OPTICAL PHASED ARRAYS FOR AUTOMOTIVE SOLID-STATE LIDAR SYSTEMS

MARCUS DAHLEM
Principal Member of Technical Staff

INTRODUCTION TO IMEC

ESTABLISHED IN 1984

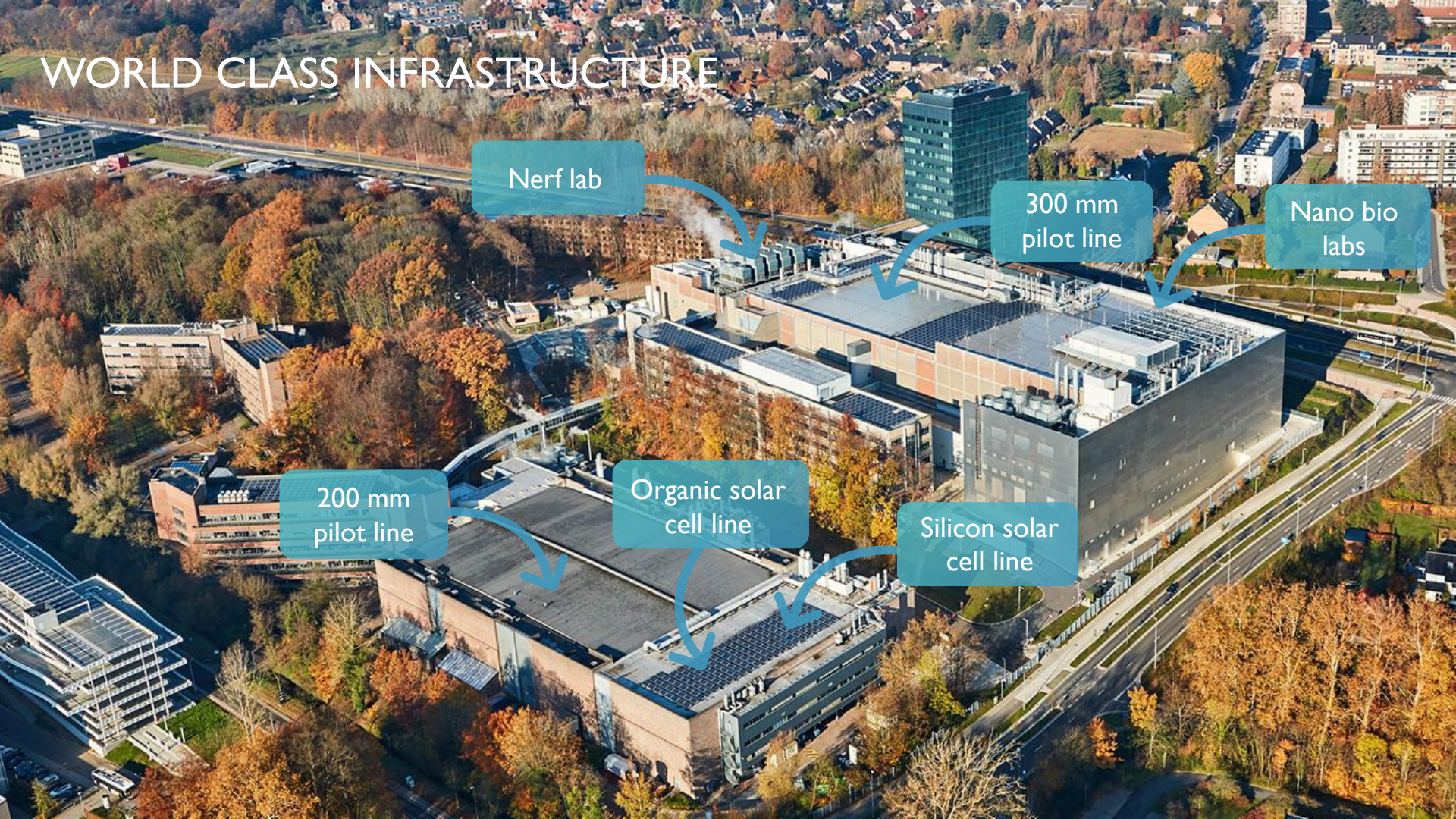
35 YEARS EXPERIENCE IN TOP RESEARCH


BELGIUM - HQ
LEUVEN
THE NETHERLANDS
EINDHOVEN
USA
SAN FRANCISCO
USA
ORLANDO
JAPAN
OSAKA
JAPAN
CHINA
SHANGHAI
TAIWAN
HSINCHU
INDIA
BANGALORE

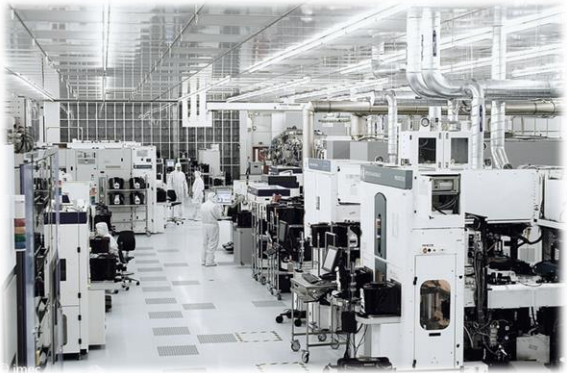
IMEC (founded in 1984)

- World-leading R&D center in **nanoelectronics & digital technologies**
- **International top talent** in a unique **>2B€ leading-edge fab infrastructure**
- Delivering **industry relevant technology** solutions in ICT, Healthcare and Energy markets, serving **600+** companies
- **>500 M€** R&D budget, **85%** direct from **industry**
- >**4000** people (from **90+** countries)
- **HQ** in Leuven (BE) + sites worldwide
- **24/7** operation (**200 mm** and **300 mm**) **cleanrooms (12,000 m^2)**

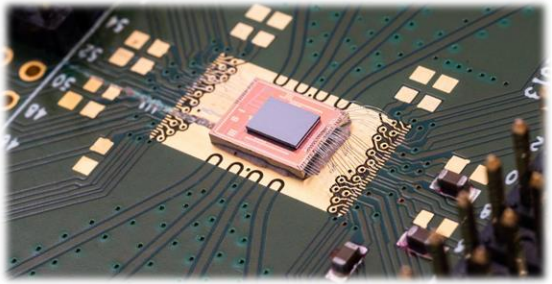
WORLD CLASS INFRASTRUCTURE



200 MM & 300 MM CLEANROOMS (24/7 OPERATION)

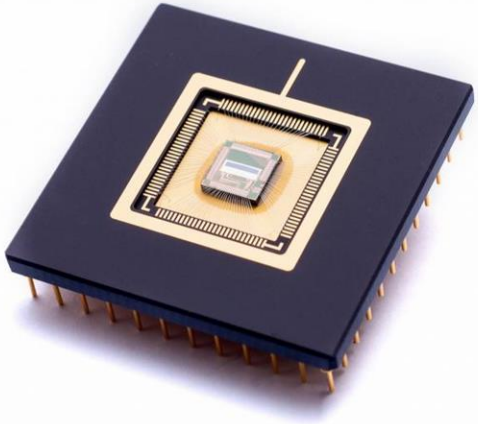


SOME AREAS OF EXPERTISE

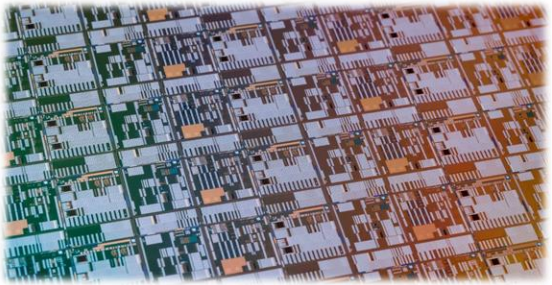


Si and SiN Photonics

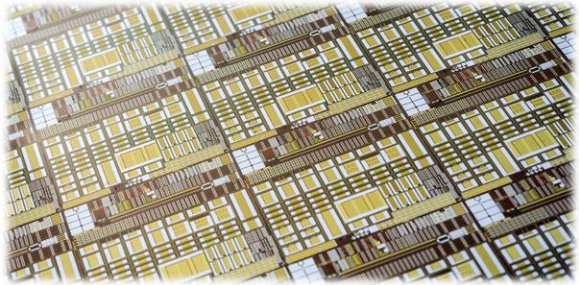
Life Sciences & Biophotonics



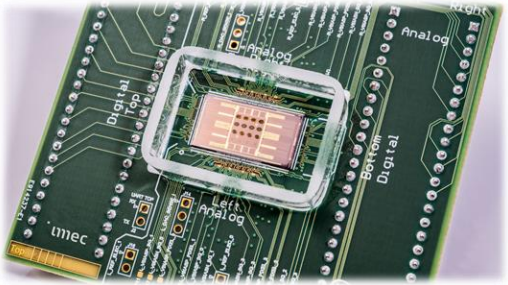
Radar Systems



CMOS and beyond CMOS



GaN

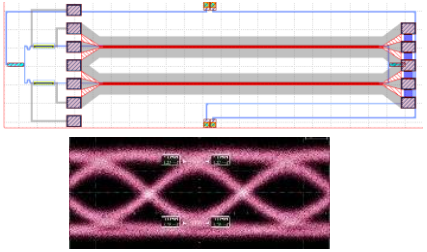


Lab-on-a-Chip

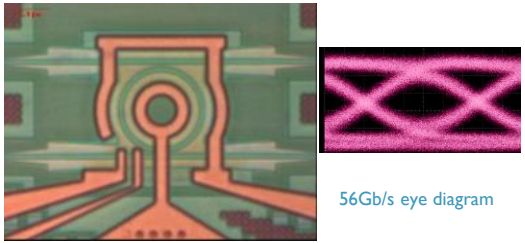
SI PHOTONICS PLATFORM @ IMEC

State-of-the-art mature and versatile platform

56G Silicon Mach-Zehnder Modulator

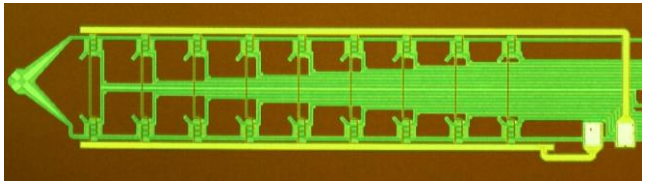


56G Silicon Ring Modulator

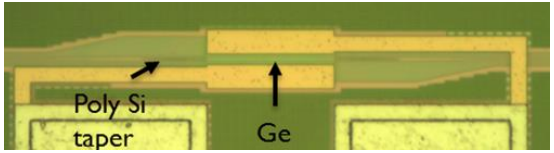


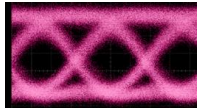
56Gb/s eye diagram

8+1-channel DWDM (De-)Multiplexing Filter



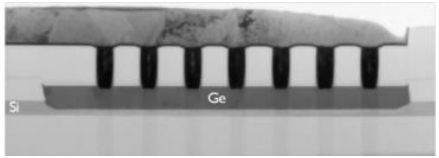
56G GeSi Electro-Absorption Modulator



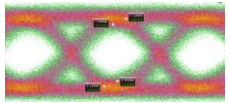


56Gb/s eye diagram

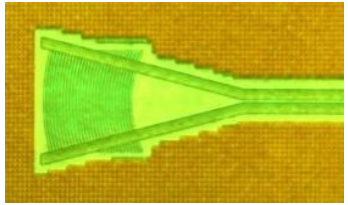
50G Ge Photodetector



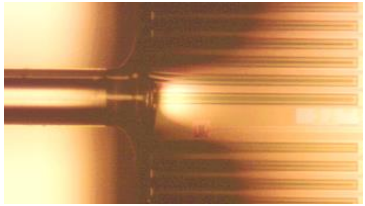
50Gb/s eye diagram



Grating Coupler



Edge Coupler

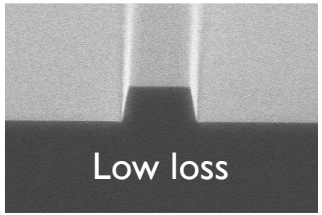


Philippe Absil et al., *Optics Express* 23(7), pp. 9369–78, 2015

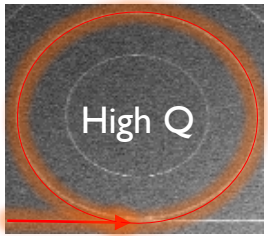
SIN PHOTONICS PLATFORM @ IMEC

A large library of experimentally verified components is available

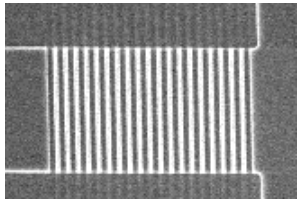
Waveguides



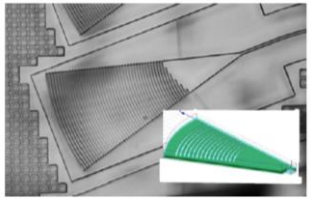
Ring Resonators



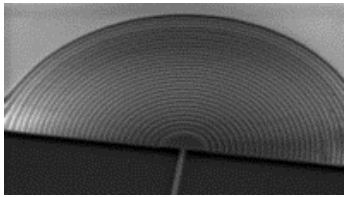
Fiber-to-WG



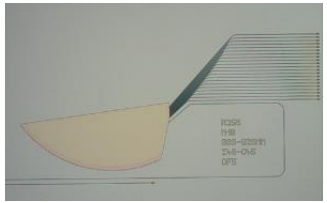
Low reflection

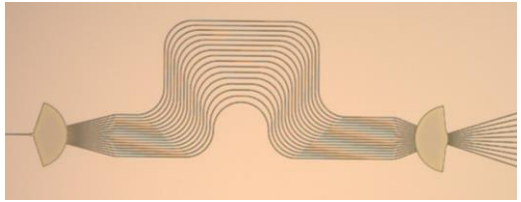


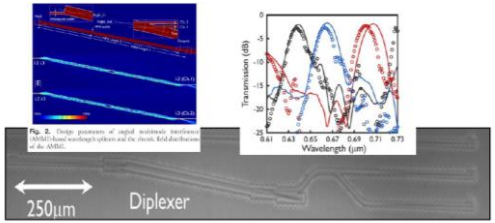
Focusing



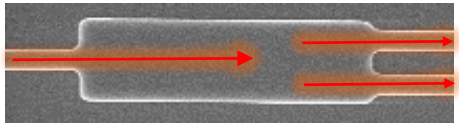
Basic spectrometers



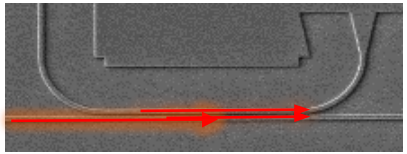




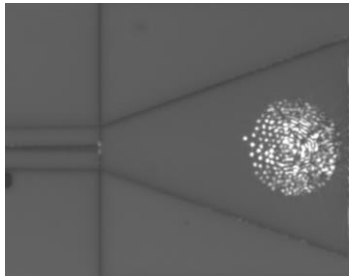
Multi-mode interferometer



Evanescent coupler



Pseudo-random



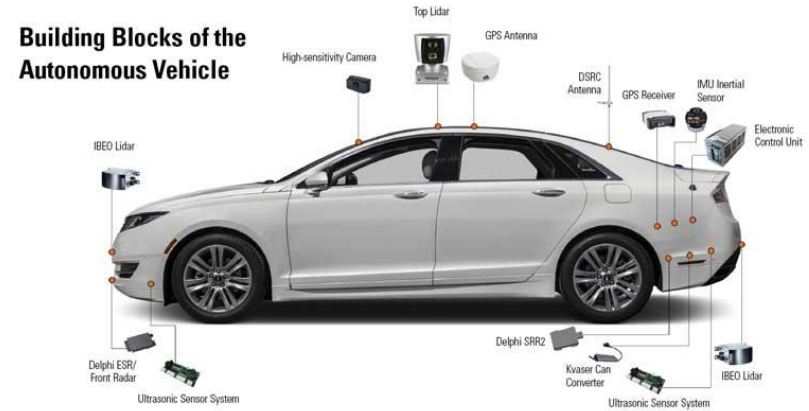
AUTOMOTIVE LIDAR

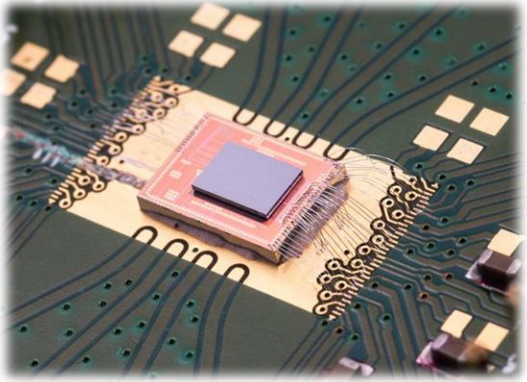
TOWARDS SOLID-STATE LIDAR SYSTEMS

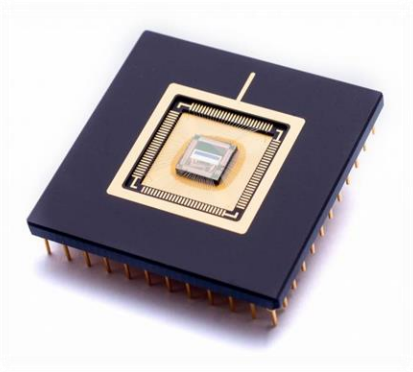
Source: http://velodynelidar.com

Low-cost integrated

LiDAR chips



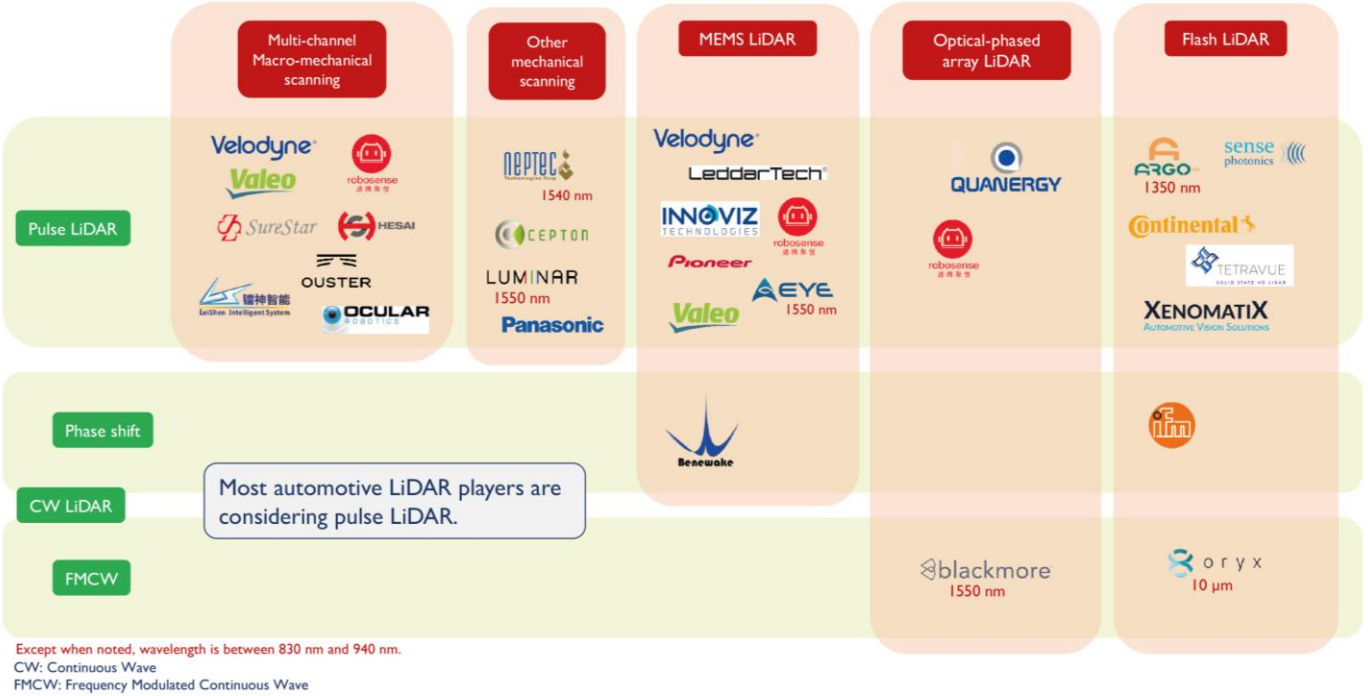




Automotive LiDAR players

2018

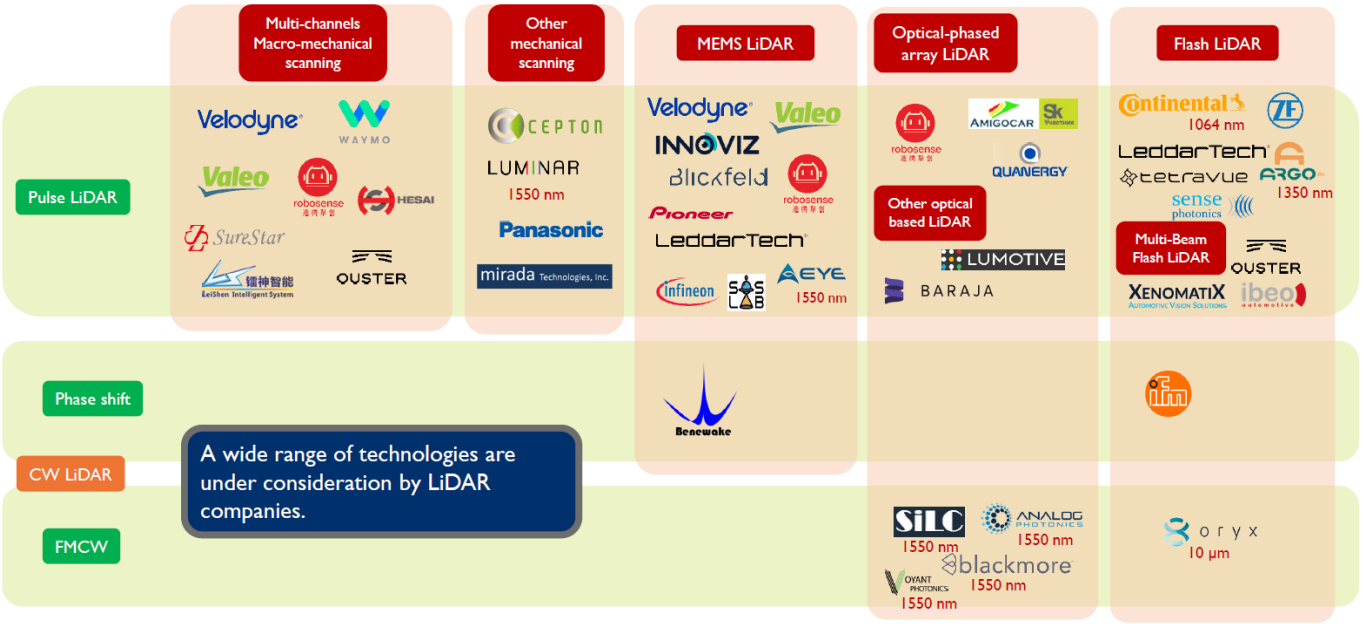
(Source: LiDARs for Automotive & Industrial Applications report, Yole Développement, Mai 2018)



Except when noted, wavelength is between 830 nm and 940 nm.
CW: Continuous Wave
FMCW: Frequency Modulated Continuous Wave

Automotive LiDAR players

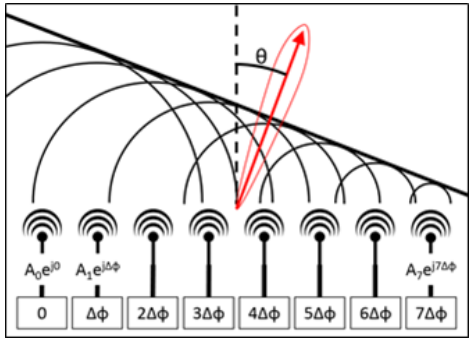
2019



ILLUMINATION & DETECTION TECHNIQUES

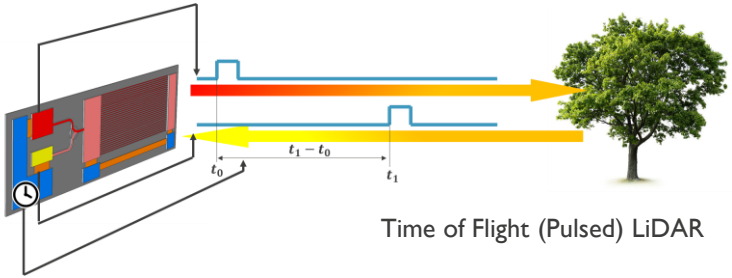
Illumination techniques:

- No beam steering:
  - Flash LiDAR (uses ToF imaging arrays)
- Beam steering:
  - Bulky mechanical devices (large, heavy and costly)
  - MEMS mirrors (vibrations may be limitation)
  - Optical Phased Arrays (no-mechanical parts; can be integrated on a chip; 1D or 2D)

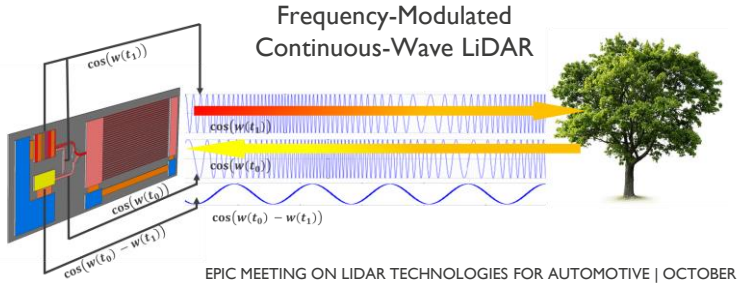


Main detection schemes:

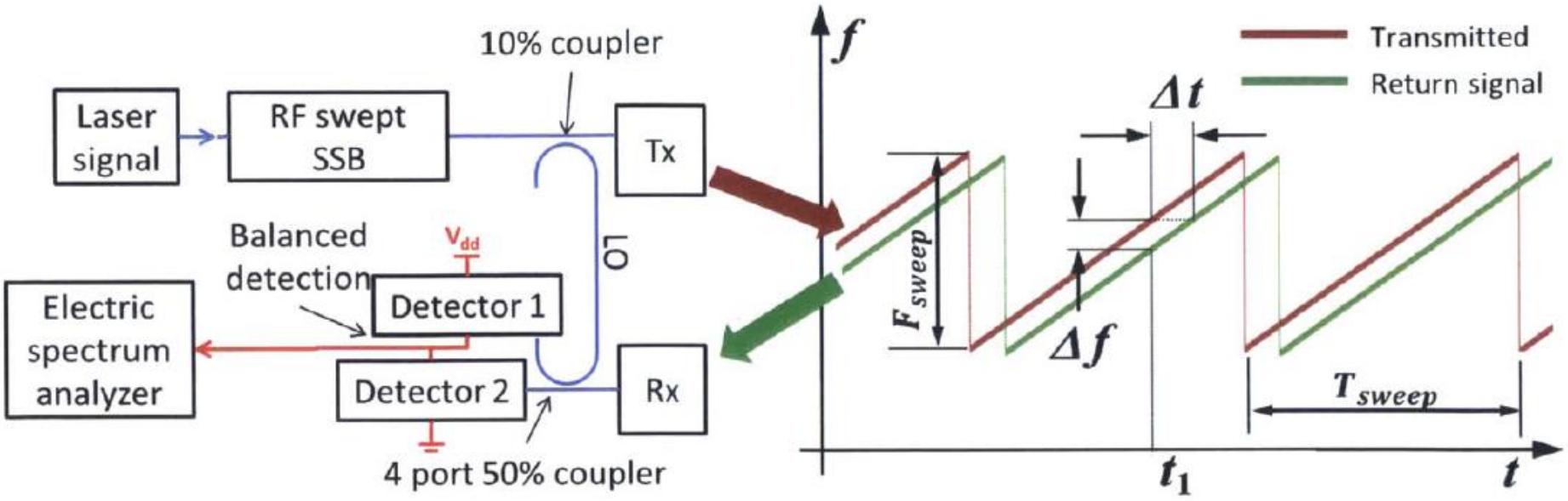
- Direct Time of Flight (ToF) – High Laser power; eye safety issue (at 905nm); crosstalk/background light; noise limit
- Coherent Detection (FMCW: Frequency-Modulated CW) – Shot noise limited; better dynamic range; range+velocity measurements (Doppler); complex system



Time of Flight (Pulsed) LiDAR



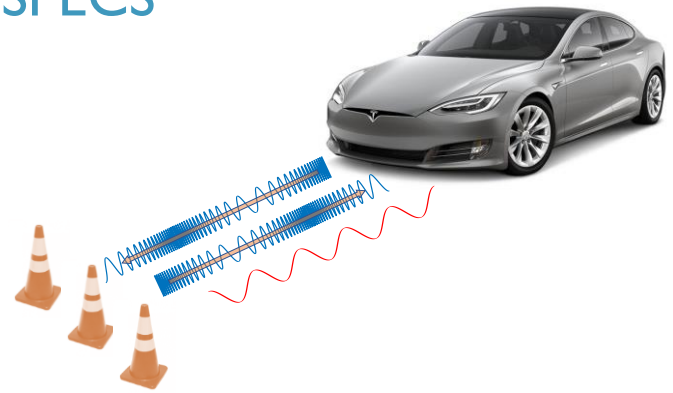
FMCW (COHERENT DETECTION)



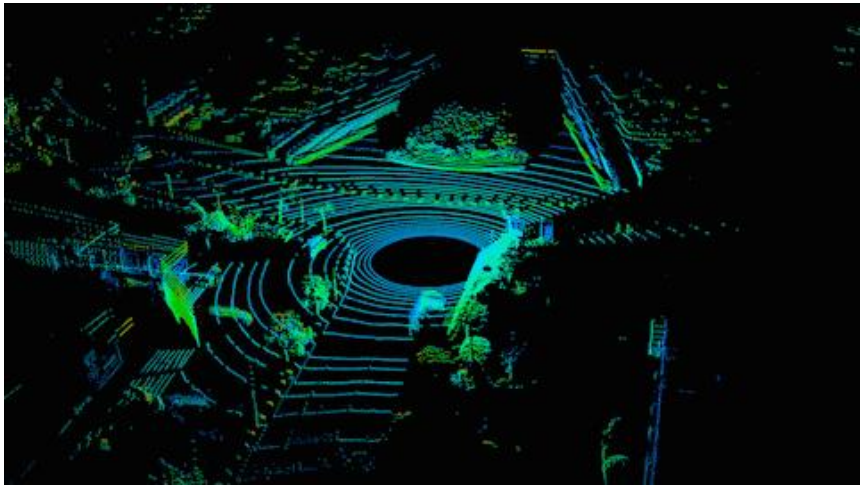
MIT (2015)

AUTOMOTIVE LIDAR GENERAL TARGET SPECS

- Sensing depth: 3D mapping
- Range: >200 m
- Cost for high volume production: <<$1,000
- Field of view: >100° (H) × 10-30° (V)
- Angular resolution: <0.05°
- Power consumption: <50 W
- Weight: <0.5 kg
- Size: < 10 cm × 10 cm × 10 cm
- Samples per second: >>400k (frame rate: 10-30 Hz)
- Wavelength: 1550 nm (eye safe, less ambient noise)
- LiDAR engine: FMCW of TOF
- Beam delivery: Optical Phased Array (OPA)



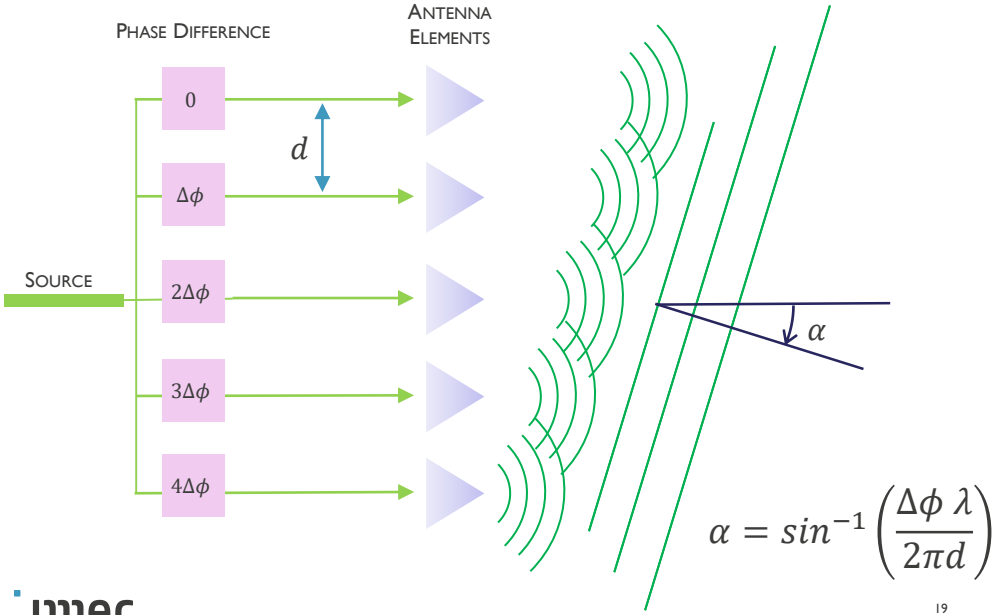
Source: Hesai

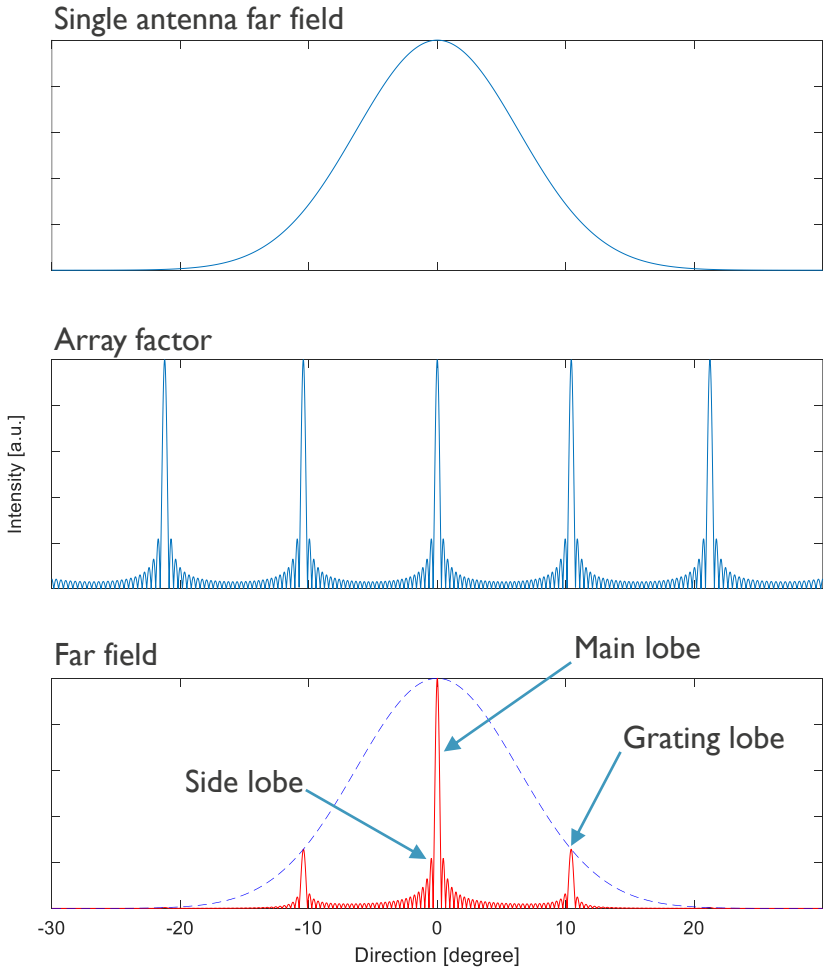


OPTICAL PHASED ARRAYS

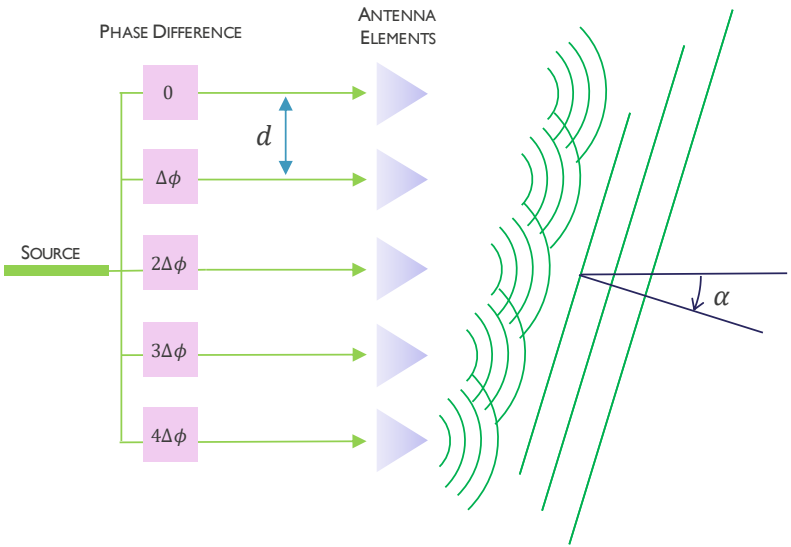
PHASED ARRAY

- A uniform phase difference $\Delta\phi$ between neighboring antennas results in beam steering
- Far-field radiation pattern is the product of the *antenna radiation pattern* and the *array factor*, assuming identical antennas

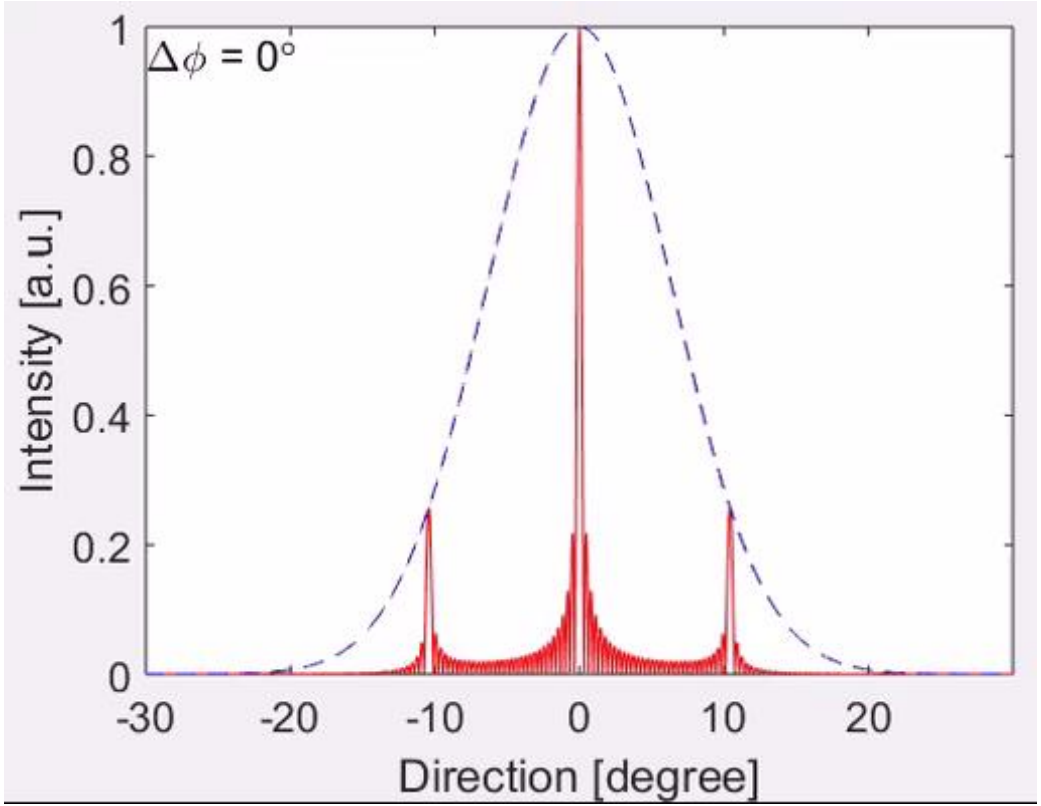




BEAM STEERING ANIMATION

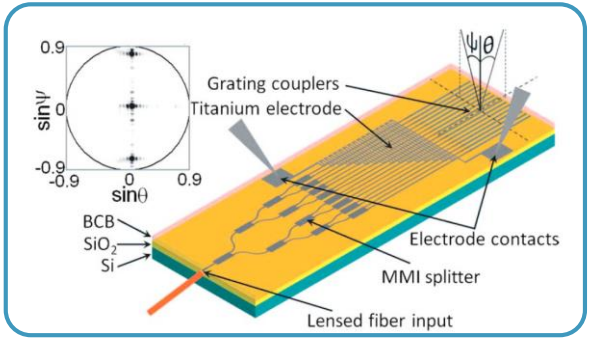


$$\alpha = sin^{-1}\left(\frac{\Delta\phi\ \lambda}{2\pi d}\right)$$

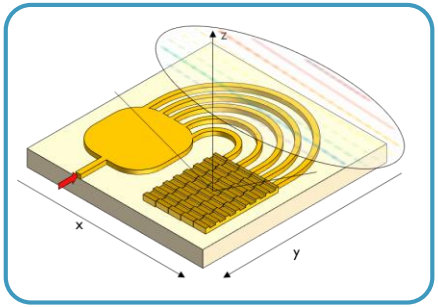


STATE-OF-THE-ART

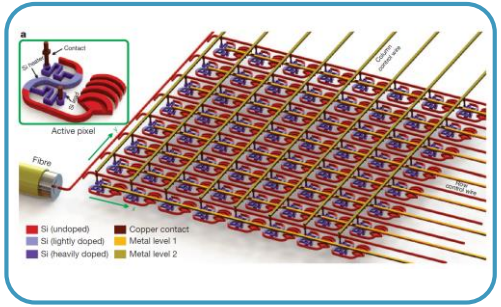
Ghent University (2009)



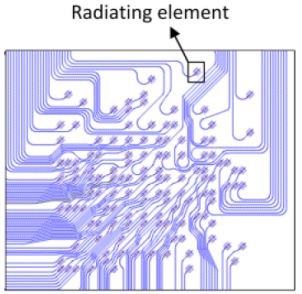
Ghent University (2011)



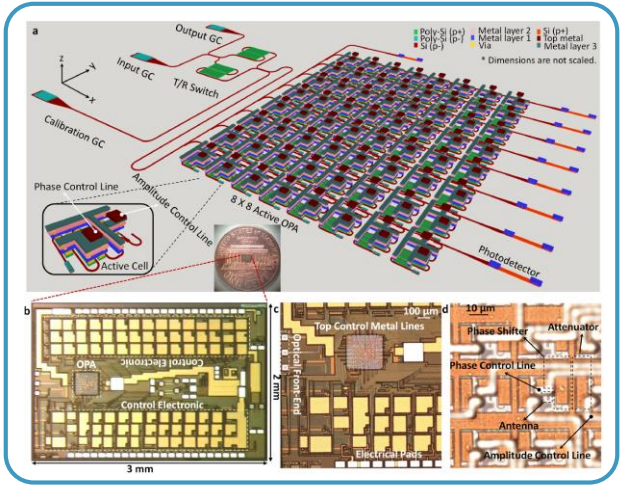
MIT (2013)



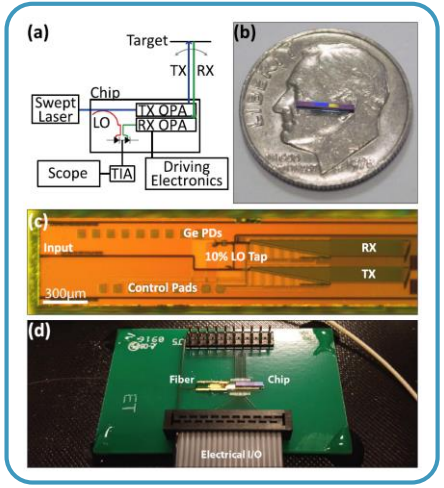
Caltech (2018)



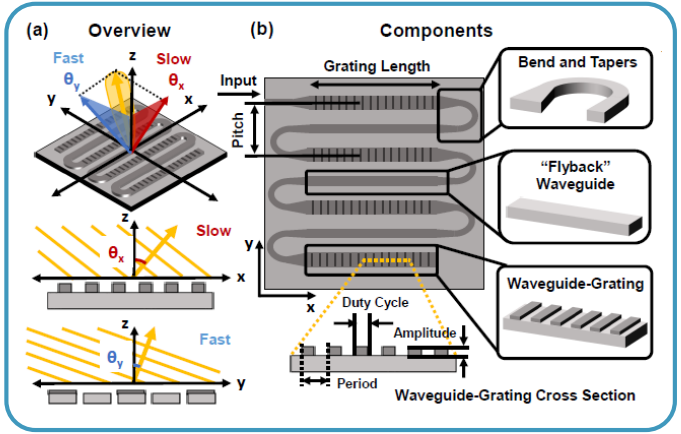
University of Southern California (2015)



MIT (2017)

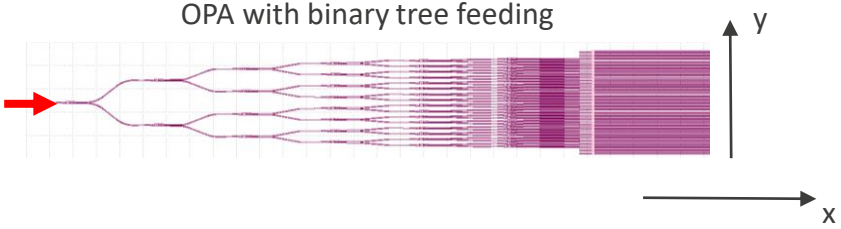


Boston University (2019)



1D & 2D STEERING DEMONSTRATION

OPA with binary tree feeding



OPA with binary tree architecture:

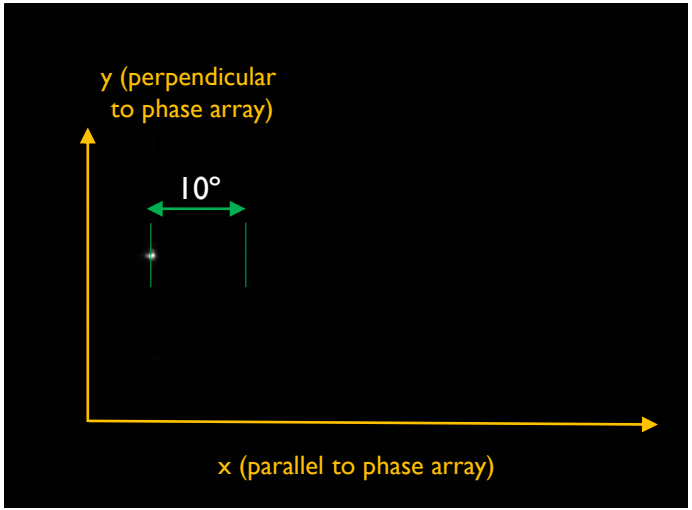
- SiN with low phase error for power routing
- Si antennas with high confinement for tight pitch
- 64 antennas at 3 µm pitch, at 1550 nm
- Wavelength tuning in the x direction
- Beam divergence: 0.47° × 0.4°

(S. Dwivedi et al., *IPR 2019*, IM4A.3)

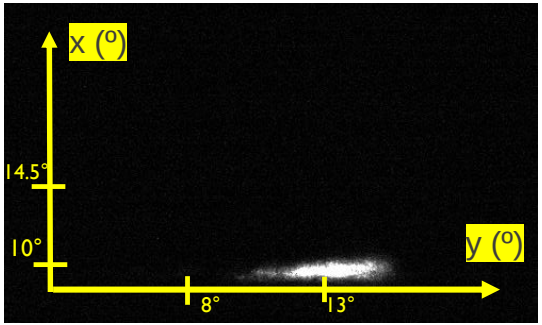
OPA with binary tree architecture:

- Si for power routing and antennas
- 8 antennas
- Thermo-optic phase shifters for tuning in the y direction
- Tuning in the x direction with source wavelength

1D λ-based steering demonstration



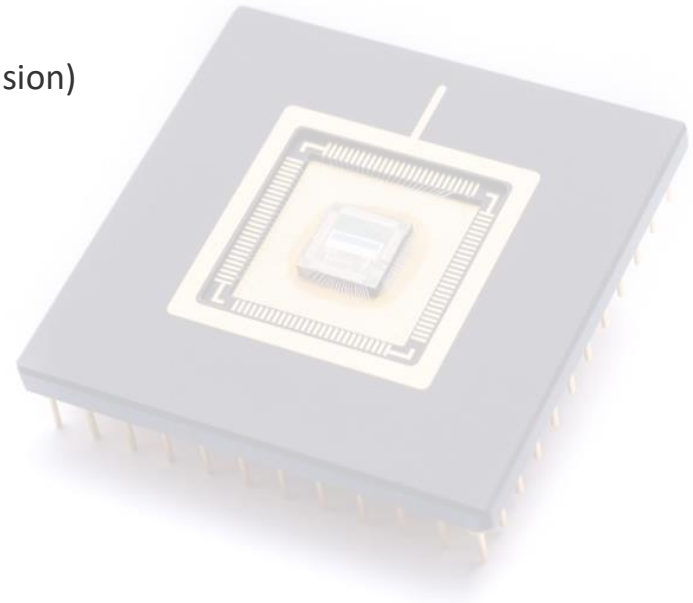
2D steering demonstration



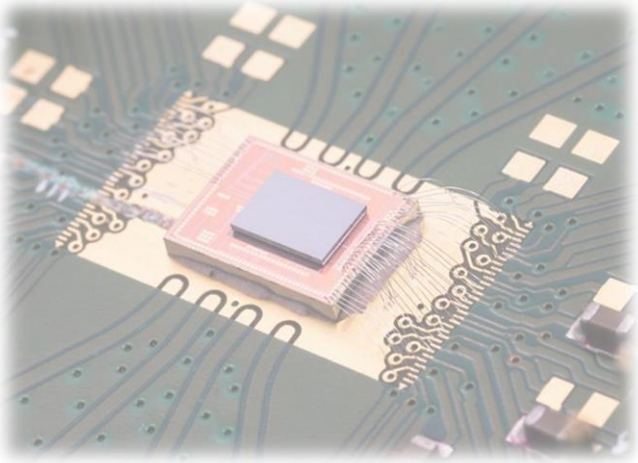
R&D OPPORTUNITIES

- Main challenges:
  - Insertion loss
  - Power consumption (for phase shifting)
  - Number of antennas (for large aperture size)
  - Electronics control for phase shifters (phase interrogators, ASIC)
  - Tight specs on tunable laser (linewidth, power, wavelength precision)
  - CMOS integration desired for complex electronics

- Main research activities @ imec:
  - Si and SiN hybrid platforms
  - Laser development and integration on Si/SiN
  - Chip packaging solutions
  - New materials for low-power phase shifters

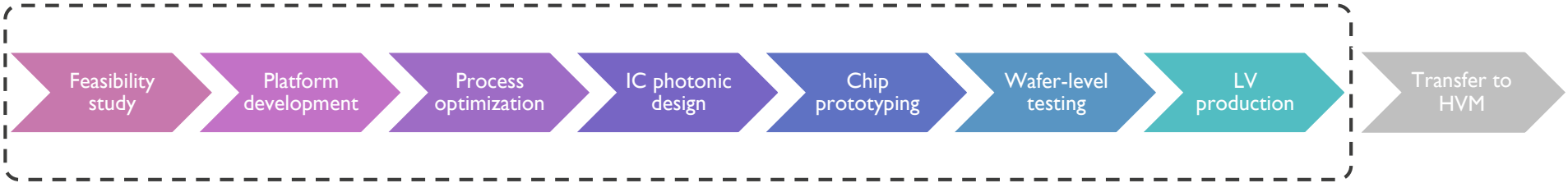


IMEC R&D ECOSYSTEM



- What you can do for us:
  - Help us to better understand the LiDAR market dynamics
  - Expose us to your key technology needs, problems and challenges
  - Partner for system-level OPA LiDAR demonstrators
  - Collaboration in R&D projects

- What we can do for you:



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This presentation was presented at EPIC Meeting on LIDAR Technologies for Automotive 2019

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