EPIC
European Photonics Industry Consortium

elmos

Current CMOS SPAD based developments dedicated for automotive LiDAR

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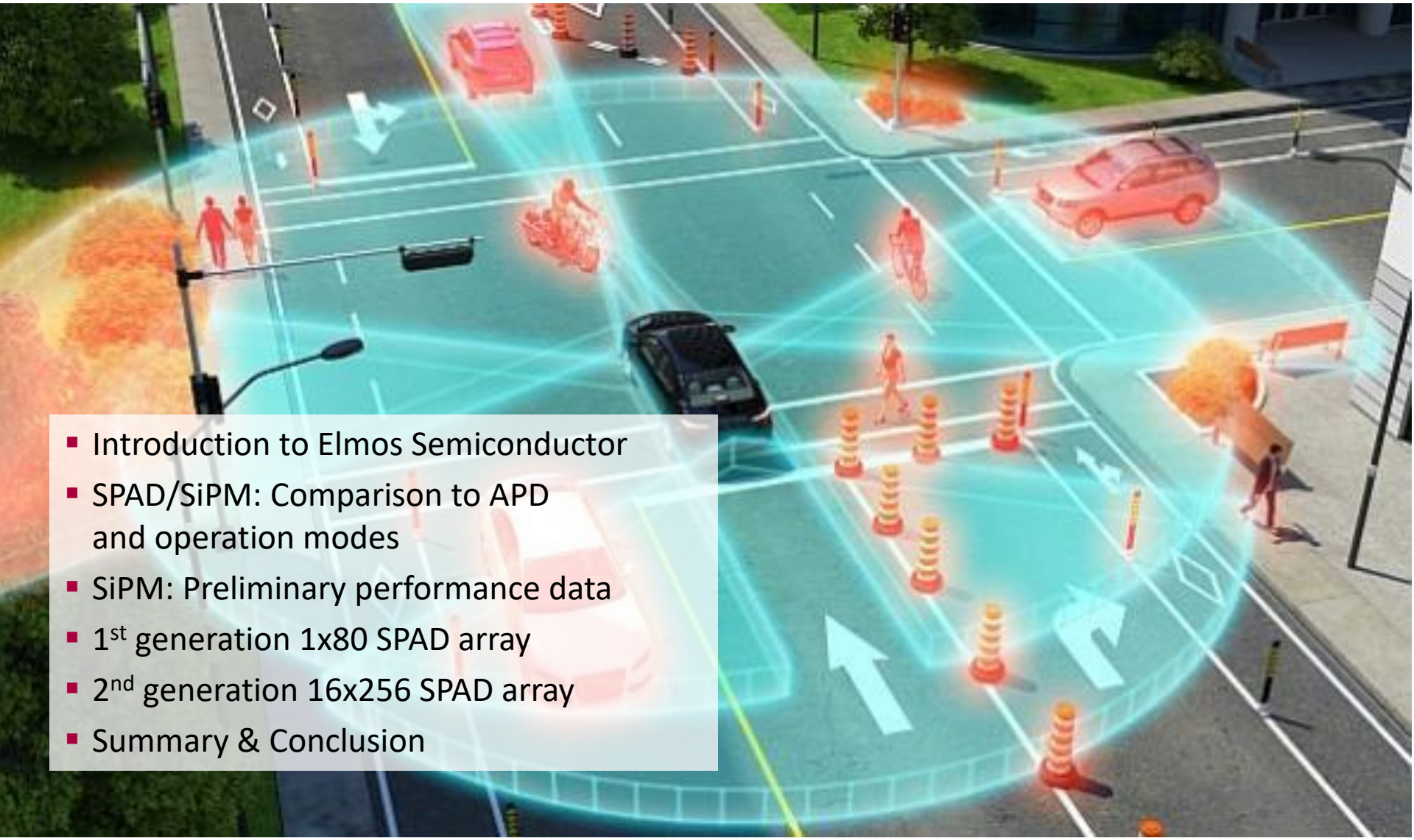
Outline



- Introduction to Elmos Semiconductor
- SPAD/SiPM: Comparison to APD and operation modes
- SiPM: Preliminary performance data
- 1st generation 1x80 SPAD array
- 2nd generation 16x256 SPAD array
- Summary & Conclusion

Expert in analog mixed signal solutions focused on automotive market

35 years experience

- Development, production & marketing of **Integrated Circuits (ICs)**
- Sales: ~85% **automotive** ~15% **non-automotive**
- **Main strength:** design of innovative products and specialized application know how

Worldwide leading products

- Elmos serves the **megatrends** (ADAS, EV…) & **attractive niches** with benchmark innovations
- **#1 positions:**
  - Ultrasonic Parking Assistance
  - Ambient LED Light
  - Motor Control Applications
  - Gesture Control
  - **Soon** Rear Light LED & more…

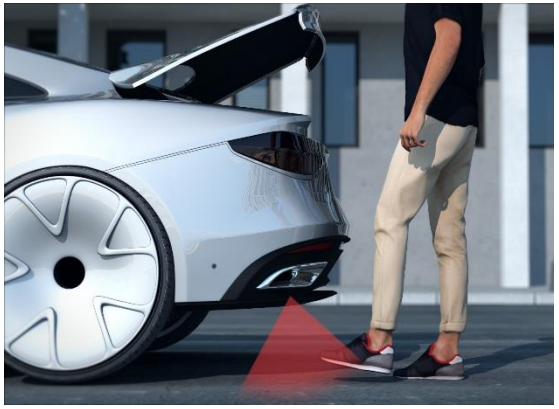
Ready for further growth

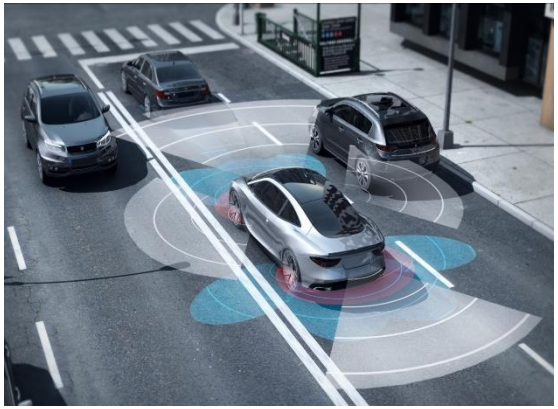
- **Global player for automotive** ASSPs and ASICs
- Significant addition to **design/application resources**
- **Fablite:** Flexible production strategy for Frontend and soon for Backend (Test)

From a statistical point of view: >**4 Elmos ICs** in every new car *…soon >5!*

IC = Integrated Circuit / ASSP = Application Specific Standard Product / ASIC = Application Specific Integrated Circuit

Elmos Optical Sensors Portfolio





HALIOS® IR Sensor IC

- Pioneering in gesture control with **>50 million ICs in the field**
  - Applications e.g. proximity, swipes, object detection and touchless door access
- **2012: Market launch** (VW Golf 7)
- Today: available in almost **all VW group** models – started in **BMW models**
  … more OEMs to come

3D ToF - Imager

Exterior gesture recognition
Interior gesture control

2019: Market launch

Next Gen 2020

SPADs & SiPM for LIDAR

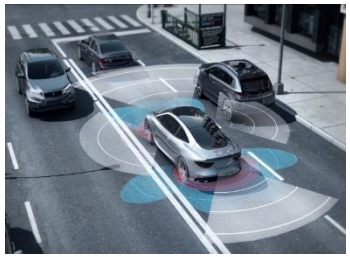
Emergency breaking
Pedestrian detection
Environment mapping
Collision warning

Product definition, Customer Sampling

HALIOS®= High Ambient Light independent Optical System /
SPAD=Single Photon Avalanche Diode/SiPM=Silicon Photomultiplier/

ToF= Time of Flight
LIDAR= Light Detection and Ranging

The Role of LiDAR in Advanced Driver Assistant Systems



Ultrasonic

Short- / Medium Range RADAR

LIDAR / Infrared

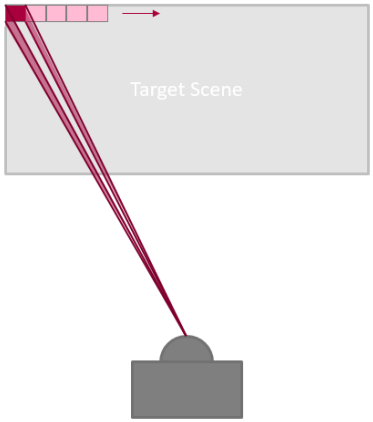
Camera

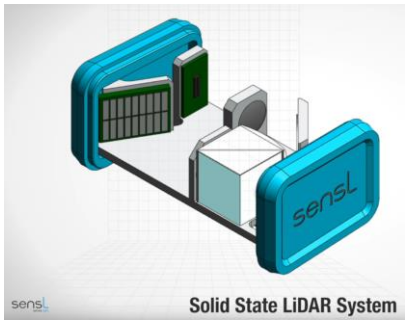
Long Range RADAR

Approaches to full Solid-State LiDAR systems

Solid State Scanning LiDAR

- Micro mirrors or optical phased arrays used
- High optical power density
- Detector array required
  (in most cases currently APD used)
- Small size
- Limited scan rate
- High system cost
- Decreased reliability

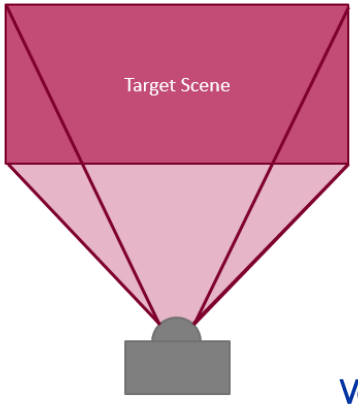


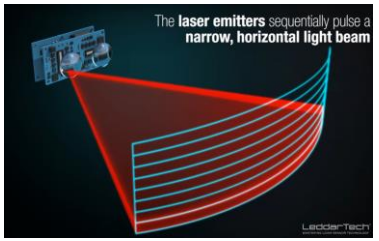


QUANERGY
Valeo
ibeo automotive
Velodyne LiDAR
CEPTON
LUMINAR
blackmore

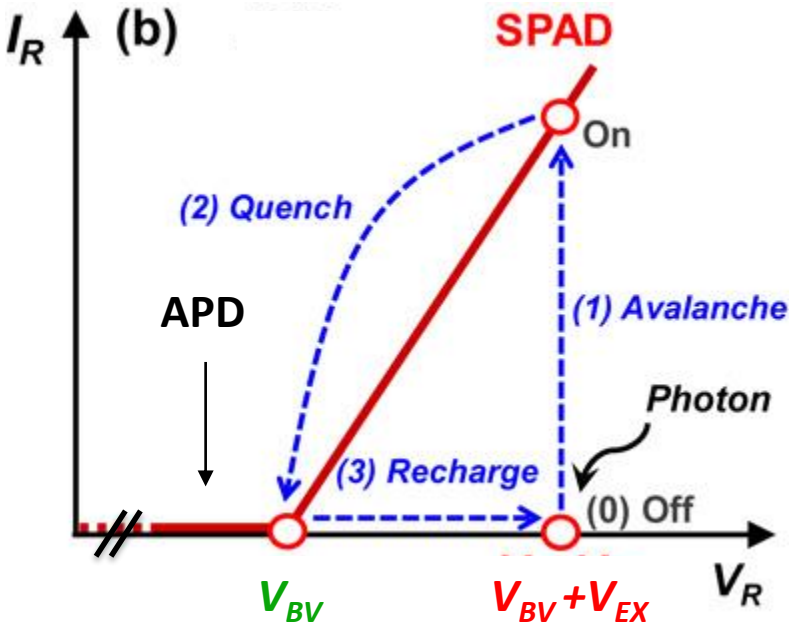
Flash LiDAR

- Complete or parts of FoV in one shot
- No moving parts
- Low optical power density
- Simple laser source
- High framerate possible
- Low cost
- Small size
- Limited to low/
  mid distance





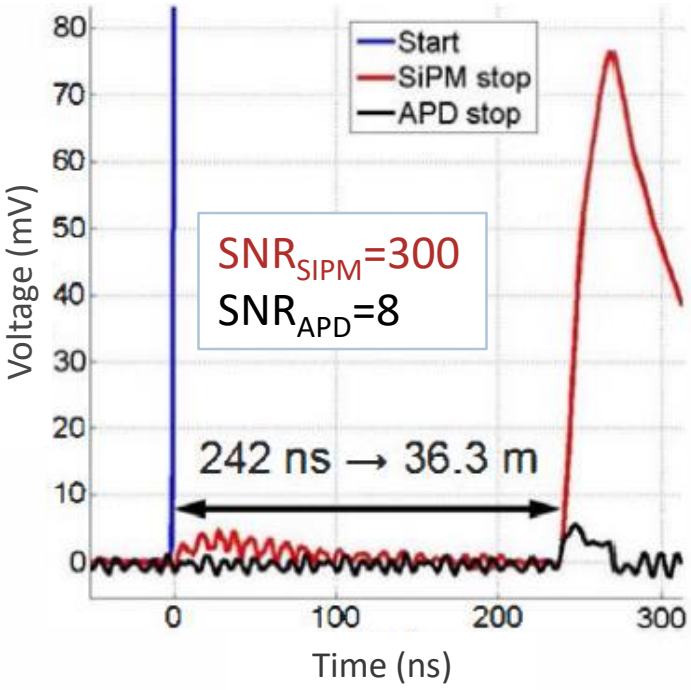
XENOMATIX
AUTOMOTIVE LIDAR SOLUTIONS
Continental
The Future in Motion
LeddarTech
INNOVIZ TECHNOLOGIES
Velodyne LiDAR



- **APD**
  - Bias: slightly below V_{BV}
  - Linear-mode (amplifier-mode)
  - Gain: limited (<1000) and noisy

- **SPAD/SiPM**
  (SPAD array with passive quenching)
  - Bias: well above V_{BV}
  - Geiger-mode (working as trigger)
  - Gain: large ($10^5..10^6$)

- **ToF of APD vs SiPM**

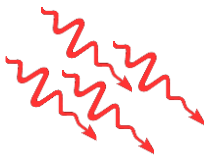


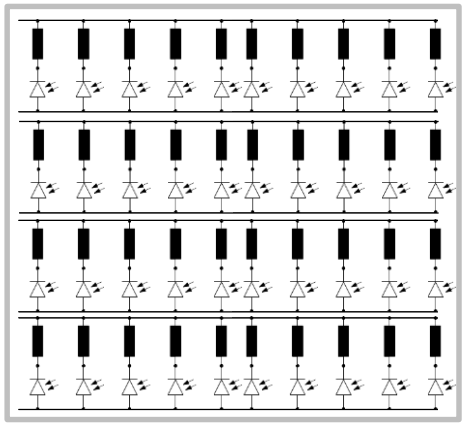
Source: G. Adamo, *"Time Of Flight measurements via two LiDAR systems with SiPM and APD"*, AEIT, 2016

One Structure – Two Different Devices

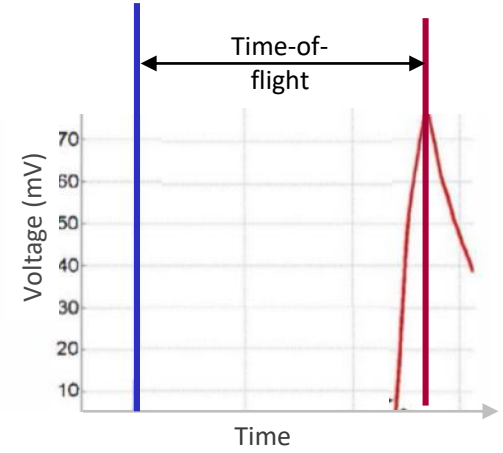
Silicon Photomultiplier (SiPM)

n photons



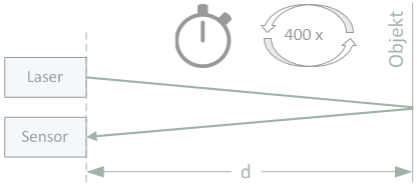


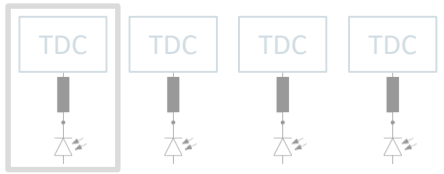
single measurement



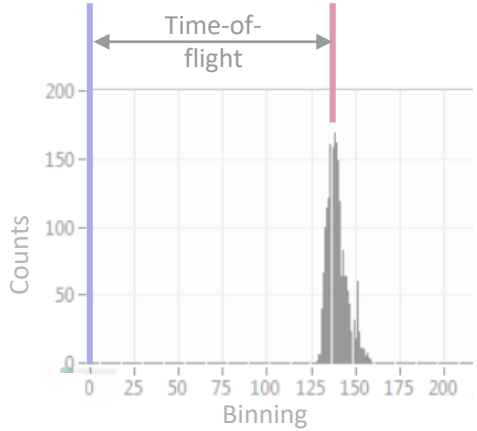
ToF SPAD imager array

n times a
single photon





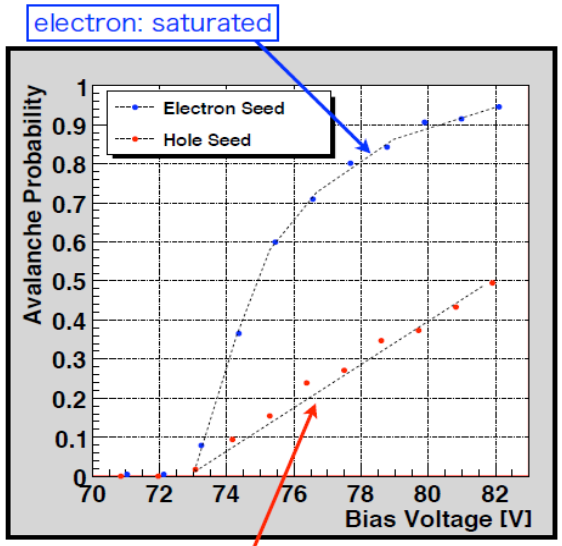
n measurements



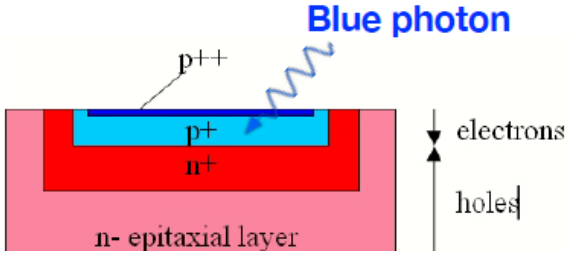
Approach to Red Sensitive SiPM

$$PDE = EQE \times FF \times AP$$

PDE	Photon Detection Efficiency
EQE	External Quantum Efficiency
FF	Fill Factor
AP	Avalanche Probability

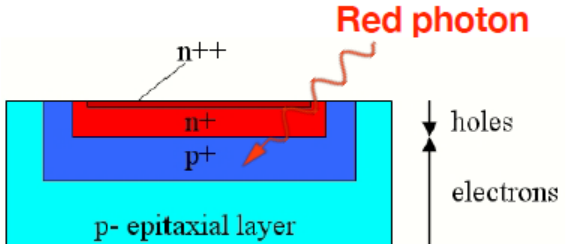


H. Otono, et al., PANIC08



p-over-n (pSPAD)

→ blue sensitive
isolated from p-substrate

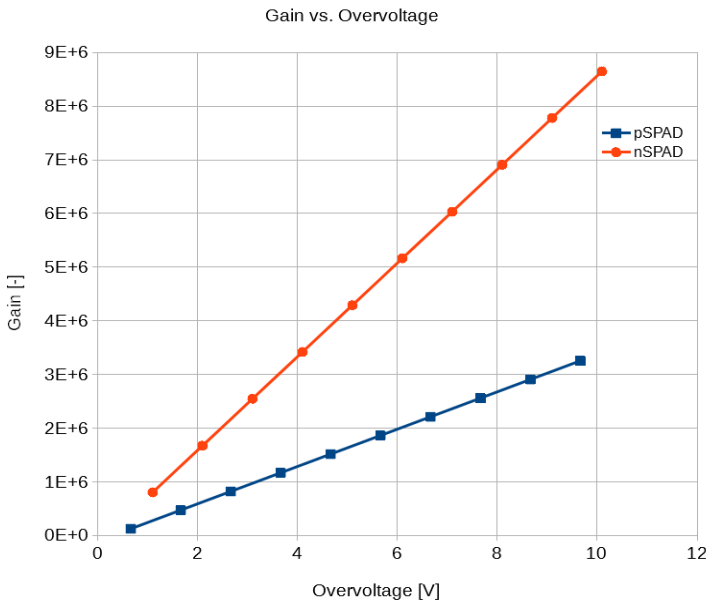


n-over-p (nSPAD)

→ sensitive to red and NIR
typically not isolated from p-substrate

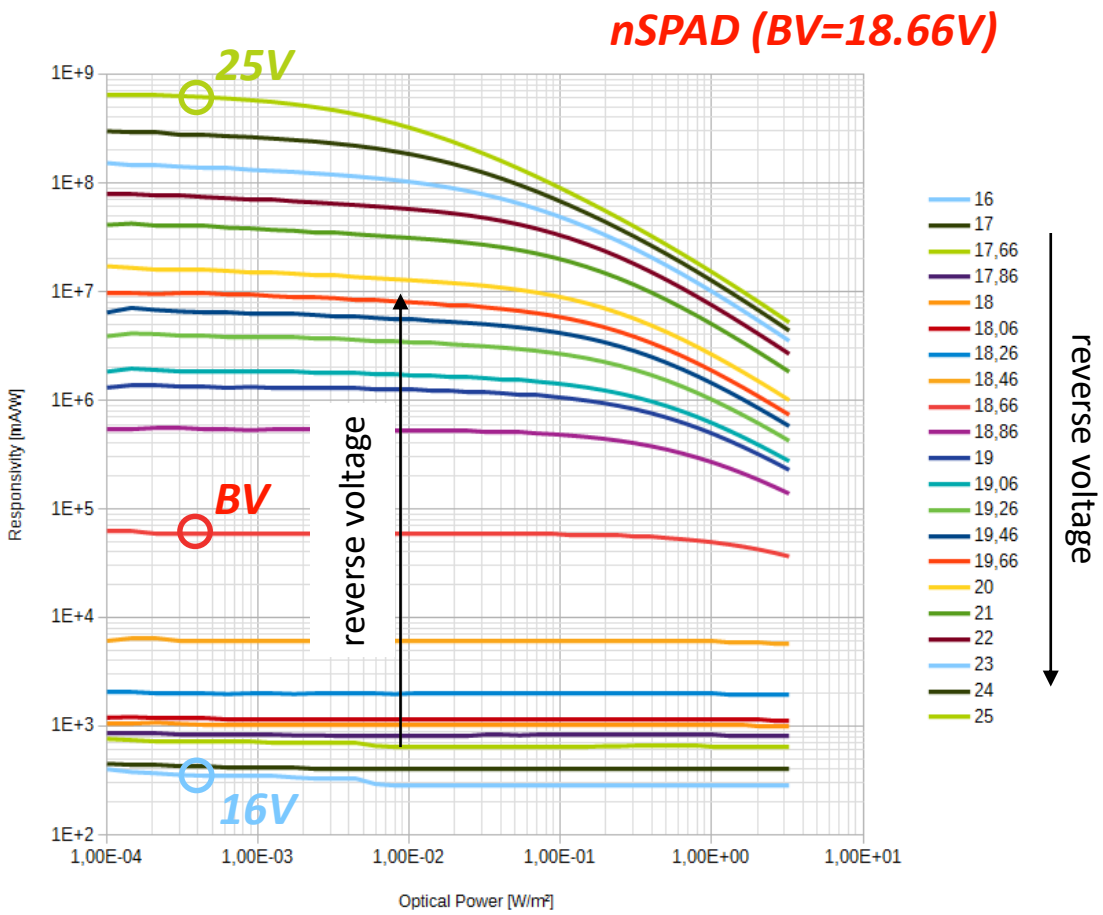
Source: W.Ootani, *"SiPM-Status and Perspectives"*, CERN, 2015

- **Gain**
  - extracted in dark (DCR)



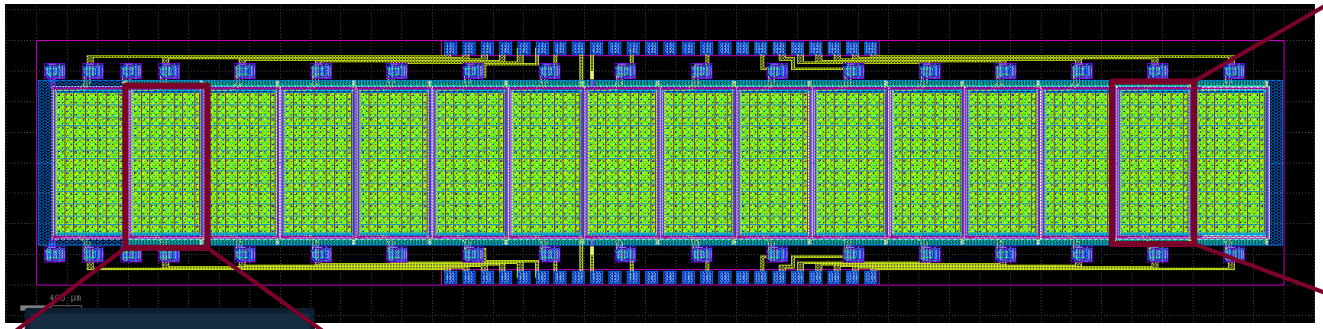
- **PDE (λ=890nm)**
  - Increased by factor of ~2
    (nSPAD vs pSPAD; over reasonable excess voltage range)

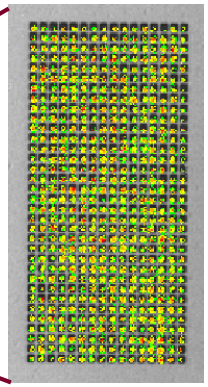
- **Responsivity (λ=890nm)**



1x16 SiPM Array for LIDAR Applications

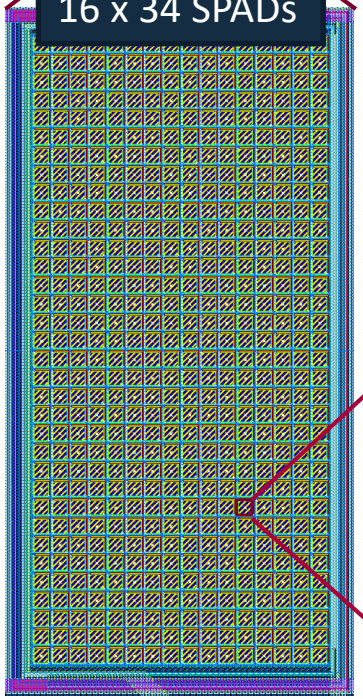
Total Chip Size: 8200 x 1600 µm²



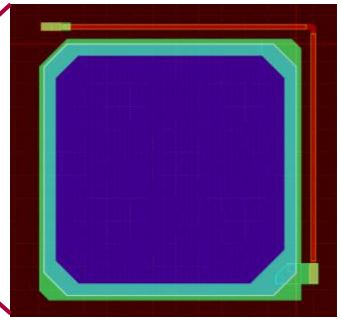


avalanche glowing under weak illumination

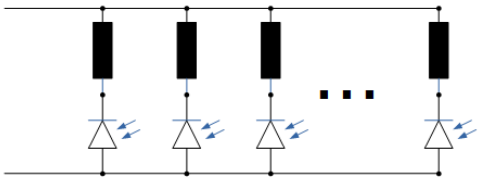
16 x 34 SPADs

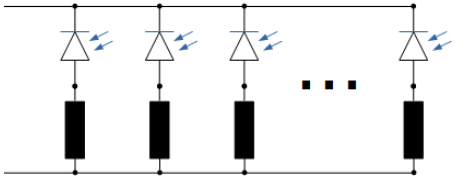


SPAD
Active: 20µm
pitch: 27µm
FF: 54%



- Passive resistive quenching applied
- Both nSPAD and pSPAD version is available
- operating voltage:
  Vop≈22V (nSPAD) and 30 V(pSPAD)
- suited for actual and future LIDAR designs





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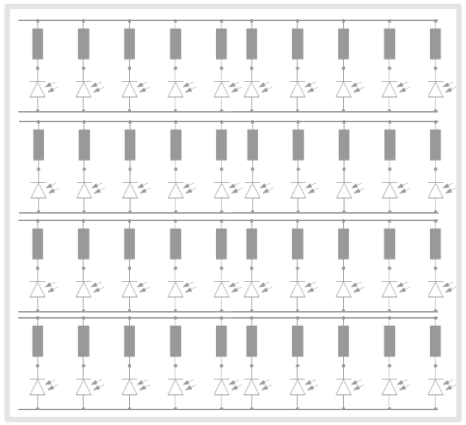
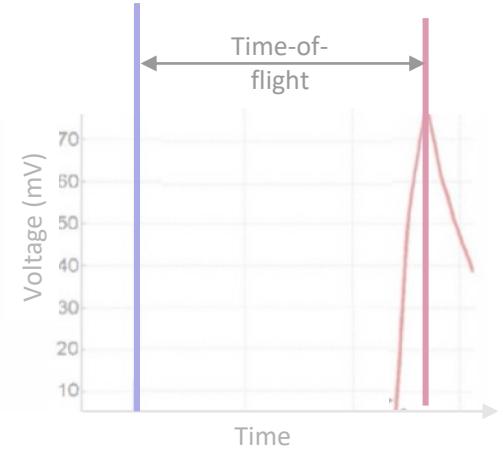
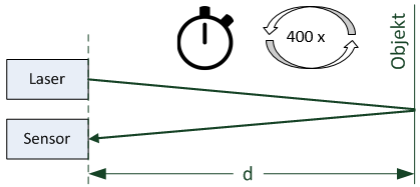


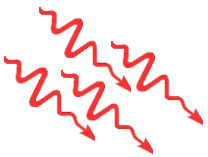
single measurement

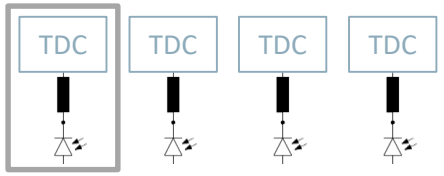


ToF SPAD imager array

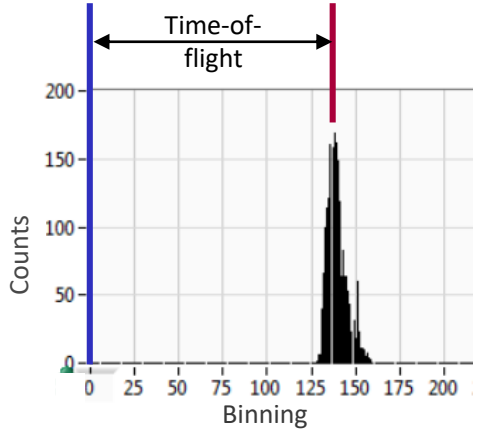
n times a
single photon



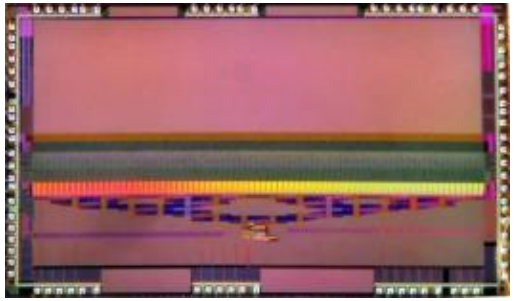


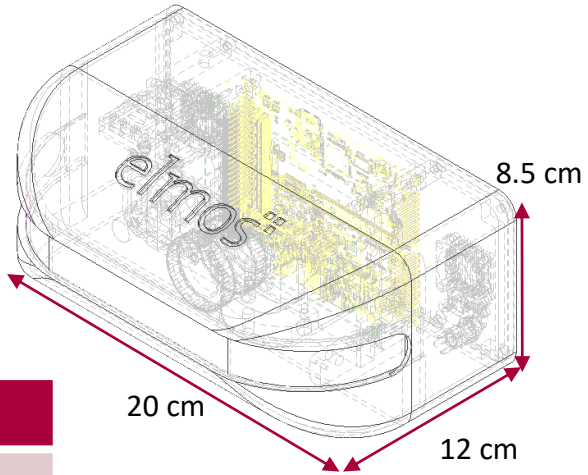


n measurements

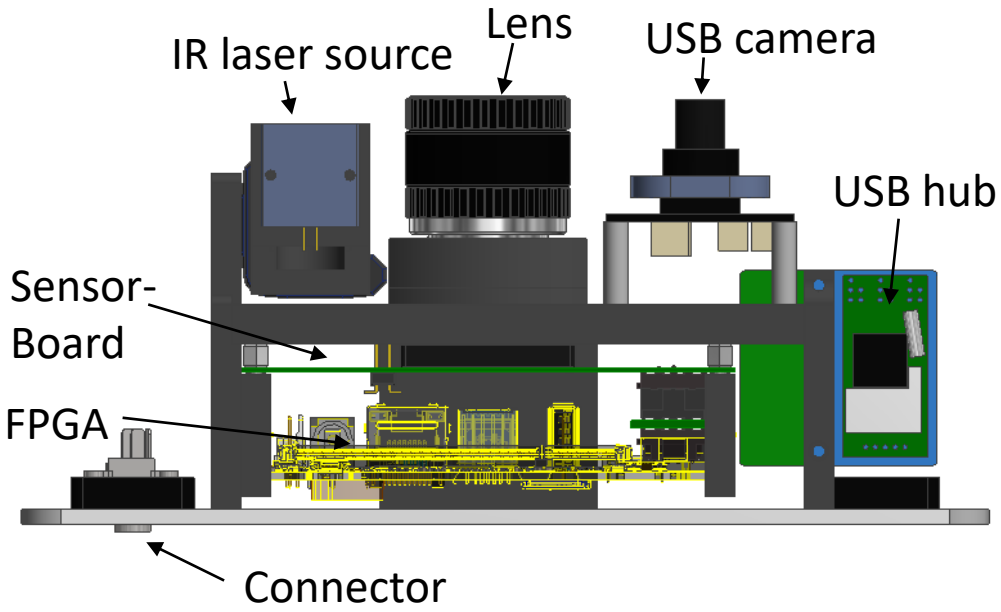


1st Elmos LiDAR demonstrator 1x80 pixels (2017)

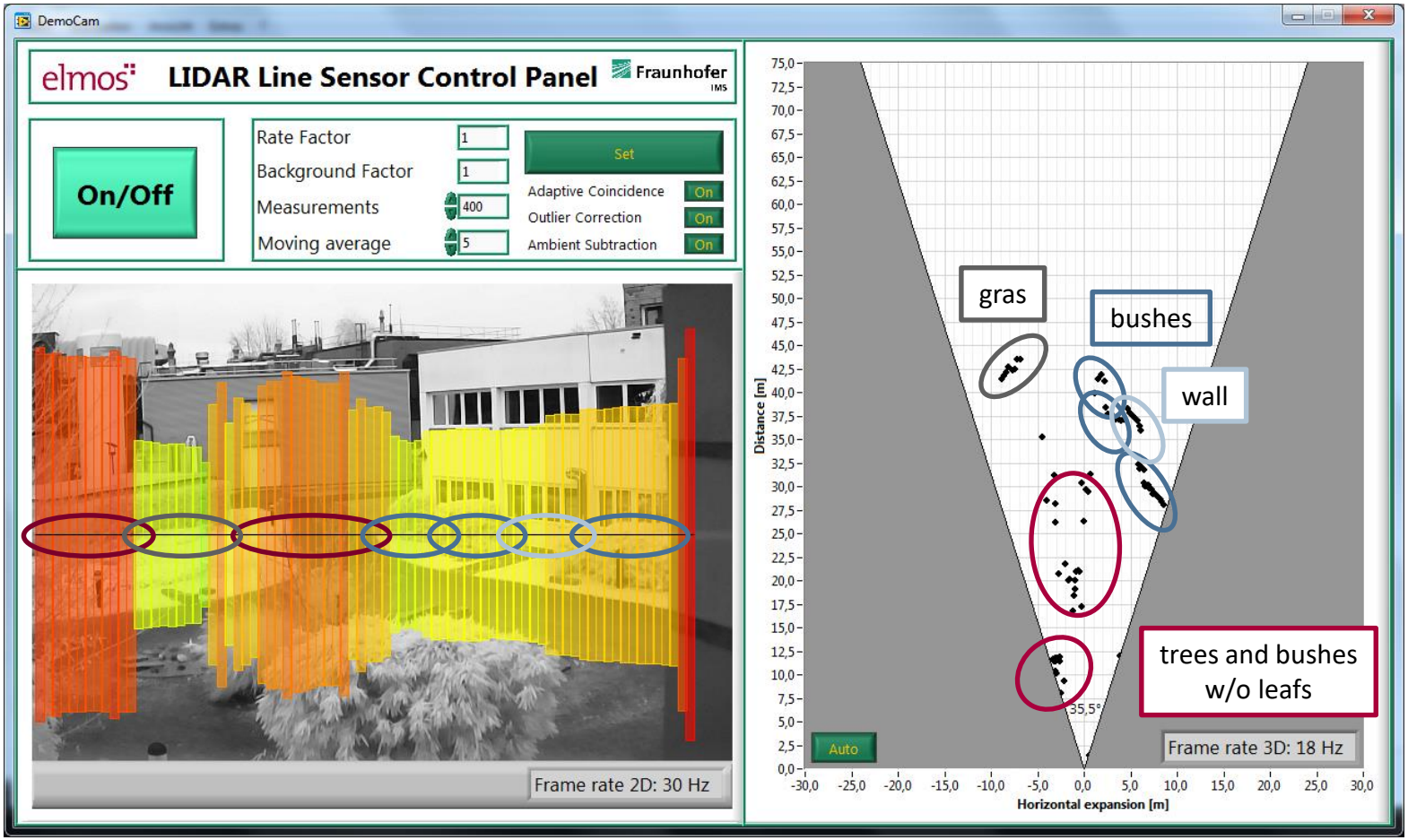




Parameter	
Matrix	1x80
Laser source	905nm 75W
Laser pulse width	18ns
Field of view (FoV) horizontal vertical	 35.5° ~1°
Max. Range	up to 70m
Timing/Distance Resolution	312ps/~5cm
Frame Rate	~20Hz

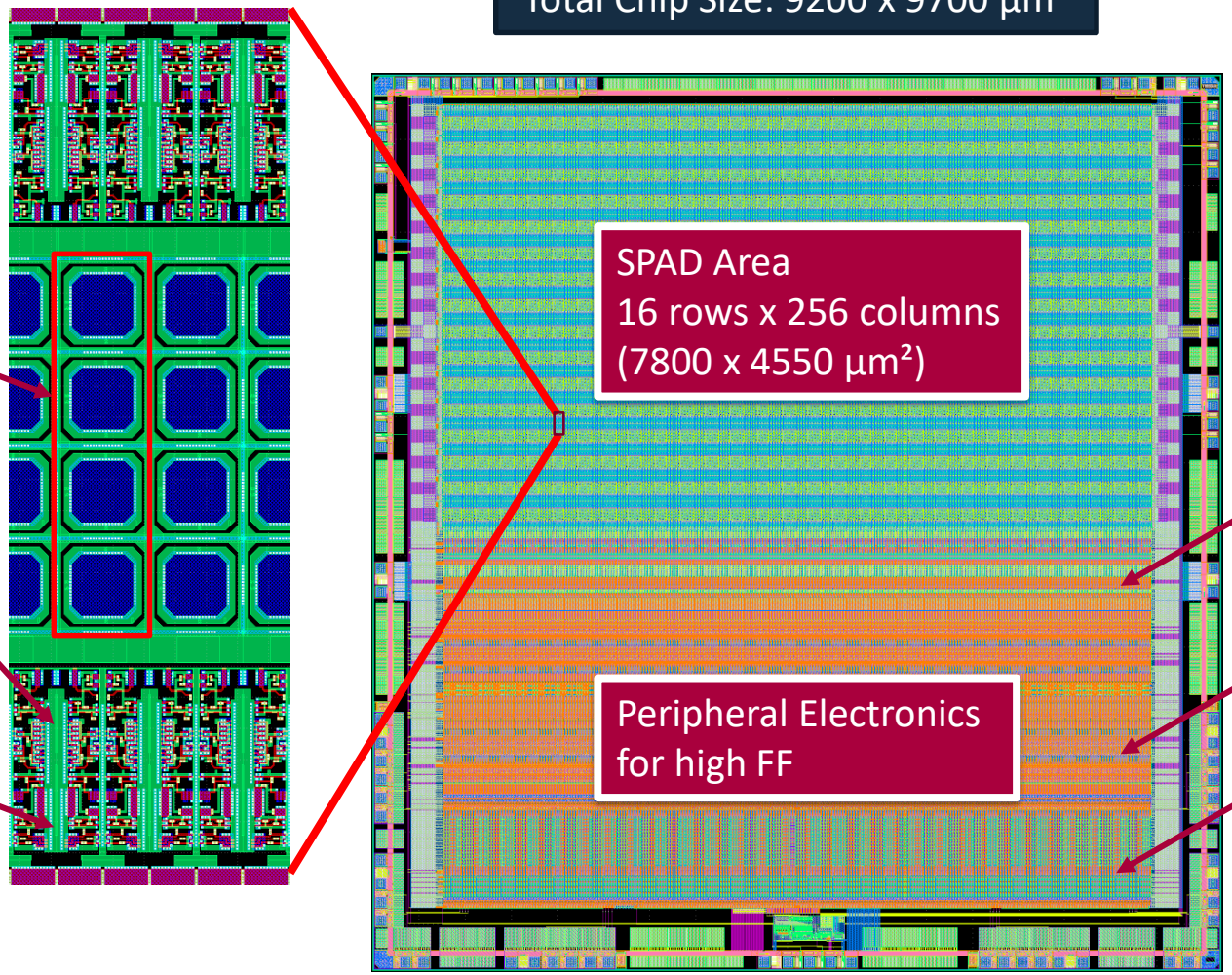


Daylight outdoor operation with auto-adjustment



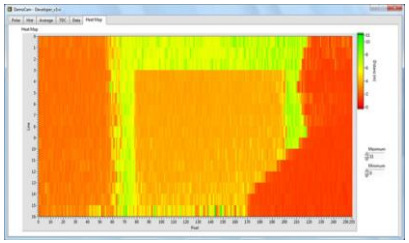
- Proper photon coincidence condition selected for each individual pixel dynamically
- Reasonable targeting in the range of about 40m (up to 70m demonstrated)

2nd Gen 16 x 256 Pixel SPAD CMOS Array



16 x 256 Pixels SPAD CMOS Array
In-Depth Specification

- 16 rows x 256 columns CMOS SPAD Array (4096 Pixels)
- Photon counting mode for ambient light detection and 2D imaging
- Ready for **auto-adjustment of photon coincidence**
- **Multi-event detection mode**
  (up to 4 events per pixel and laser pulse)
- Column integrated TDC with 312.5 ps resolution (~5 cm resolution) and 1.28 µs full range (192 m max. theoretical range)
- **Rolling shutter (row-by-row read-out)**
- **Demonstration will be given at CES2020**



Angular Resolution
x: 0.23° @60° FoV
y: 0.80° @20° FoV

Reduced sensitivity to noise and background light

Increased range and noise immunity

Increase of array fill factor

Flexibility with respect to laser source
(Flash / MEMS Mirror / Multiple Laser Sources)

Summary and conclusion

- CMOS based silicon SPAD/SiPM arrays are an appropriate solution for low-cost, mid-range LiDAR systems

  CMOS SPADs and SiPMs will be the "eyes" of the next generations LIDAR sensors

- First Samples of 1x16 CMOS SiPM array with NIR improved PDE are available, which can be used as substitute for APD within scanning LIDAR systems; customer demands on request → ***kindly looking for your input***

- Within the high-level approach possible by on-chip circuit in Flash LIDAR systems performance of SPAD performance can be significantly increased by measure of **photon coincidence and multi-event detection** leading to effective suppression of noise (DCR and background) and increased range

- Samples of 1x80 and 16x256 SPAD arrays already available; evaluation boards will follow
  2nd generation demonstrator in work → ***see you at CES 2020***

Acknowledgments

IPCEI on MICROELECTRONICS

Technology Field 3
„Smart Sensors“

Supported by:

Federal Ministry
for Economic Affairs
and Energy

on the basis of a decision
by the German Bundestag

in cooperation with:

Fraunhofer IMS

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Thank you for your attention !

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