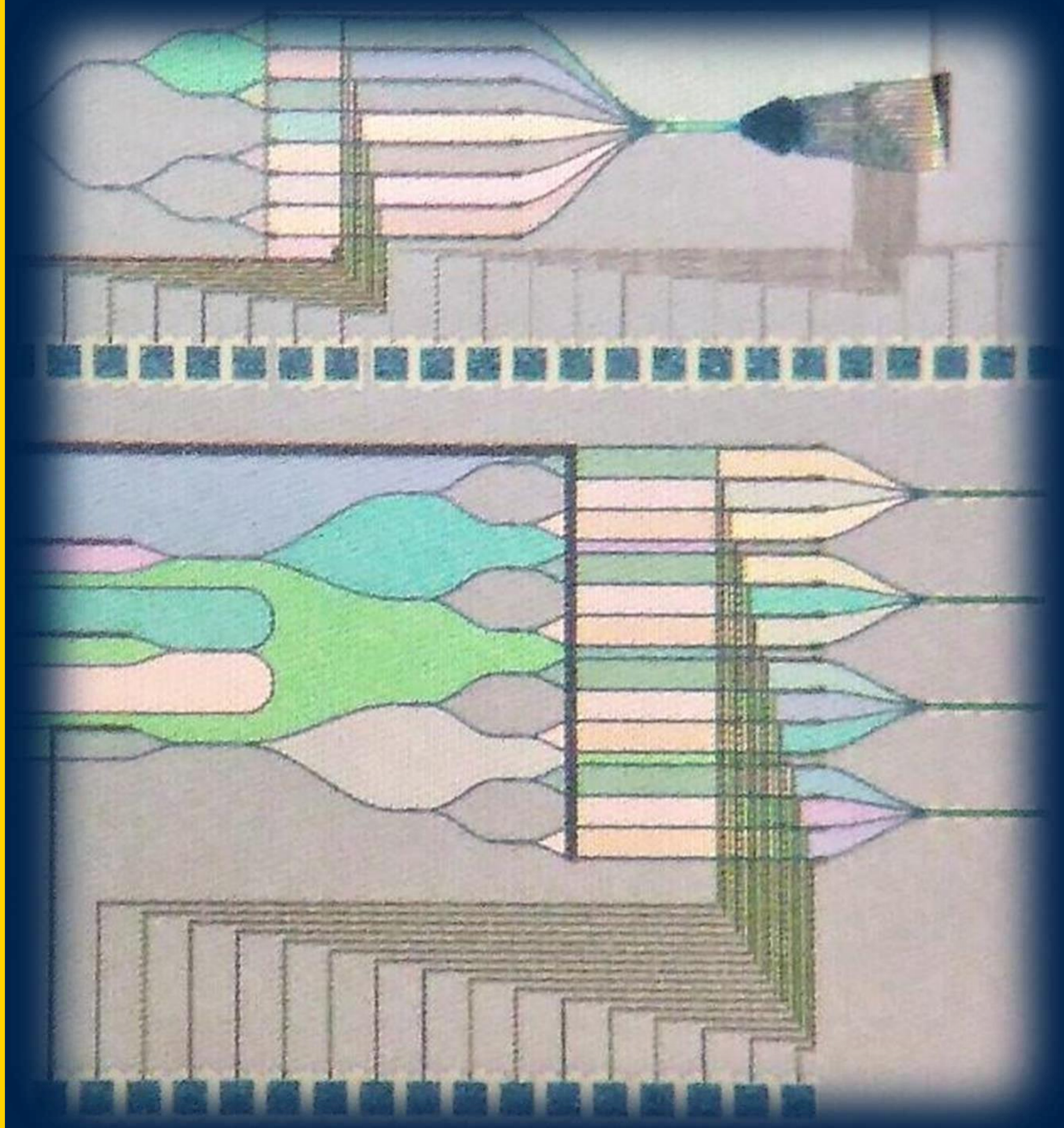

A (European) Silicon Photonics Platorm

Frederic Boeuf , Ph.D.

Technical Director

Strategy & Innovation

Technology & Design Platform

STMicroelectronics, Crolles

Si Photonics in STMicroelectronics

2011

STMicroelectronics started working on Si-Photonics in 2011

2015

Fully automated Optical sorting

From 2015-2021 production for 100G transceivers

2018

400G-DR4 test chip

400G technology risk production ready

2019

Advanced R&D programs toward new applications

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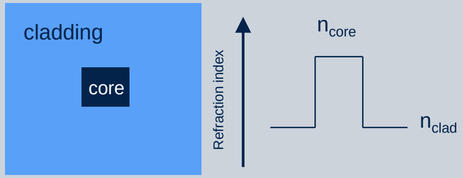
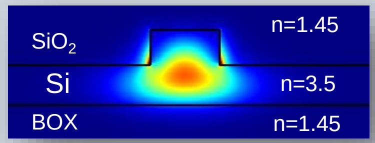
Silicon Photonics Basic Elements

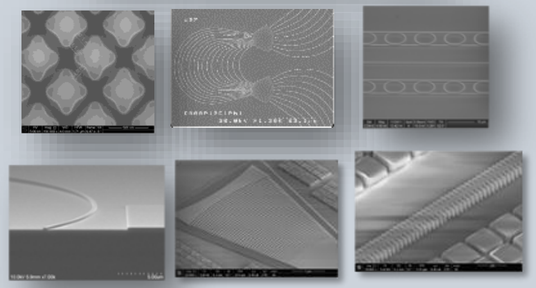
λ = 1.31µm, 1.55µm

Waveguide

Guiding in high index layer



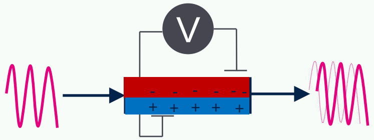




Modulation

Phase modulation

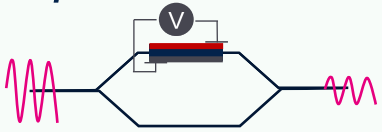
PN diode or Thermo-optic



$$\Delta n = a\Delta N^x + b\Delta P^y$$

$$\Delta n(V) \rightarrow \Delta\varphi(V) = \frac{2\pi\Delta nL}{\lambda}$$

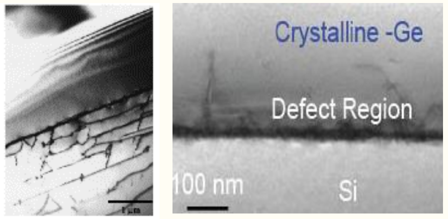
Amplitude modulation



$$I = I_0 cos^2\left(\frac{\Delta\varphi}{2}\right)$$

Photodetection

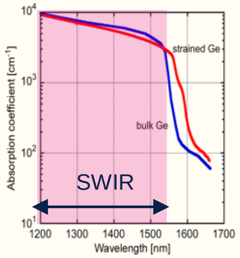
Ge on Si

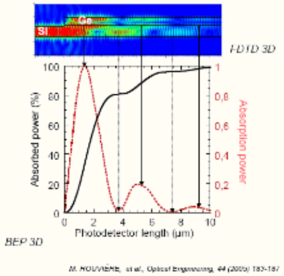


Currie et al., APL 1998 (MIT)

Nayfeh et al., APL 2004 (Stanford)

Ge absorbs λ<1.6 µm



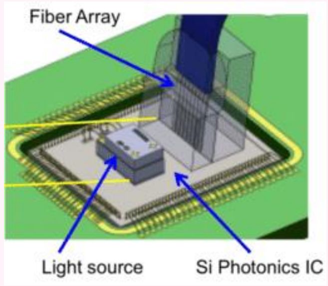


Ge Absorption in the O,C and L bands

Compact Ge PD can be fabricated

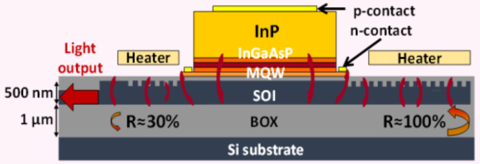
Source

External Lasers



(from Luxtera)

Hybrid III-V/Si Lasers



B. Ben Bahkir et al, 2011 (LETI)

Evolution of PIC Platforms at ST

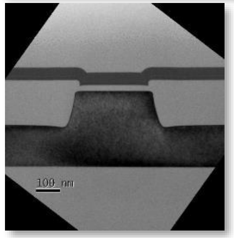
λ = 1.31μm

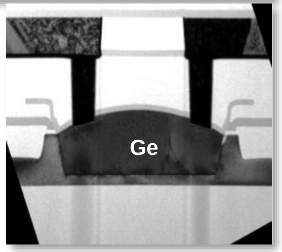
λ = 905nm, 1.31μm, 1.55μm

100G — **400G** — **Datacom & Beyond**

100G

- 300mm / 12’’
- NRZ signal
- 20GHz Ge PD
- PN Modulator
- Rib Si-Waveguides
- Grating coupler



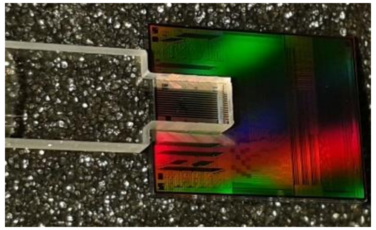


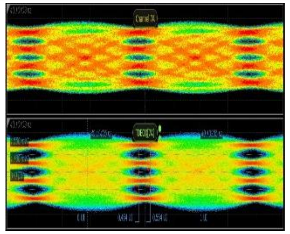
F.Bœuf et al. IEDM 2013

PIC25G

400G

- PAM-4 signal 50Gbd/s
- 67 GHz Ge PD
- PN Modulator Gen2
- Si/SiN waveguides
- Thick-Cu Metallization
- Glass Interposer



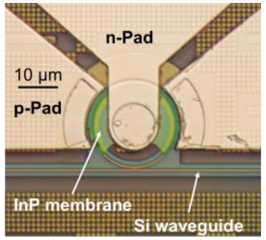


F.Bœuf et al. IEDM 2019

PIC25G and PIC50

Datacom & Beyond

- PN Modulator Gen3
- Si PD (905nm)
- Si/SiN waveguides
- Low loss Si-Waveguides
- Hybrid III-V/Si Devices(*)



F.Bœuf et al. IEDM 2021

(*) not in 12’’

DAPHNE

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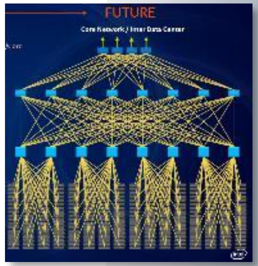
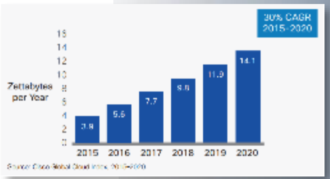
Si-Photonics : Beyond Datacom

DATACOM

Photonic cables connecting people





Bandwidth

Optical Loss

Power Management

System

Manufacturing

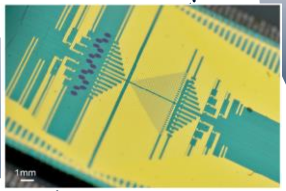
Assembly & Test

Cost

Footprint

Single Technology

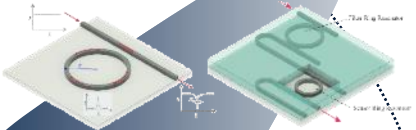
Quantum



Quantum Computing, QKD
Ji Wang et al., Science

BioSensing

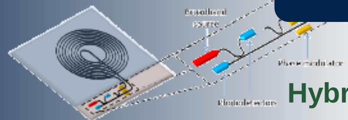
Silicon-Based Optical Biosensors
Laura Lechuga et al.



Beyond Interconnects

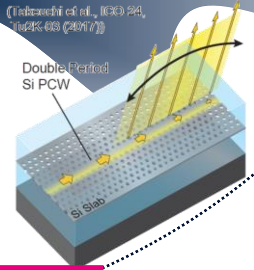
Photonic sensors connecting objects

Automotive

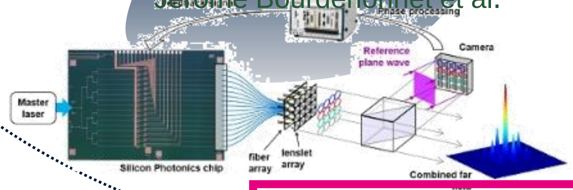


Hybrid silicon waveguide optical gyroscope
John Bowers et al.

Photonic Crystal based Lidar
T. Baba et al.

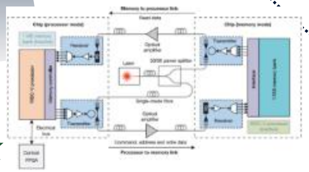


Atmospheric LiDAR Anemometer
Jérome Bourderionnet et al.



Depth-Sensing

HPC/ONN



Intra Processor Link
Chen Sun et al.

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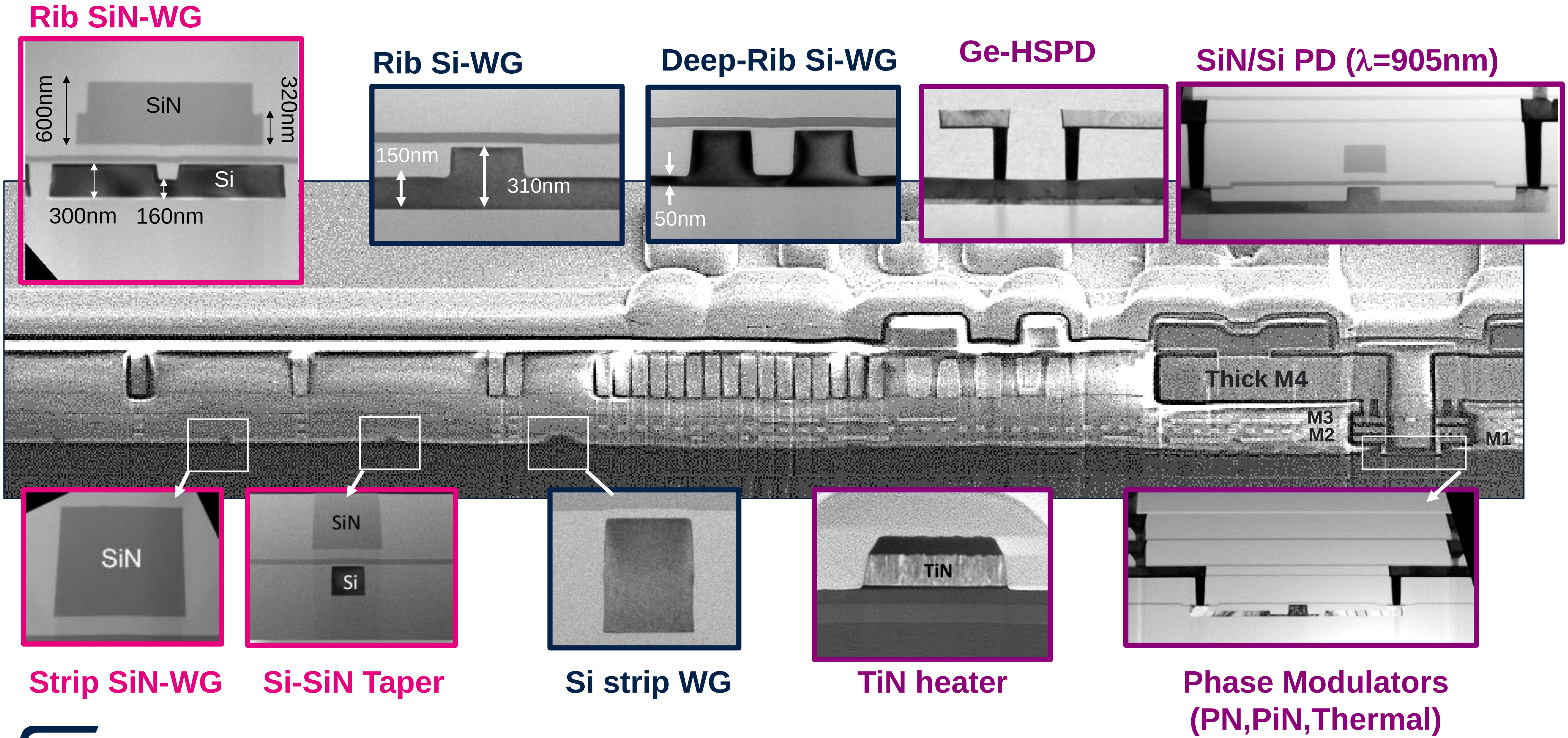
STMicroelectronics Platform Overview



F.Bœuf et al., IEDM 2019, IEDM 2021

Beam steering for 3D Sensing

3D-Sensing with Silicon Photonics

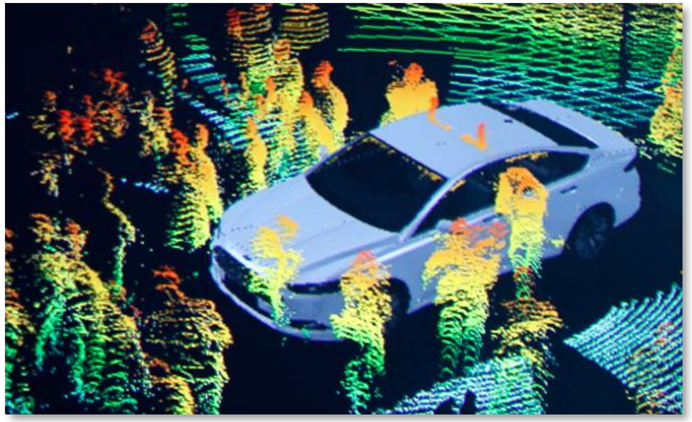


Photo: Jeff Kowalsky/Corbis

https://3dprint.com/117809/depth-sensing-phone-cameras/

- Distance measurement (Z-imaging)
  - Up to 200m for automotive : ADAS L3
  - 10-50m for AR/VR applications

Silicon Photonics advantage

- Compatibility with eye-safe wavelength
- Non-mobile part beam scanner
- « Natural » compatibility with FMCW LiDAR by re-using telecom know how (coherent detection)
- No need of III-V SPAD in SWIR for photo detection
- LiDAR-on-chip

Both 905nm and 1550nm are considered today : demonstration on a single SiPho platform

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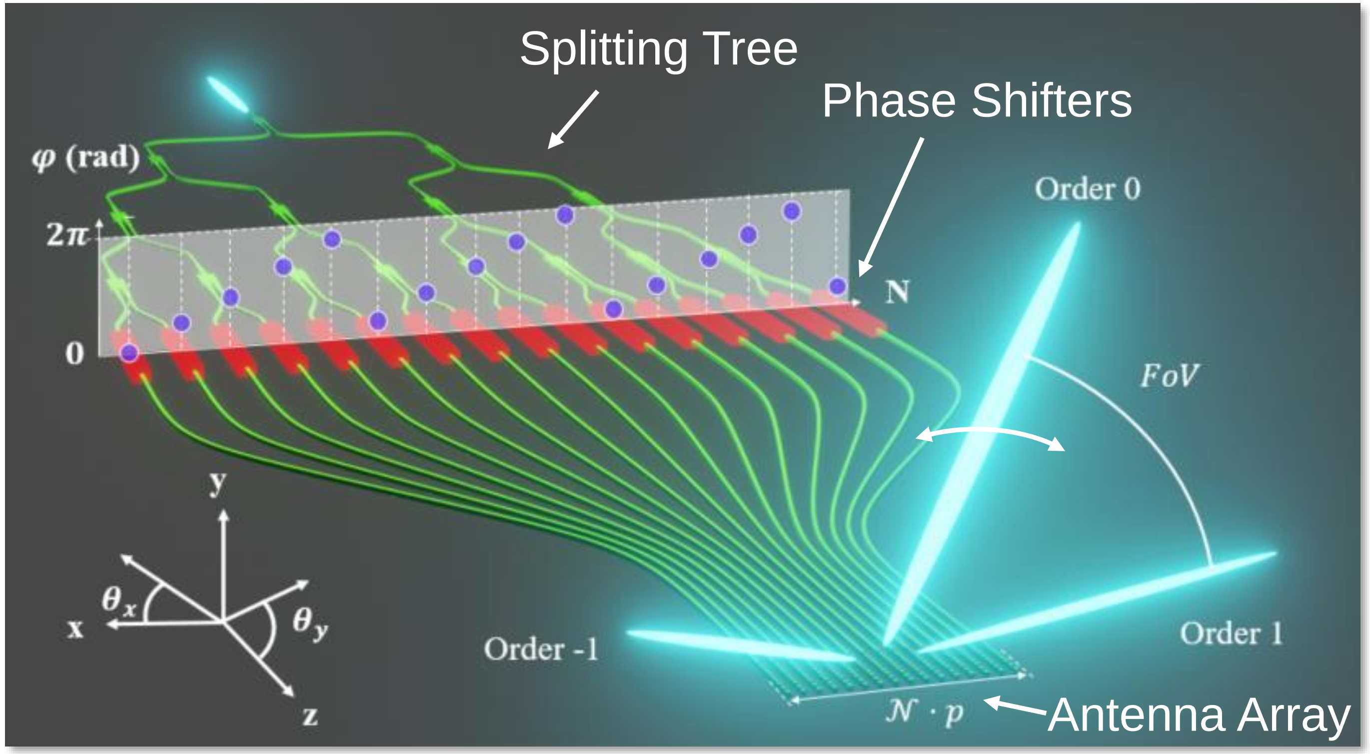
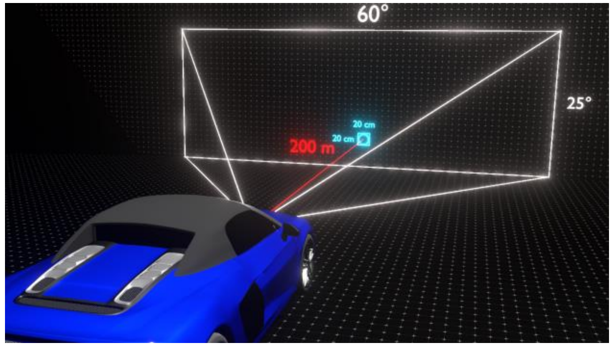
The example of OPA (Optical Phased Array)

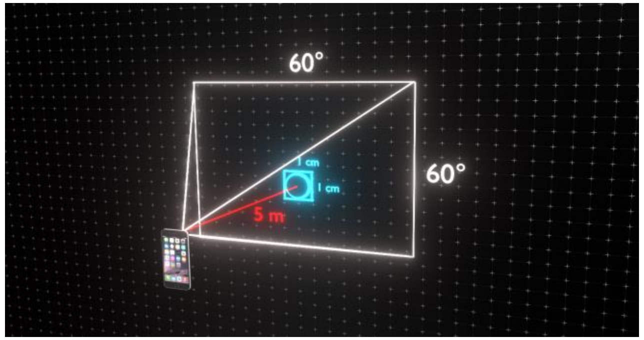
Constructive interference angle is controlled by array phase value



Automotive



Mobile



1 mrad divergence, 60° FoV, 15 Hz framerate, and low power

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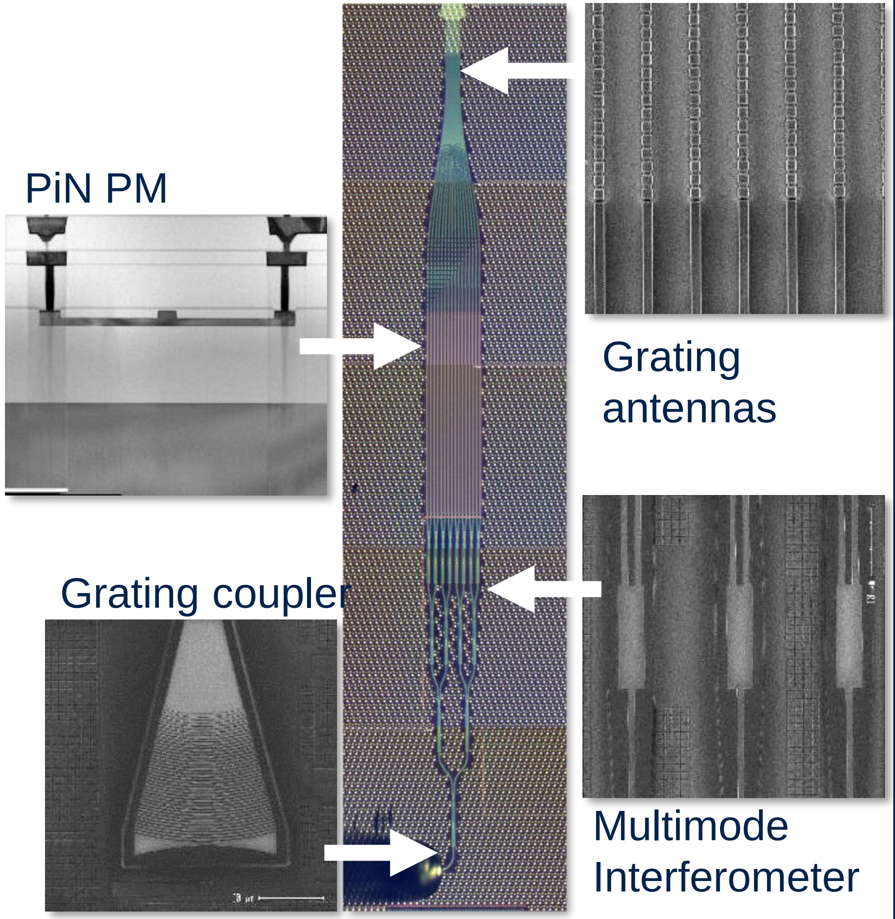
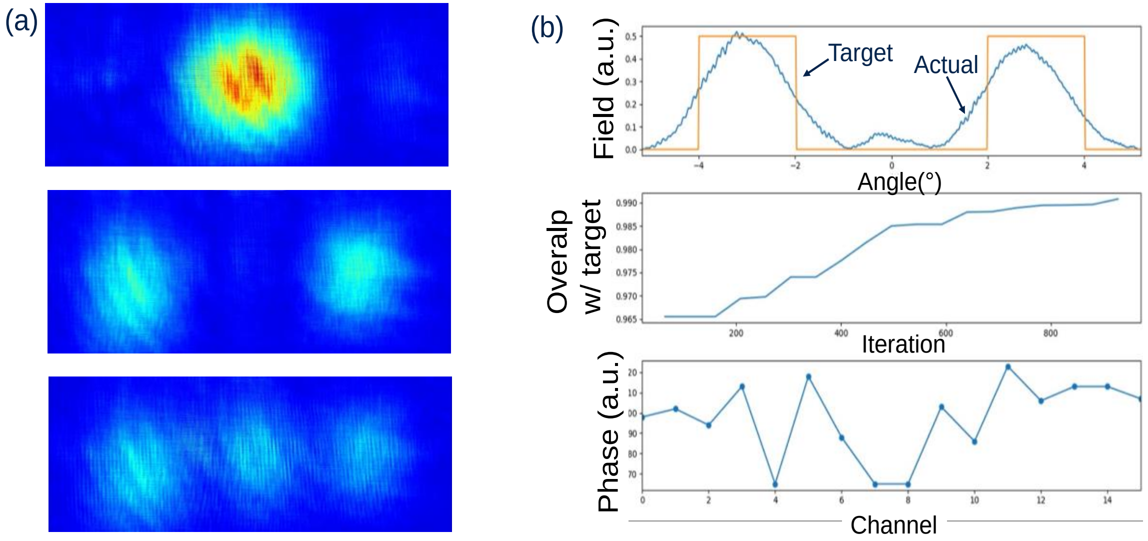
16 channels Si-OPA, 16 PiN Phase Modulators

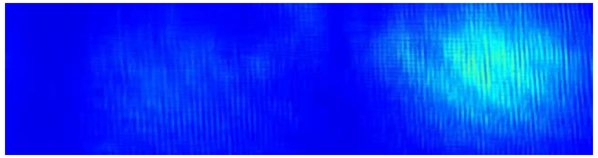
Silicon OPA operating at 1550nm



C. Barrera et al , SPIE Ph.West 2021; ST/LETI

Example of Beam Shaping





Steering Power ~ 1.9 mW/ antenna

F.Bœuf et al , IEDM 2021; ST/LETI

Low Power OPA challenge

Thermo-optics

	Power consumption (Pπ) / channel	Max Freq (Hz)	$L_{2\pi}$ (μm)	Total Steering Power for 512 antennas
Si Heater	~50 mW	~ 400kHz	~250	25W
TiN Heater (w/ SiN waveguides)	6* - 90mW *=need air trenches	~10KHz	~1000	3-45W
PiN Diode	~2 mW	~100MHz	~400	1W
PN junction @1MHz	~0.01mW	>1GHz	~16000	5mW
Hybrid III-V/Si SISCAP @1MHz	~0.01mW	~1GHz	**~1000**	**5mW**

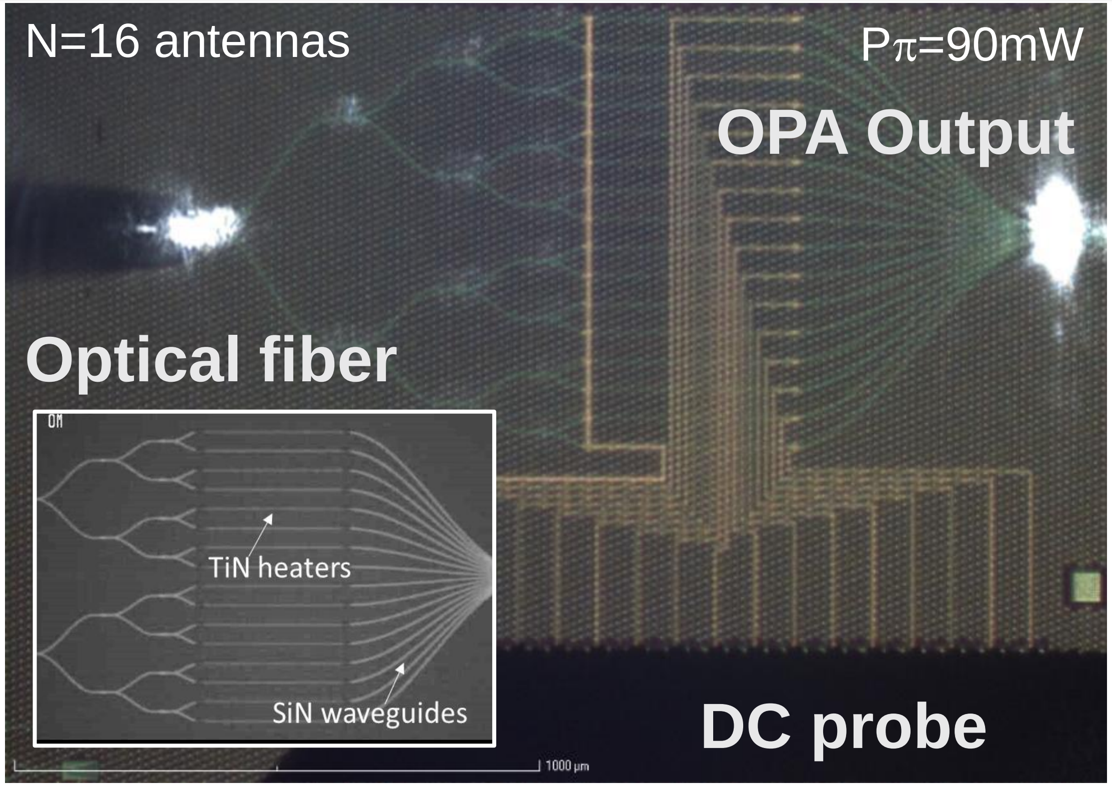
Electro-optics

For low power OPA → EO modulation instead of TO

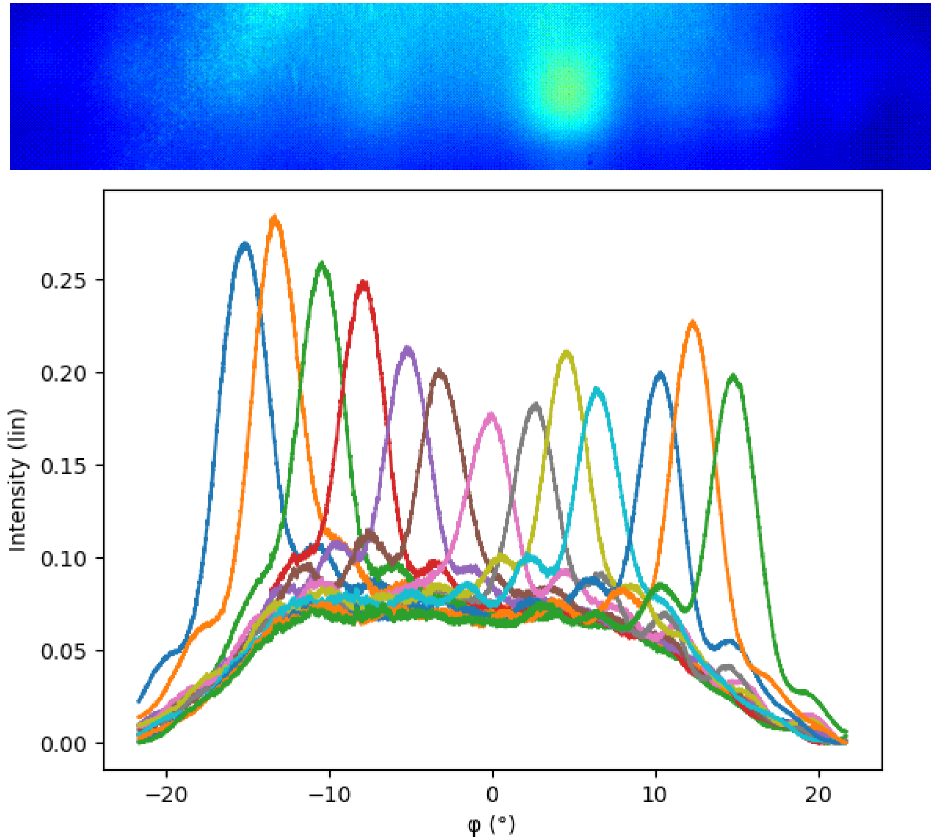
BUT optical loss / decoherence = shortest as possible = high efficiency

SiN OPA operating at λ=905nm

Silicon Nitride OPA operating at 905nm



Silicon Nitride OPA scanning operation



S.Monfray et al. OFC 2022

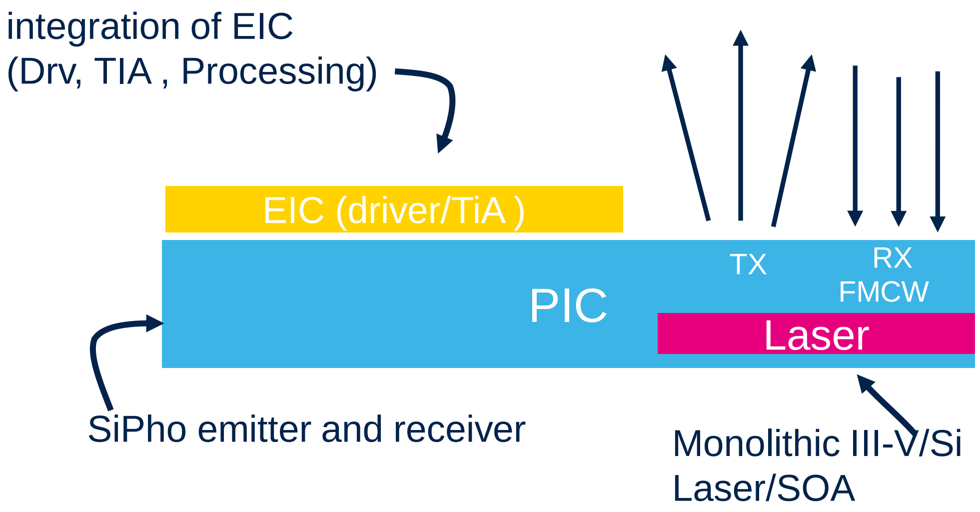
Obtained on same wafer as 1550nm Silicon OPA

Research on III-V/Si Hybrid Integration

Source for 3D Imaging System using SiPho

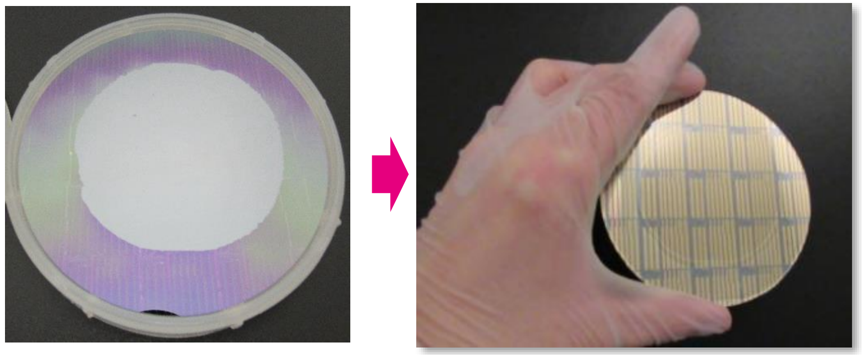
Adding intelligence to the laser source : FMCW and Scanning

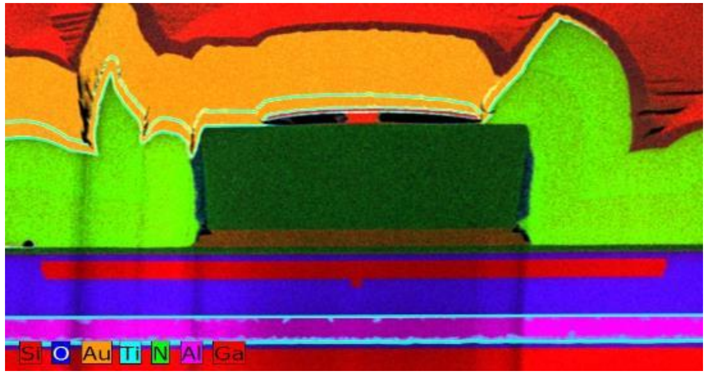
Monolithic III-V/Si Laser Solution



Front side Laser integration : issue with BEOL topology
Back side Laser integration is the solution

Backside Laser Integration





J. Durel et al. IEDM 2016 (ST/LETI/IMEP) , ST Patent

Next challenge : demonstrate Laser source integration on DAPHNE

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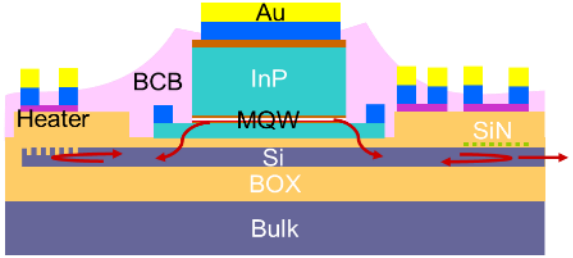
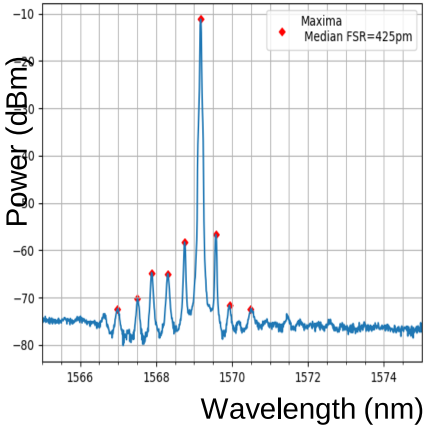
NANOELEC.

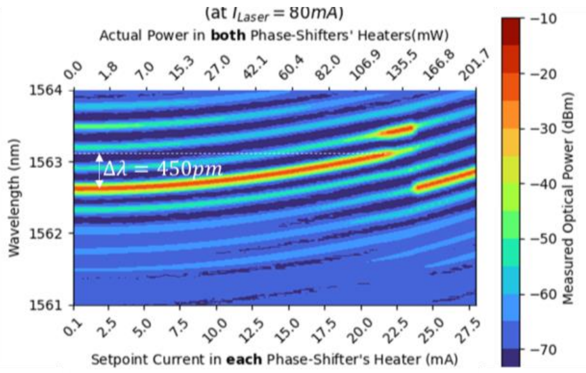
FMCW Hybrid III-V/Si Source Prototype

Laser Prototype Principle

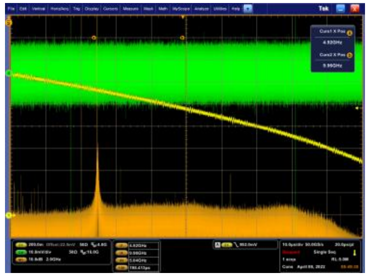


Hybrid III-V/Si FMCW source





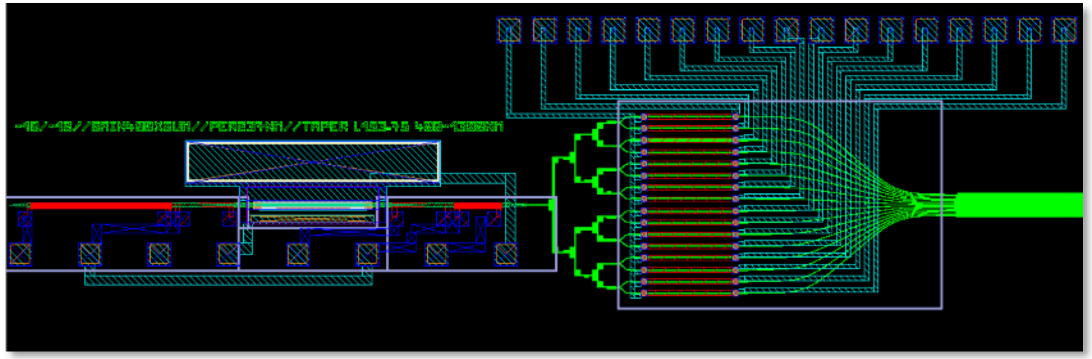
Thermal Modulation

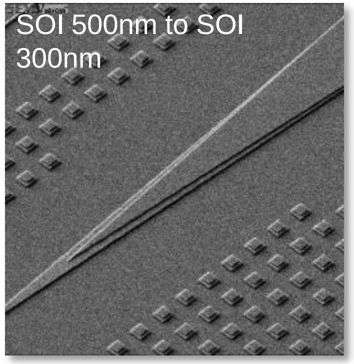


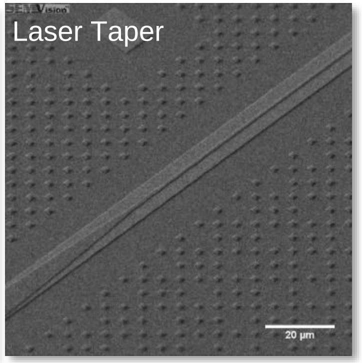
FMCW detection (in fiber)

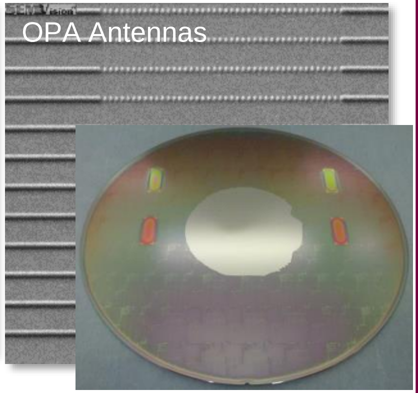
J. Gaudy et al. SSDM 2022

Laser + OPA Demonstration









Conclusion

- STMicroelectronics has developed Silicon Photonics technologies in 300mm
  - Mass production experience for data-communication
  - R&D for « beyond datacom » applications
- Partnership with universities for quantum applications
- Our current plan is to continue improving the technology to match the future challenges of datacom and sensing applications

Thank you

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