

# Silicon Nitride – a versatile, low loss PIC platform

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EPFL



LIGEN TEC

Located in Lausanne, CH  
Spin-off from EPFL-LPQM (Kippenberg Lab)  
Leader in low loss Silicon Nitride Integrated Photonics

# Problem - Barriers for Breakthrough Photonic Integrated Circuits (PICs) ...

... have a huge potential



## Disruptive PICs:

- Size: 100x smaller
- Weight: 100x lighter
- Power: 1/10<sup>th</sup> of energy consumption
- Cost: 1/100<sup>th</sup> of cost

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

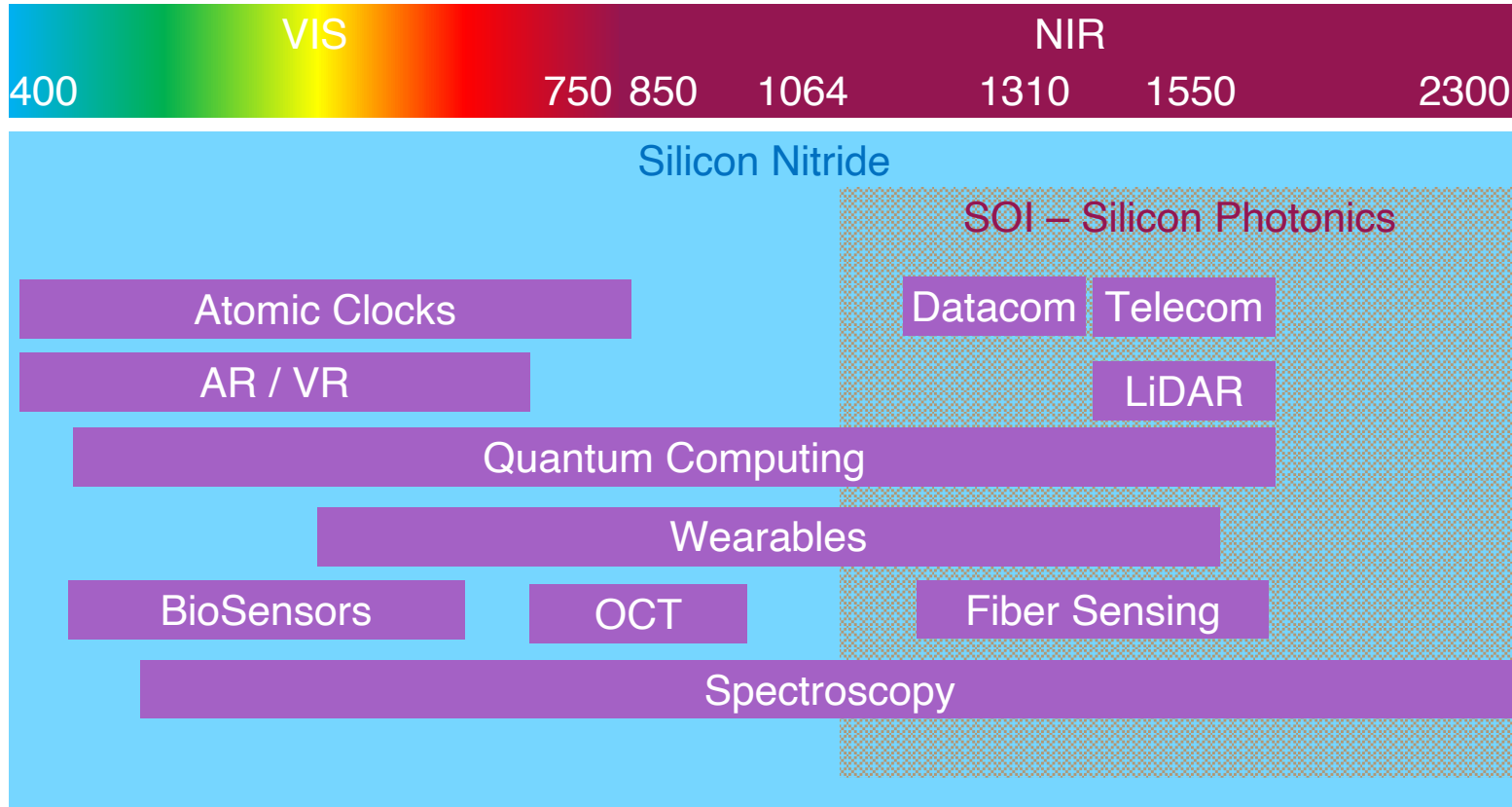


but larger scale adoption



is challenged by

- propagation losses
- coupling losses
- long & expensive R&D cycles
- no one fits all solution



## Combine the best

Wavelength

Non-linear effects

Phase noise

Density

Bandwidth

Propagation Loss

Power

Optical power

Scalability

Uniformity

Linearity

Size

Voltage

Cost

Back reflection

Crosstalk

- Very high application diversity.
- No one fits all solution / PIC platform,
- Optimizing for a single application possible for some applications with volume
- How to lower adoption barriers?

- Use a scalable base platform for general circuitry.
  - Standard I/Os, lower integration and packaging effort
  - Well understood PDK
  - Scalable to volume
- Add special function as required by application by heterogeneous integration

Large transparency window:

400 – 4'000 nm

Reference Silicon: 1'100 – 4'000 nm

Low propagation loss: 0.2 to 0.05 dB/cm

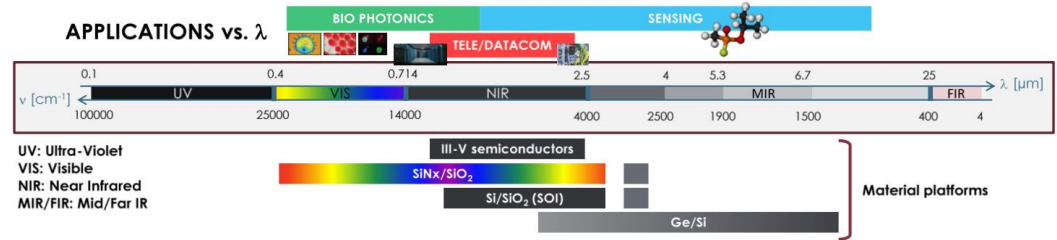
Reference Silicon: 2.5 to 1 dB/cm

High optical power: > 5 W per waveguide ( $10^9$  W/cm<sup>2</sup>)

Reference Silicon: 0.1 W per waveguide

Scalable to volume

Non exotic material

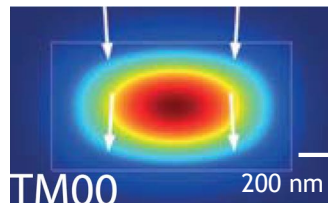
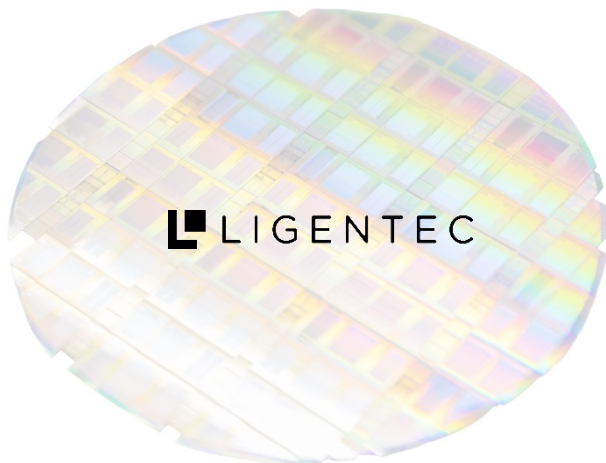


Muñoz et. al., Sensors **2017**, 17, 2088



required for many applications

*Our game Changer*  
**Thick Film Silicon Nitride**



90% of the light is  
inside the waveguide

**Addressing the main challenges:**

- (i) Low propagation loss ( $< 0.1$  dB/cm)
- (ii) Low coupling loss ( $< 1$  dB/facet)
- (iii) Fast turn around ( $< 9$  w)
- (iv) Platform for heterogeneous integration

**Plus:**

- ✓ Modular, CMOS compatible & scalable process
- ✓ High optical power handling (Watts)
- ✓ Broadband (VIS to IR)
- ✓ High bend radius => small chips
- ✓ Dispersion engineering, non-linear optics

**All Nitride Core Technology:** combining the benefits of

- **Silicon Nitride** (VIS-IR, low loss, high power) with
- **Silicon Photonics** (small chip size, scalability)

**3+ thicknesses**

**10 process modules**

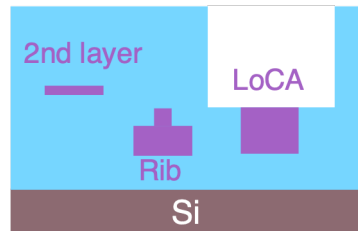
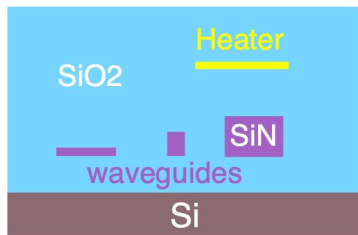
**Extensive PDK**

800 nm

400 nm

150 nm

custom



Design rules

Design Rule Checks

Layout files

Primitives

Building Blocks

IP Cores

Components

- Waveguides, delay lines
- Couplers / MMIs
- Crossings
- Filters (RRs, AWGs)
- Switches
- Polarization mgt

Optical I/O

- Grating couplers
- Inverted tapers
- Spot size converters

Design flows



Component simulations





### Light Source

*There are no integrated SiN Lasers*

Laser

SOA

### Light Manipulation

*Perfect for passives, limitations for high-speed modulation or SHG*

High Speed Switching

High Speed Phase modulation

2<sup>nd</sup> Harmonic Generation

### Light Detection

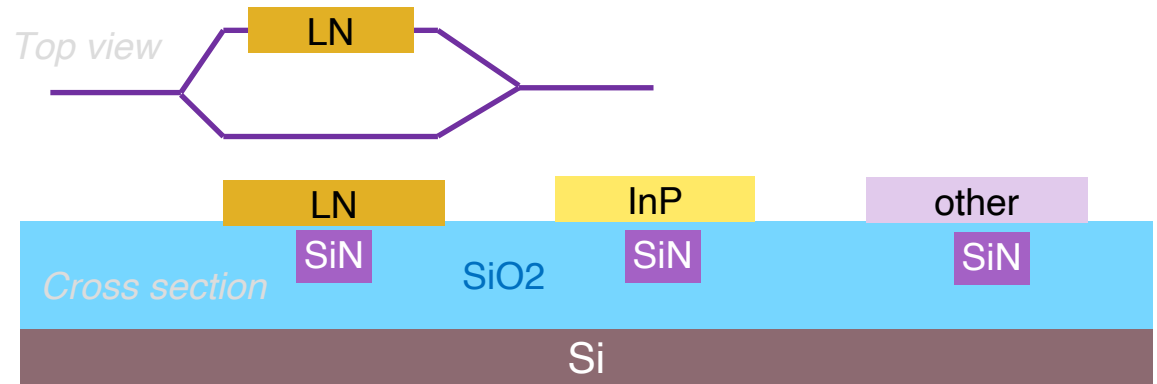
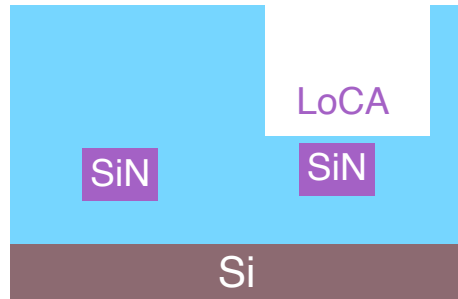
*There is no light detection in SiN*

Photodiodes

Integration options:

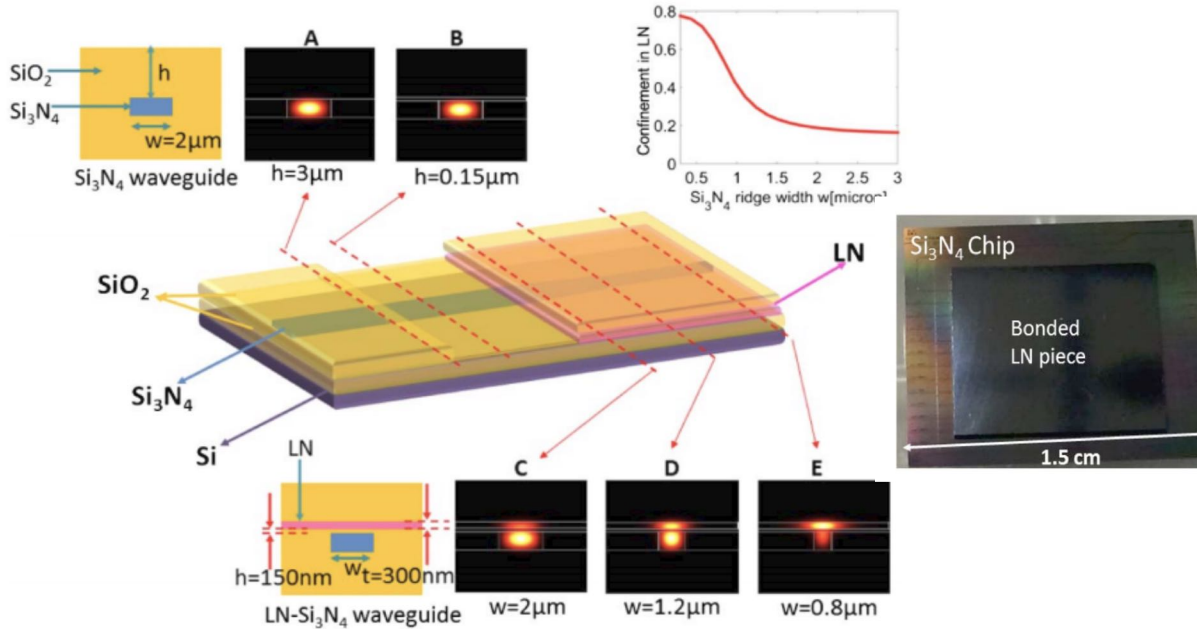
- Fiber coupled
- Hybrid integration
- Heterogeneous integration

# Heterogeneous Integration

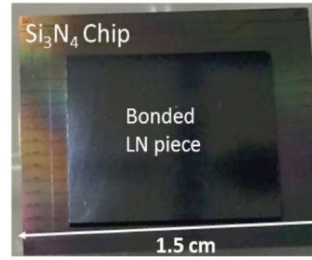
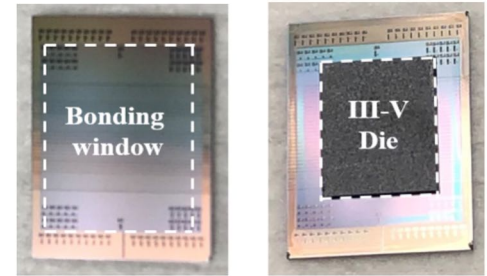


Active functionality can be added by combining with other materials

LNOI: chi<sup>2</sup> material



InP: Lasers and Detectors



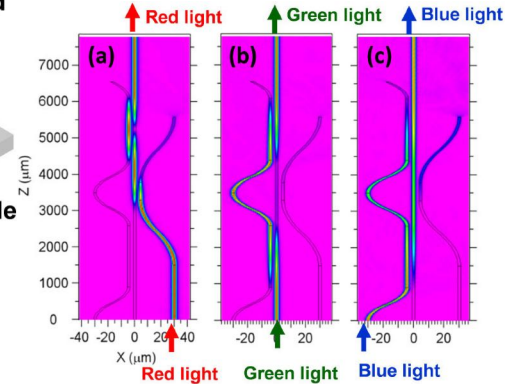
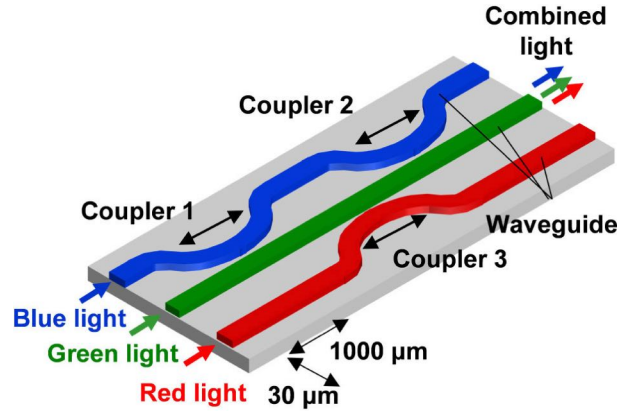
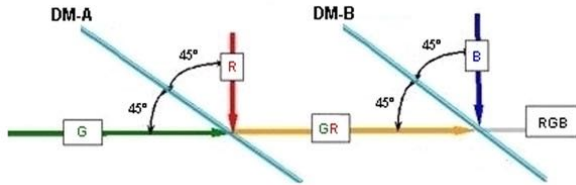
Yu et al., Optics Express (2020)

# AR/VR



# Application - AR / VR

## Beam combiner



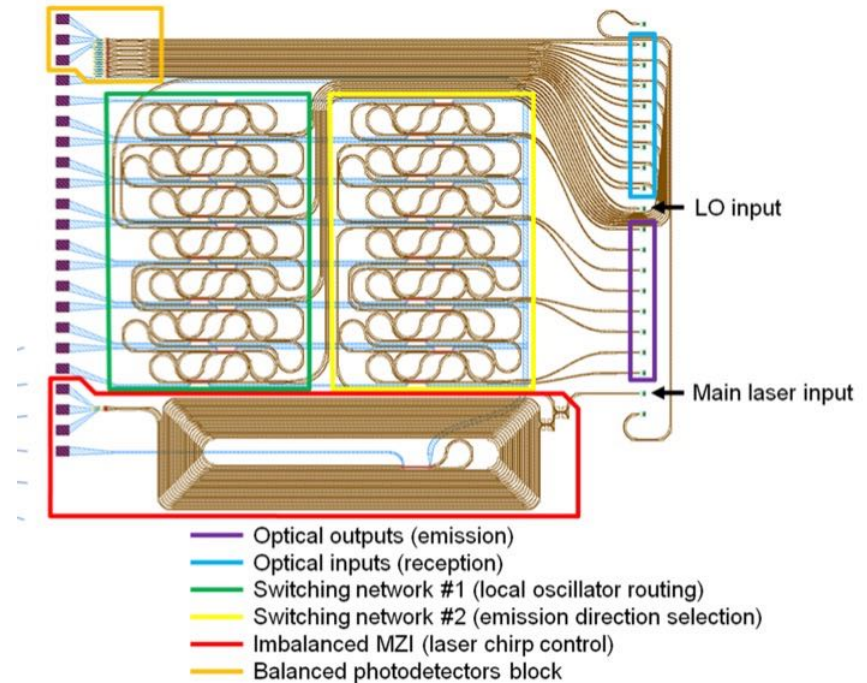
Katsuyama et al. 2014 <https://doi.org/10.1117/12.2072420>

# LiDAR



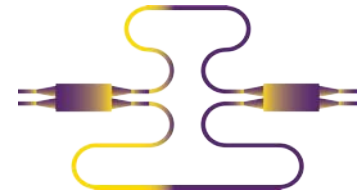
**Key requirements include:**

- High power propagation
- Low loss propagation
- Low phase errors
- Low loss switches
- Low cross talk





- Short bend radii
  - Low loss 5 dB/m
- => Long delay lines



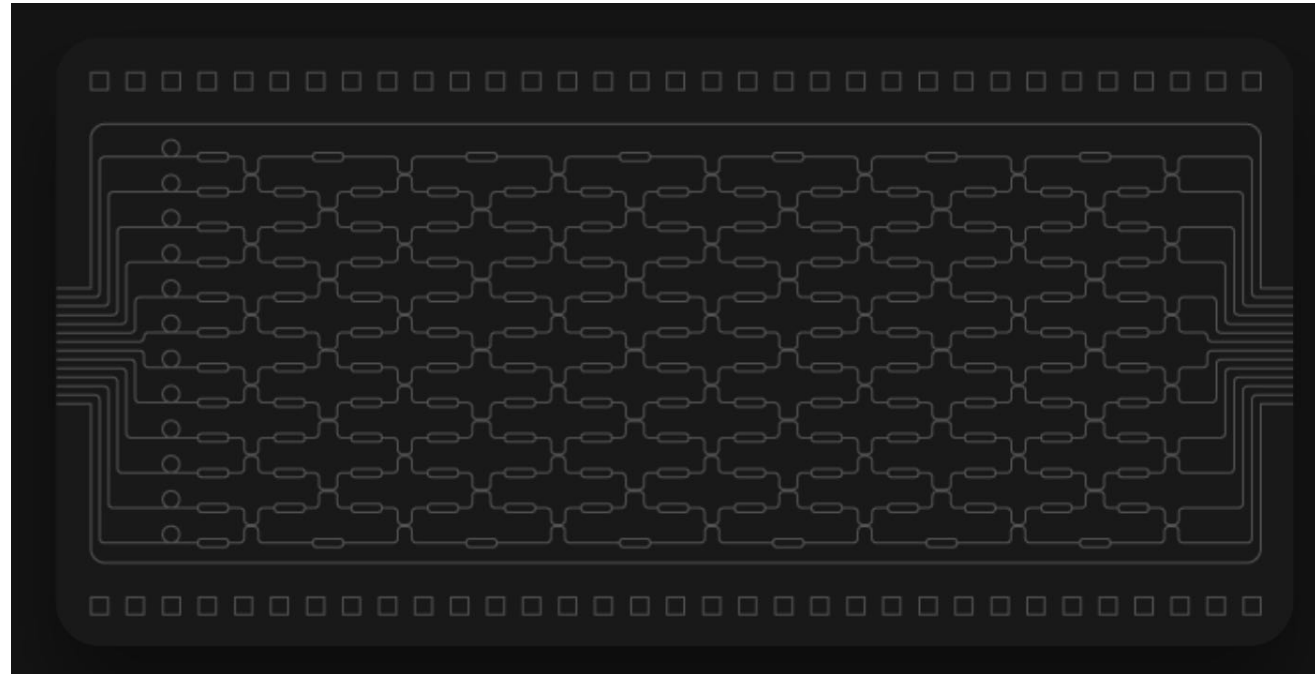
- Small waveguide roughness
  - High mode confinement
- => Low loss & low phase noise

Delay lines up to 1 m on 5x5 mm<sup>2</sup>

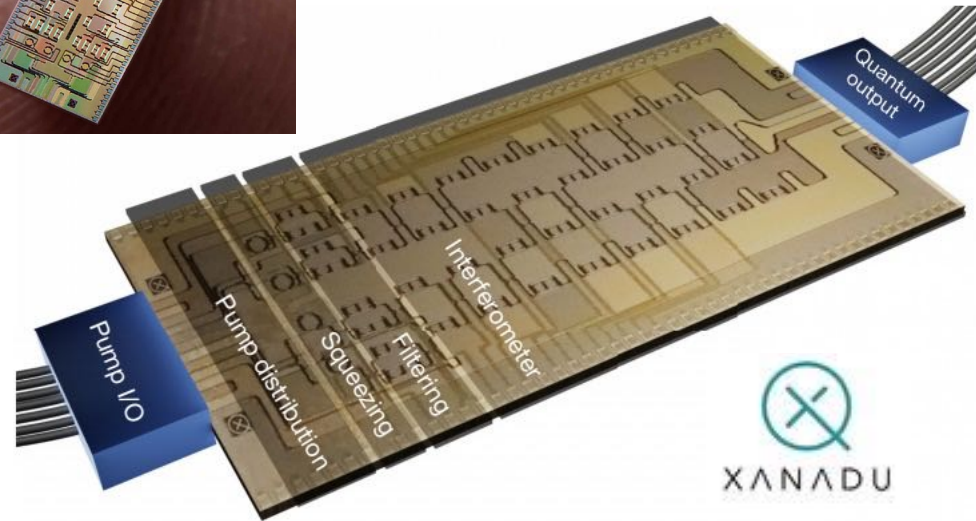
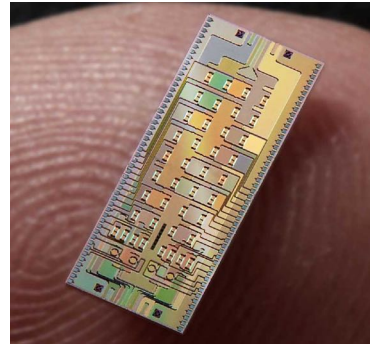
**High confinement enables  
Long and low phase noise delay lines**



# Quantum Computing

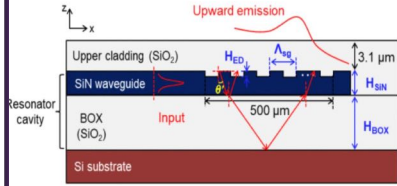


- No moveable parts  
=> high phase stability
- Small size components  
=> integrated on a chip
- Wafer technology  
=> Scalable to high volumes



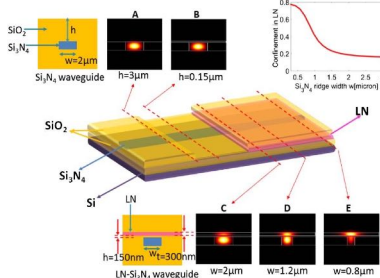
# Used cases examples of LIGENTEC platform

## Phase Arrays



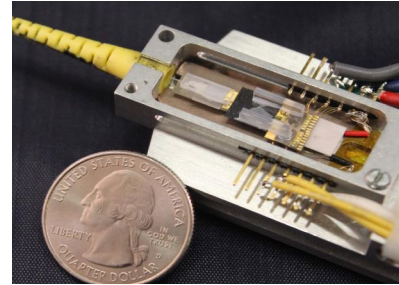
**Optical phased array enabling efficient wavelength-tuned beam steering**  
 Im et al., *IEEE Photonics Journal* Vol 12 (10/2020)

## LiNbO3 Integration



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

## Frequency Combs



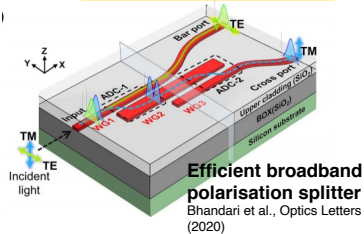
**Frequency comb generation**  
 B. Shen, et al. *Nature* **582** (2020)

## Squeezing



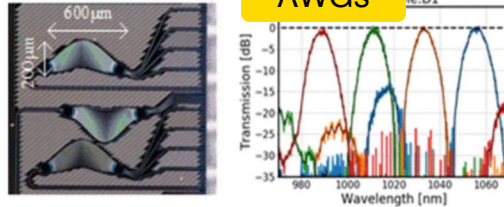
**Squeezed light on a chip**  
 Vaidya et al., *Science Advances* **6** (2020)

## Polarization mgt



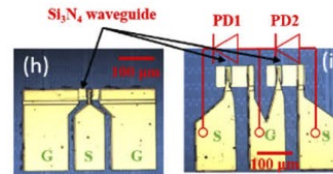
**Efficient broadband polarisation splitter**  
 Bhandari et al., *Optics Letters* (2020)

## AWGs



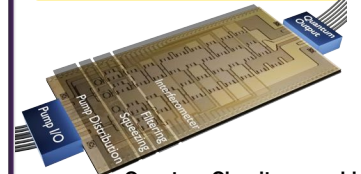
**Ultra-low loss SiN (de-)muxes**  
 Cheung et al., *OFC 2020*

## PD Integration



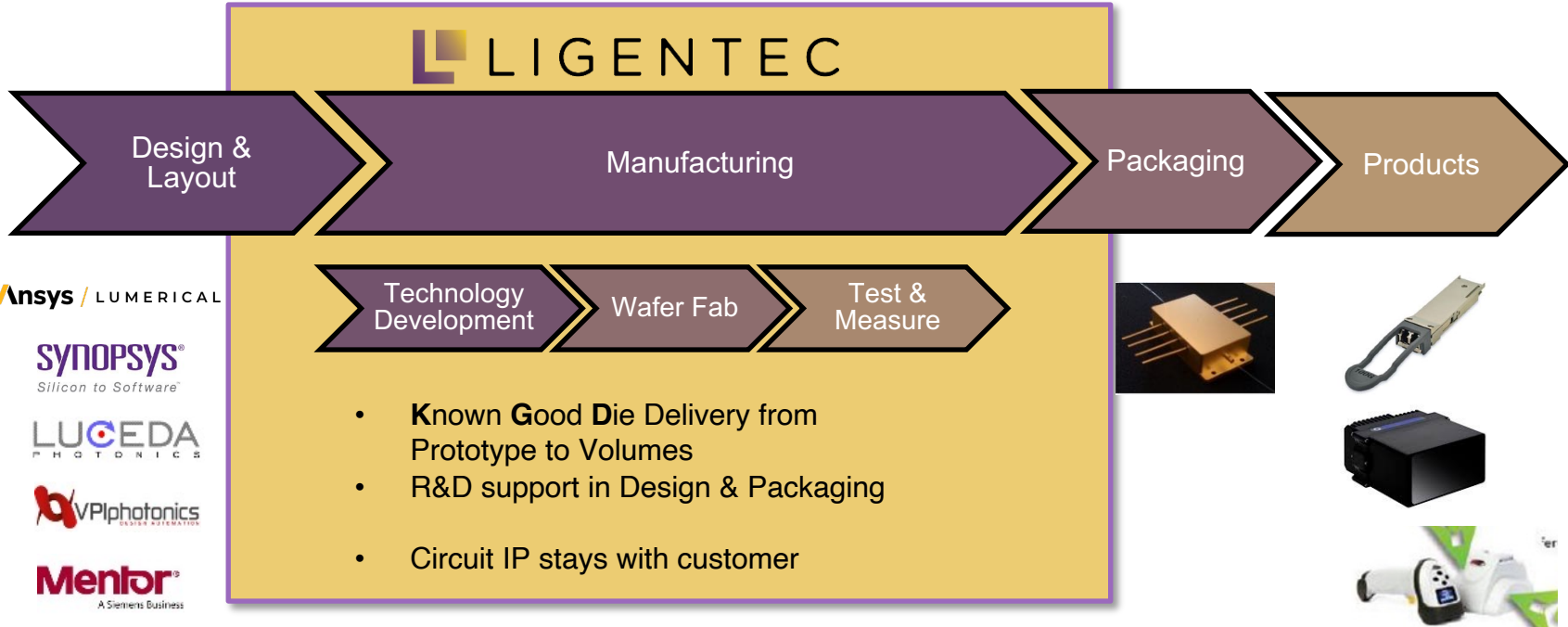
**Heterogeneous photodiodes on SiN**,  
 Yu, *Optics Express* **28** (2020)

## Quantum Computing



**Quantum Circuits on a chip**  
 Arrazola et al., *Nature* **591** (2021)

# Business Model & Offering



**Ligentec offering:** Competent and reliable partner to realize integrated photonic solutions in low loss silicon nitride

# LIGEN TEC Offering

## How to partner with us



### Initial Contact

- Application engineering
- Feasibility

### Concept & Design

- Engineering study
- PDK access
- Design / Layout support

### Prototyping

- MPW runs, fast (10 weeks) 4x per year, fixed dates
- Process flexibility
- Device Characterization
- Packaging support

### Pilot to Volume Fabrication

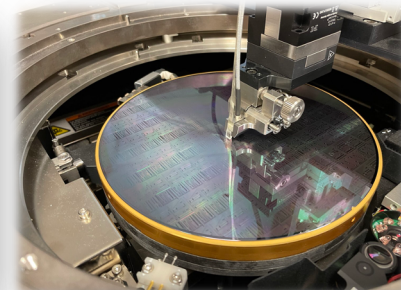
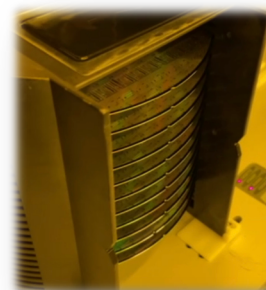
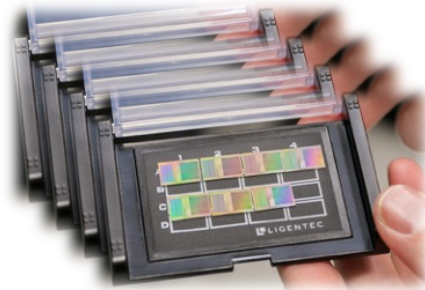
- Pilot and niche quantities
- Large volumes
- High-capacity wafer fab and fully automated testing

**"We are impressed with the device performance."**

*USA customer*

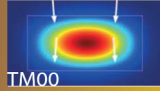
**"We even got the chips before estimated shipping date."**

*Canadian customer*



# Low Loss SiN - Platform Overview

## The Basics

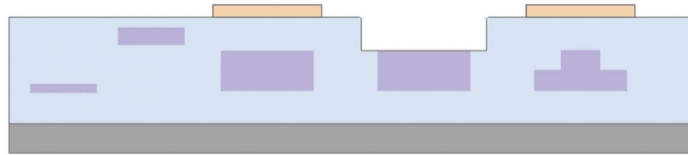
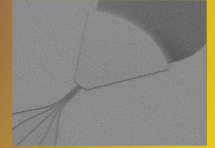


- ✓ High Mode Confinement
- ✓ Low Loss
- ✓ Small Footprint
- ✓ High Power

**Versatile platform with flexibility and short R&D cycles and volume capability**

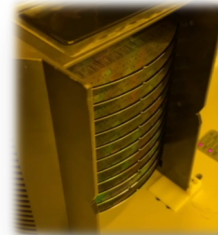
## Full Creativity (PDK)

- ✓ Couplers
- ✓ Mux / DeMux
- ✓ MZIs / DLIs
- ✓ Resonators
- ✓ Polarization control



## Actives

- ✓ Electrical Tuning
- ✓ *Modulators*
- ✓ *Lasers*
- ✓ *Detectors*



## World Connections

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

