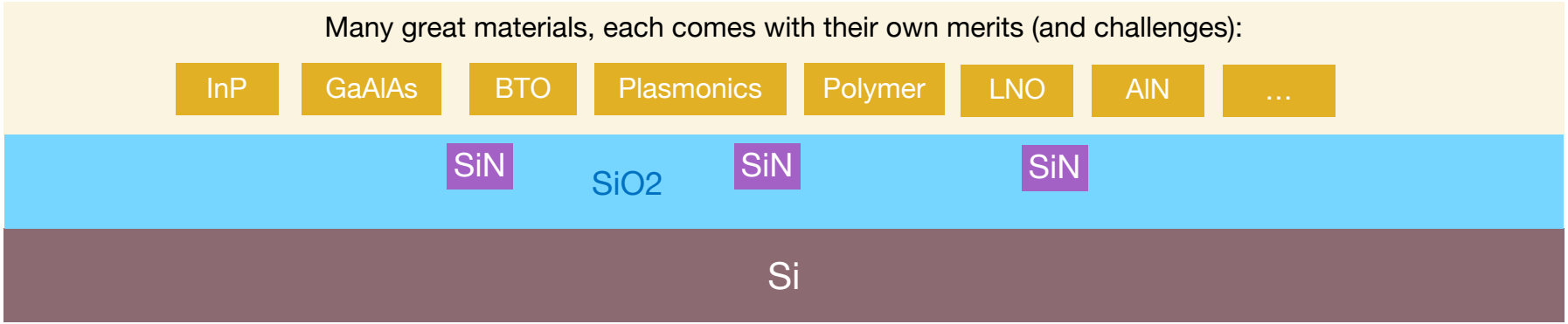
One basis, large diversity in the add-ons

Materials and Functionalities

Use SiN as base platform for general circuitry
- o Comprehensive PDK
- o Standard I/Os
- o Scalable to volume

Add-on Functionalities for Light
- o Generation
- o Modulation
- o Amplification
- o Detection

Many great materials, each comes with their own merits (and challenges):



Integration Technologies

Monolithic Integration

Deposited *or grown on the wafer*

- Best cost option
- Limited material choice

InP PICs

SOI Modulators

Heterogeneous Integration

Transferred */ bonded on the wafer*

- High flexibility
- Low cost potential

Wafer to wafer

Chip to wafer

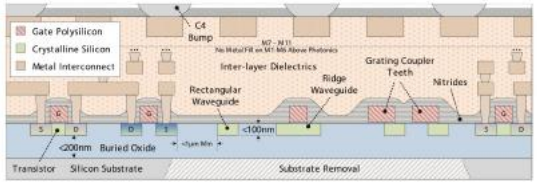
uTP

Hybrid Integration

Assembled in the package

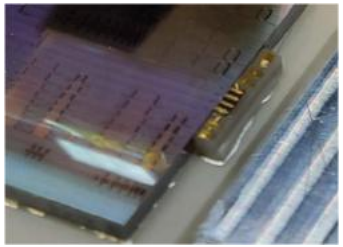
- High flexibility
- Costly in volumes

Butt coupled PDs



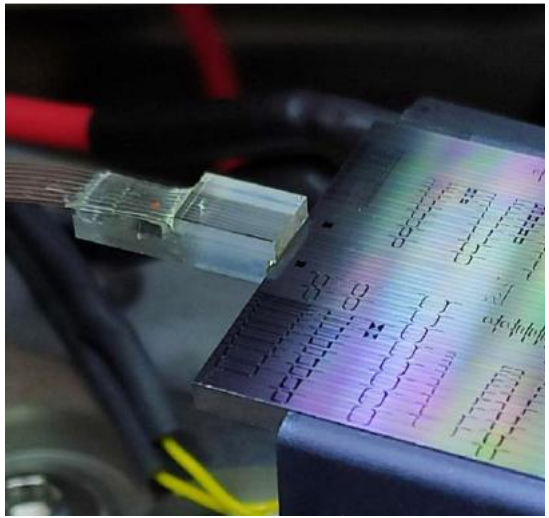
Sun *et al.*, JSSC. **50**, 893 (2016)

Source: EVG

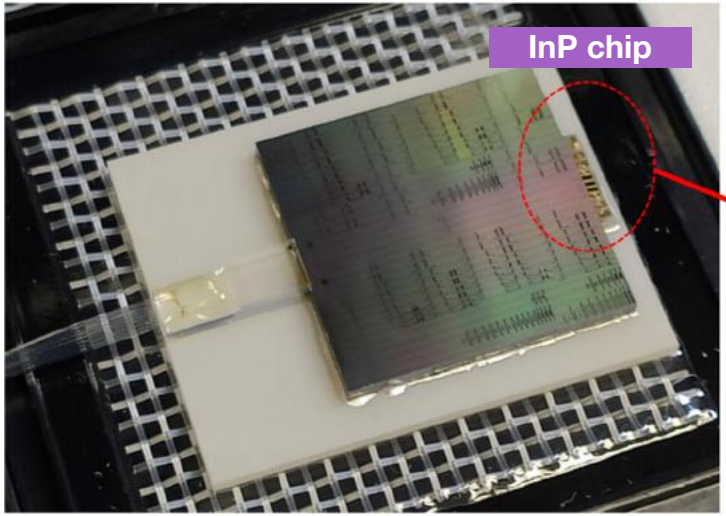


Hybrid Integration – edge coupled

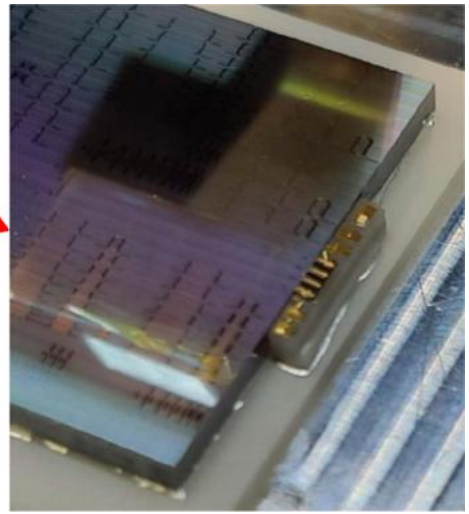
Fiber coupled passive SiN Chip with InP Chip attached



Fiber Array to SiN waveguides



Glued on carrier

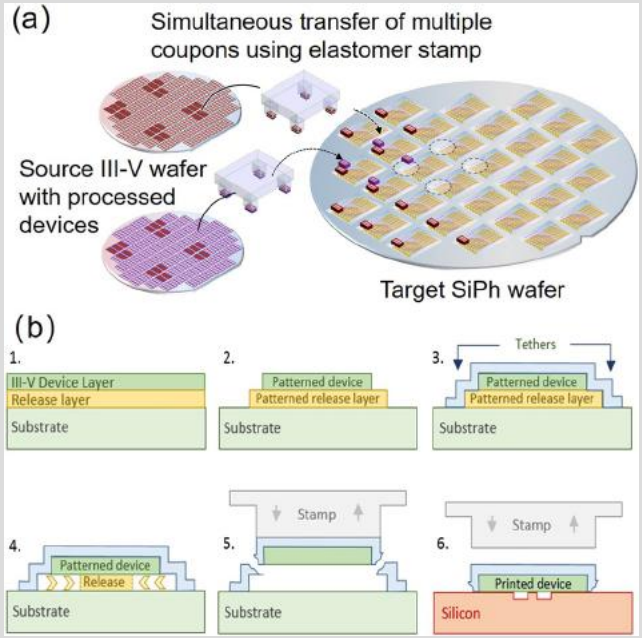


III-V Chip attached to SiN PIC

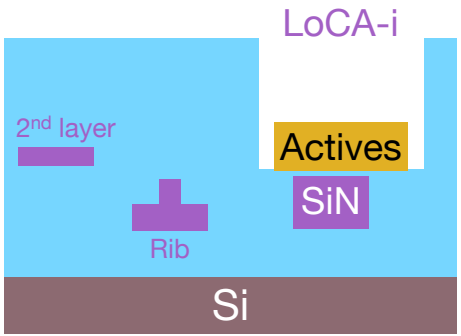
Heterogeneous Integration – Chip to Wafer Example
Micro-Transfer Printing

LIGENTEC

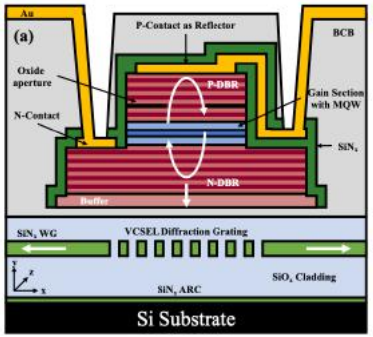
Micro Transfer Printing Technology



Roelkens *et al.*, in *2018 IEEE Optical Interconnects Conference (OI)* (IEEE, USA, 2018), pp. 13–14.



Example VCSEL on SiN PICs



Goyvaerts et. al. 2021, Optica 8, 1573-1580 (2021)

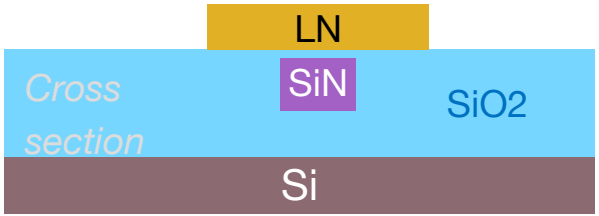
Micro Transfer Printing:

- Wide range of materials / components
- Cost effective, on-wafer processing
- Highly efficient usage of source material
- Great for the integration of III-V materials (lasers, modulators, amplifiers, modulators, detectors)
- Match of different components / materials on one wafer
- **Requires specially engineered source Epi stacks**

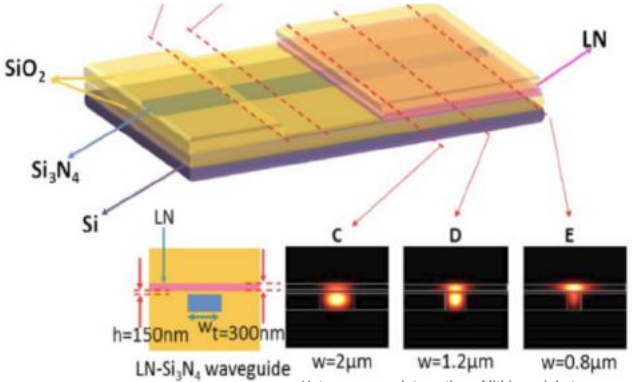
Heterogeneous Integration – example Wafer to Wafer
Thin Film Lithium Niobate on SiN

LIGENTEC

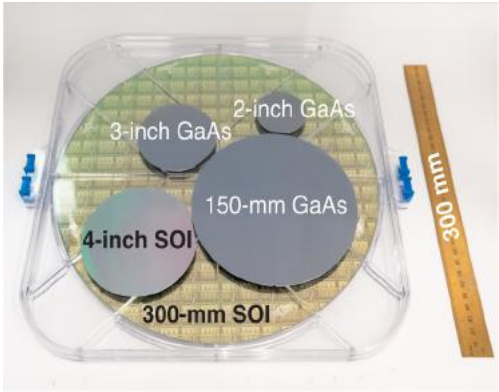
Thin Film LNOI bonded on SiN PIC wafer



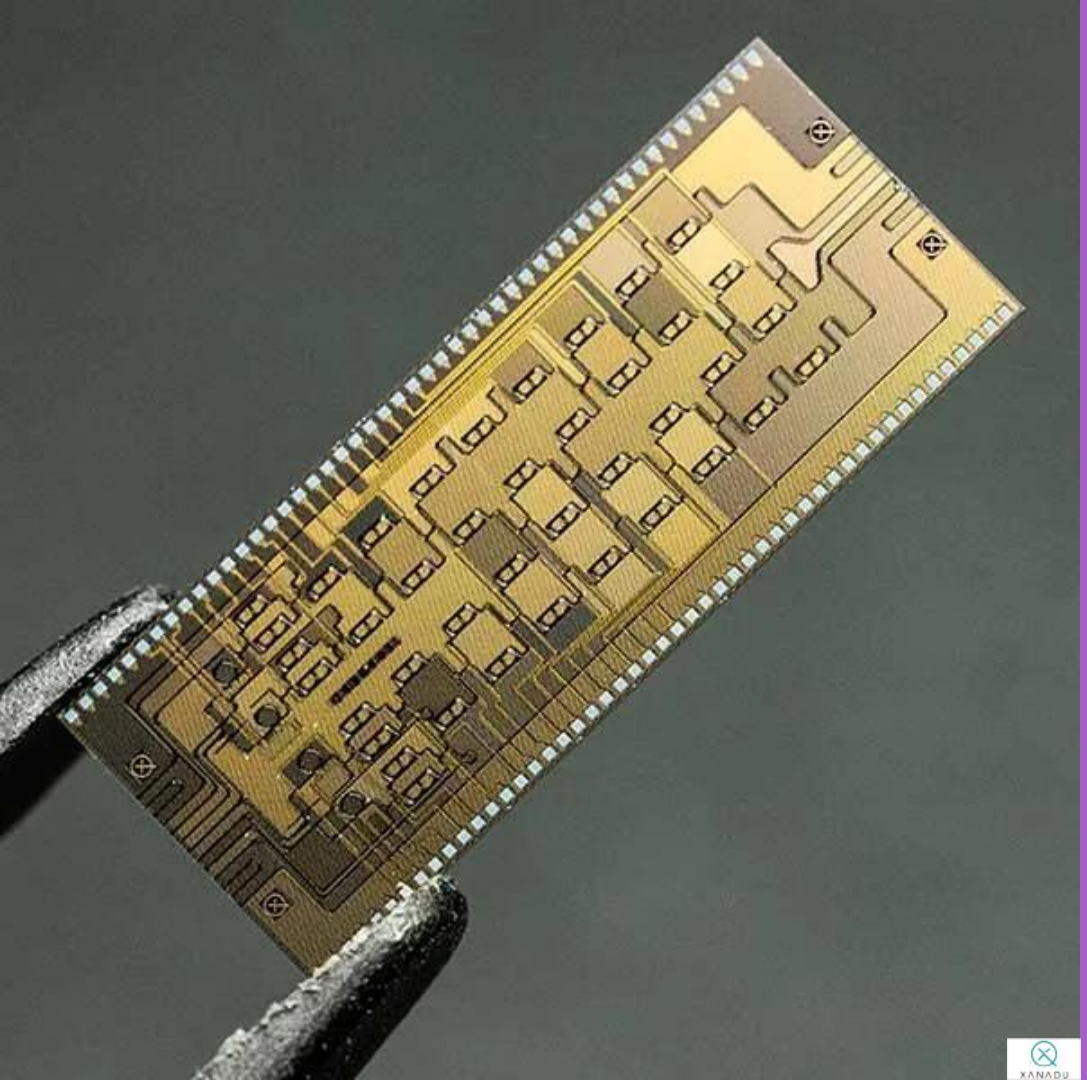
Key Benefit
- Lithography replaces mechanical positioning



Heterogeneous integration of lithium niobate, Chang et al., Optics Letters (2017)



Key Challenges
- Yield of combined stack
- Wafer size compatibility
- Source wafer utilization



PICs are useless,

PICs are useless,

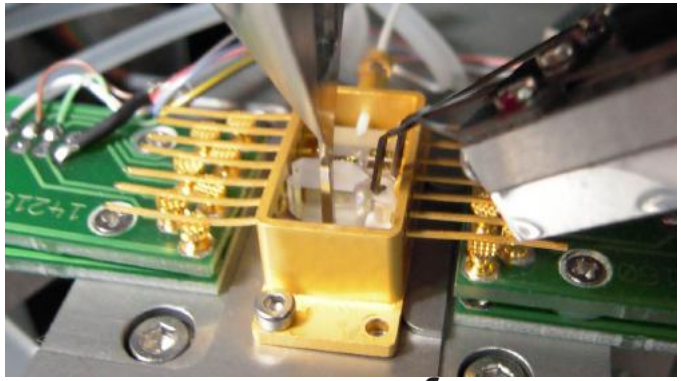
unless they are packaged!

World Connection

LIGENTEC

Electrical Connections
- Critical for high frequencies (>10GHz)

Housing / encapsulation / stabilization
- Hermetic packaging
- Thermal stabilization
- ….

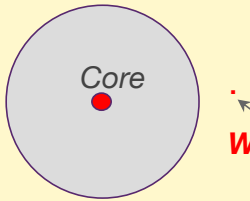


ficontec photonics assembly & testing

Optical Connections
- Important source of loss: 1dB (20%) to 6dB (65%) loss per coupling

Problem statement:
Mode mismatch, very different to electrical connections.
Sub um accuracies required.

Fiber mode (10 um) >> waveguide mode (2-3 um)



Decrease *fiber mode*

or

Enlarge *waveguide mode*

Fiber to Waveguide Coupling Strategies

LIGENTEC

Vertical

Edge

Grating couplers
(+) wafer level testing
(+) wafer level integr.
(-) bandwidth
(-) lossy

Reduce Fiber mode
- High NA Fiber
- Lensed fibers

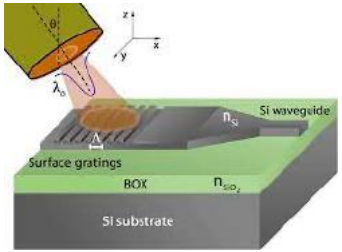
(+) coupling
(-) alignment
(-) expensive

On chip expansion
- Inverted tapers

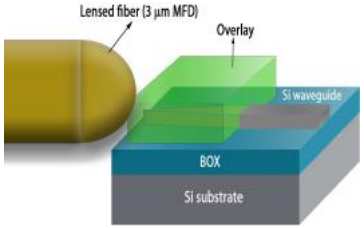
(+) coupling
(+) alignment
(+) standard SMF

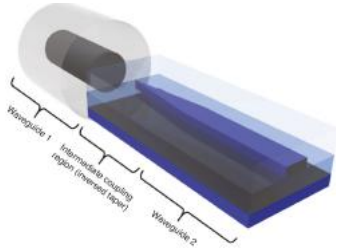
Free space
(+) coupling
(+) alignment
(-) expensive

Photonic wirebonds
(+) Chip to Chip
(o) experimental

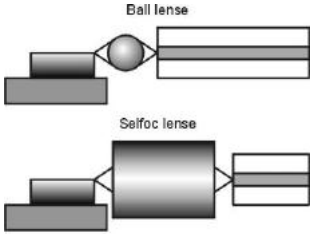


Appl. Sci. **2018**, *8*, 1142; doi:10.3390/app8071142

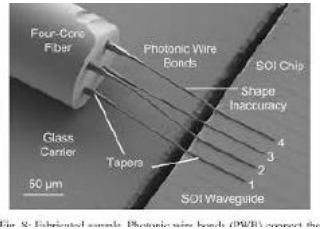




Nanophotonics 2018; 7(12): 1845–1864



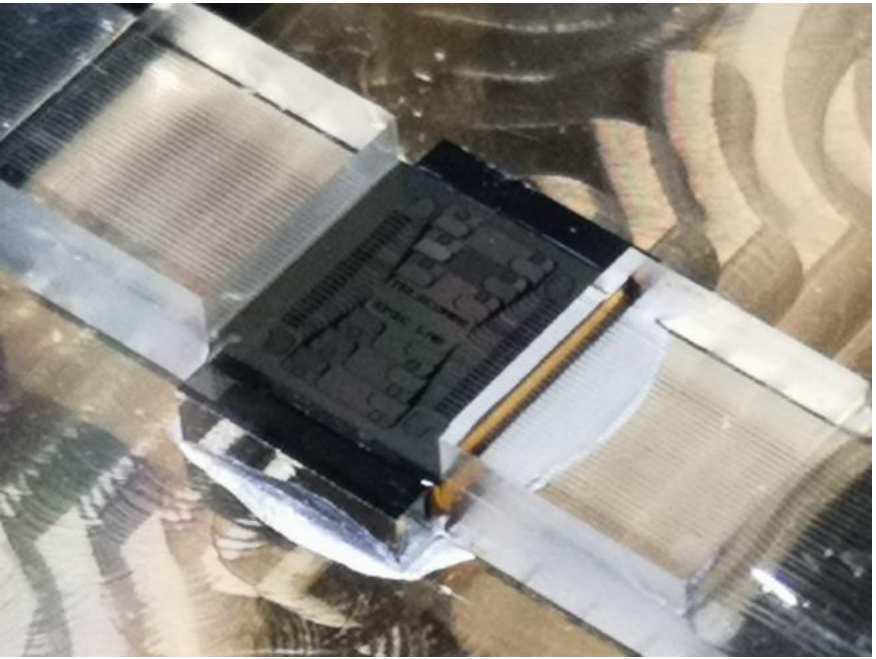
DOI: 10.5772/51626



DOI:10.1109/OIC.2014.6886114

Mode Size expansion helps

Optical I/O – there is more



Challenges:

- Mode matching
- Reflections, facet quality
- Materials
- Aging, shrinkage
- Tolerances
- **Low cost at high precision**
- **High Mix - Low Volumes**
- Missing standards

Requires

- Sophisticated mode expanders
- Design for assembly
- Close interaction PIC designer, foundry, packaging house and equipment manufacturer

Conclusions

First integrate, then assemble

LIGENTEC

Integration

- **Photonic Integration** needed & **disruptive**
- Requires use of **different technologies**
- **Wafer scale** integration preferred choice

Assembly

- Higher complexity than electronics
- Small mode fields of waveguides makes **assembly expensive**
- **Mode expansion** for cost reduction
- Use **standardization**

Swiss PIC industry needs **local expertise** in assembly & packaging to leverage existing strength in chip technologies.

Thanks to the Ligentec Team

Join our PIC journey!

check out our openings at ligentec.com/careers
or send your CV to hr@ligentec.com