CMOS SPADs for LIDAR Applications

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Outline

- Introduction to Fraunhofer IMS
- Single Photon Avalanche Diodes in CMOS
- Examples of CMOS SPAD Applications
- SPAD für LIDAR
- Design example
- Summary

FRAUNHOFER IMS

Microelectronic Circuits and Systems, Duisburg

Director: Prof. Dr. rer. nat. Anton Grabmaier

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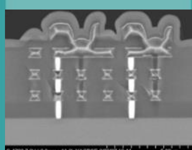
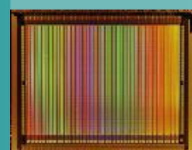
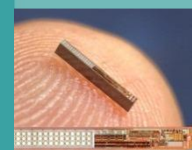
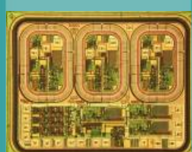
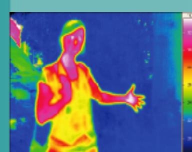
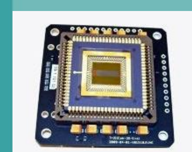
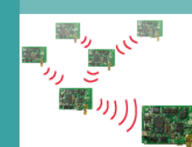
Business Fields

Technology & Devices	ASICs	IR Imagers	CMOS Imagers	Pressure Sensors	Biohybrid Systems	Wireless Transponder Systems	Ambient Intelligent Systems
 CMOS Process	 Chip Design	 640 x 480 IRFPA (Uncooled α-Si)	 1D and 2D CMOS Image Sensors	 Pressure Sensors	 Glucose and Lactate Sensors	 Embedded Systems	 inBad
 Power MOS / Smart Power	 CMOS Wafer Fab	 Infrared Thermographie	 3D CMOS Image Sensor	 Medical Implants	 Nanopotentiostate	 µ-Transponder System	 Hospital Engineering
 High Temperature µ-Electronics	 Assembly & Test	 25µm Bolometer (SEM-Image)	 3D Cam Scheme	 Pressure Sensor Systems	 Bio Sensors	 Wireless Sensor Networks/ZigBee	 Embedded IP-Networks & Middleware

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Fraunhofer IMS
Infrastructure - CMOS Fab

Total area:	1300 m^2
Clean room class:	10
Wafer size:	200 mm (8 inch; 0.35 µm)
Staff:	working in 4 shifts / 7 days a week
Capacity:	> 50.000 Wafer p.a.

Excellence of the CMOS-Line

- Complete CMOS process line plus integrated sensors (SOI, imager, pressure, mixed signal)
- ICs from a few 100 ASICs to few million

Fraunhofer IMS

Infrastructure - Microsystems Lab&Fab

Total area:	600 m²
Clean room class:	10
Wafer size:	200 mm

Mission

- Extending the application areas of CMOS ("More than Moore") by post processing on CMOS wafers.

Development Activities

- Adding layers, structures, devices onto preprocessed "intelligent substrates" (CMOS wafers) to create integrated sensor systems.
- Examples: micro bolometer arrays for IR imaging, biosensors, opto sensors.

MST Lab&Fab

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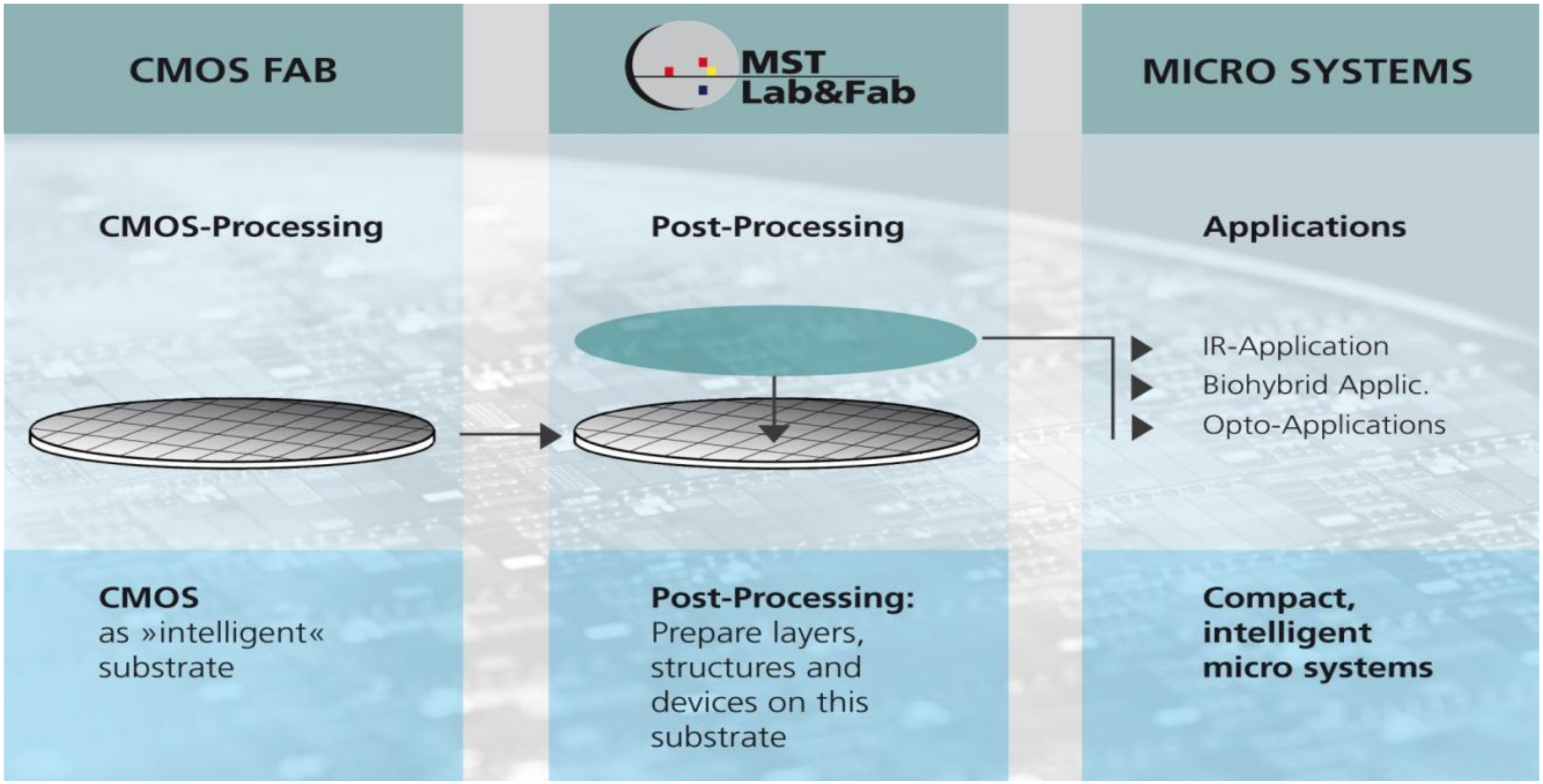
Infrastructure IMS



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Business Field: CMOS Image Sensors

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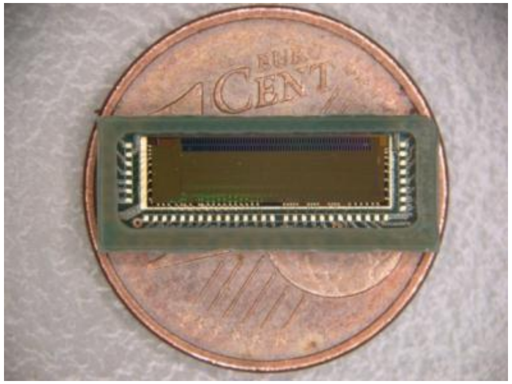
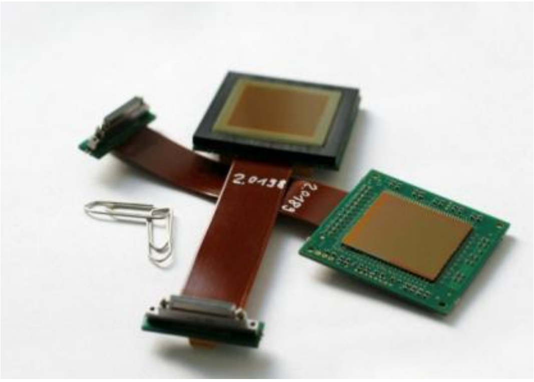
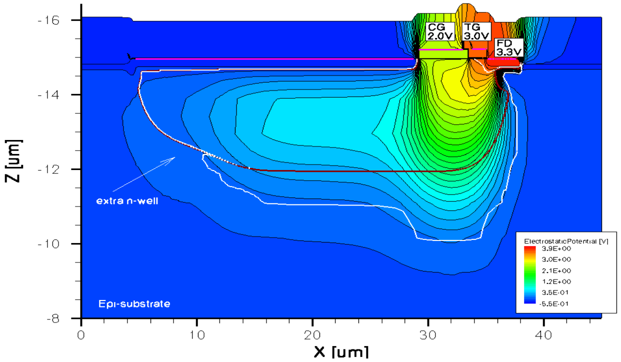
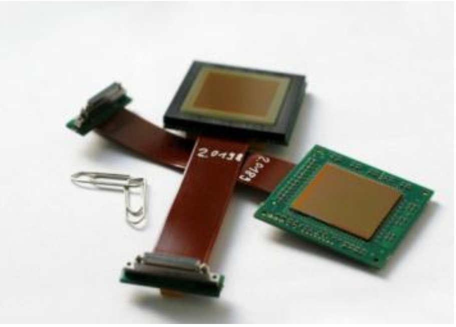






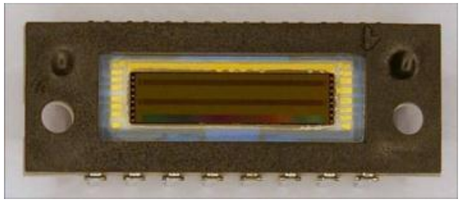
Service and Know-how - Optical CMOS Sensors

In the field of „Optical CMOS Sensors"
Fraunhofer IMS is providing:



Service and Support

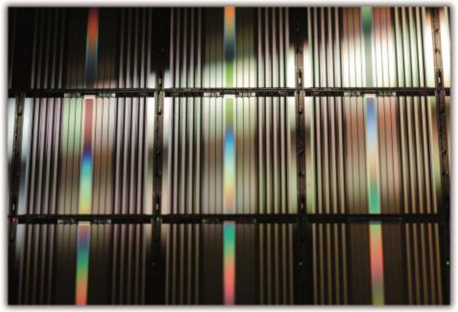
- Design of customized image sensors and dedicated optical sensors
- Wafer fabrication in Fraunhofer IMS fab (L035-OPTO) or foundries
- Electro-optical test on wafer and device level
- Device qualification
- Full service from design to fabrication



Example Project – RGB Line-Scan Sensor

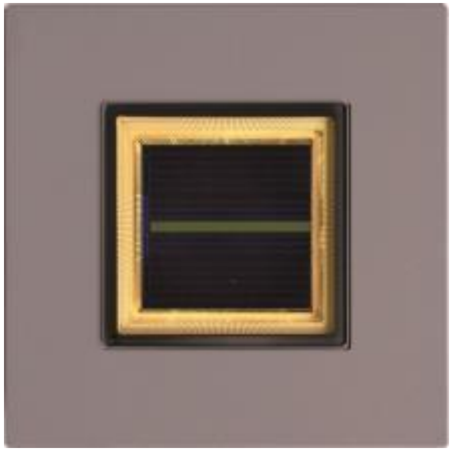
Design and Development

- Designed for high speed surface inspection

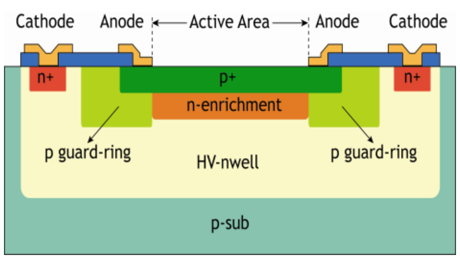


Unique Selling Points

- 2048 x 60 pixels
- 600 kHz (b/w) / 200 kHz (RGB) line rate
  ➔ **world record!**
- RGB pixel with 100% fill factor
- Column-parallel 10 bit ADCs



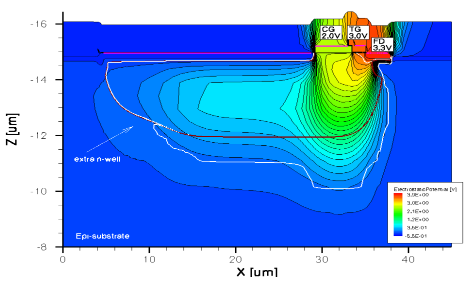
Service and Know-how - Optoelectronic Devices



In the field of „Optoelectronic Devices"
Fraunhofer IMS is providing:

Service and Support

- Development of novel optoelectronic devices
- Use of standard CMOS processes: 0.5µm, 0.35µm, and foundry processes
- Device modeling and optimization with advanced simulation tools
- Characterization of „test inserts" to extract and monitor device parameters (capacitance, dark current, spectral response, etc.)



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IMS

Technology - CMOS 0.35µm Process “Opto”

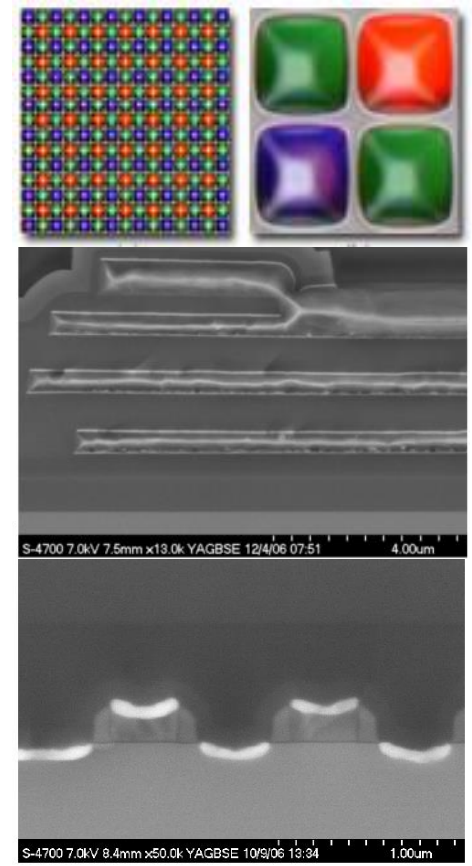
The IMS 0.35µm CMOS process “Opto” is providing:

Opto Process Features

- Stitching
- Planarization
- UV transparent silicon nitride passivation
- Salicide-blocking
- Color filter deposition & microlenses

Opto Devices

- Pinned photodiodes (low noise, low dark current)
- High temperature photodiodes
- Lateral Drift-Field Photodetectors (LDPD)
- Single-Photon Avalanche Diodes (SPADs)
- Embedded CCD

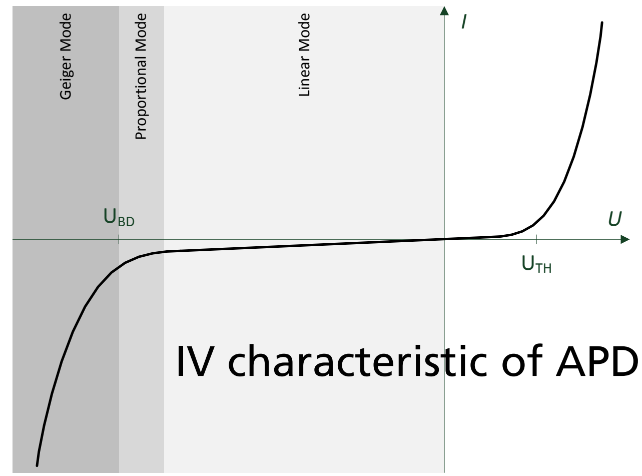


SPAD Operating Principle

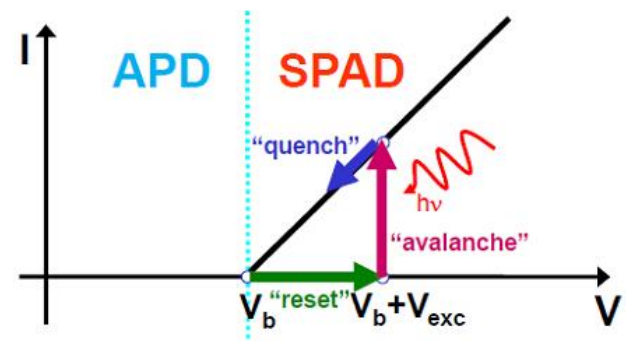
Single-Photon-Avalanche-Diode (SPAD) is an avalanche photodiode operated above breakdown voltage (= Geiger-Mode)

→ Very few photons can be detected

→ Fast operation with good time resolution



IV characteristic of APD



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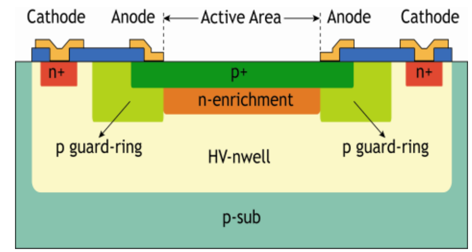
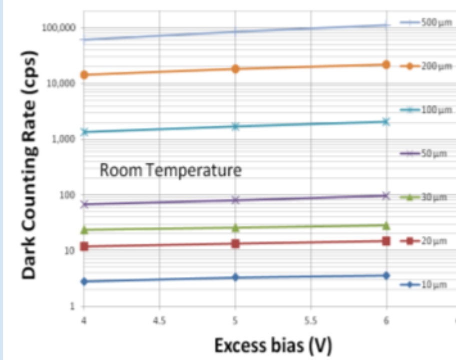
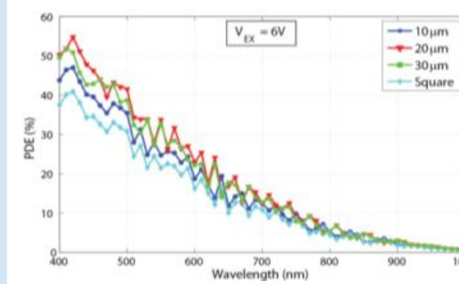
Characteristics of SPADs in IMS 0.35µm CMOS Process

SPAD characteristics (30 µm active area)

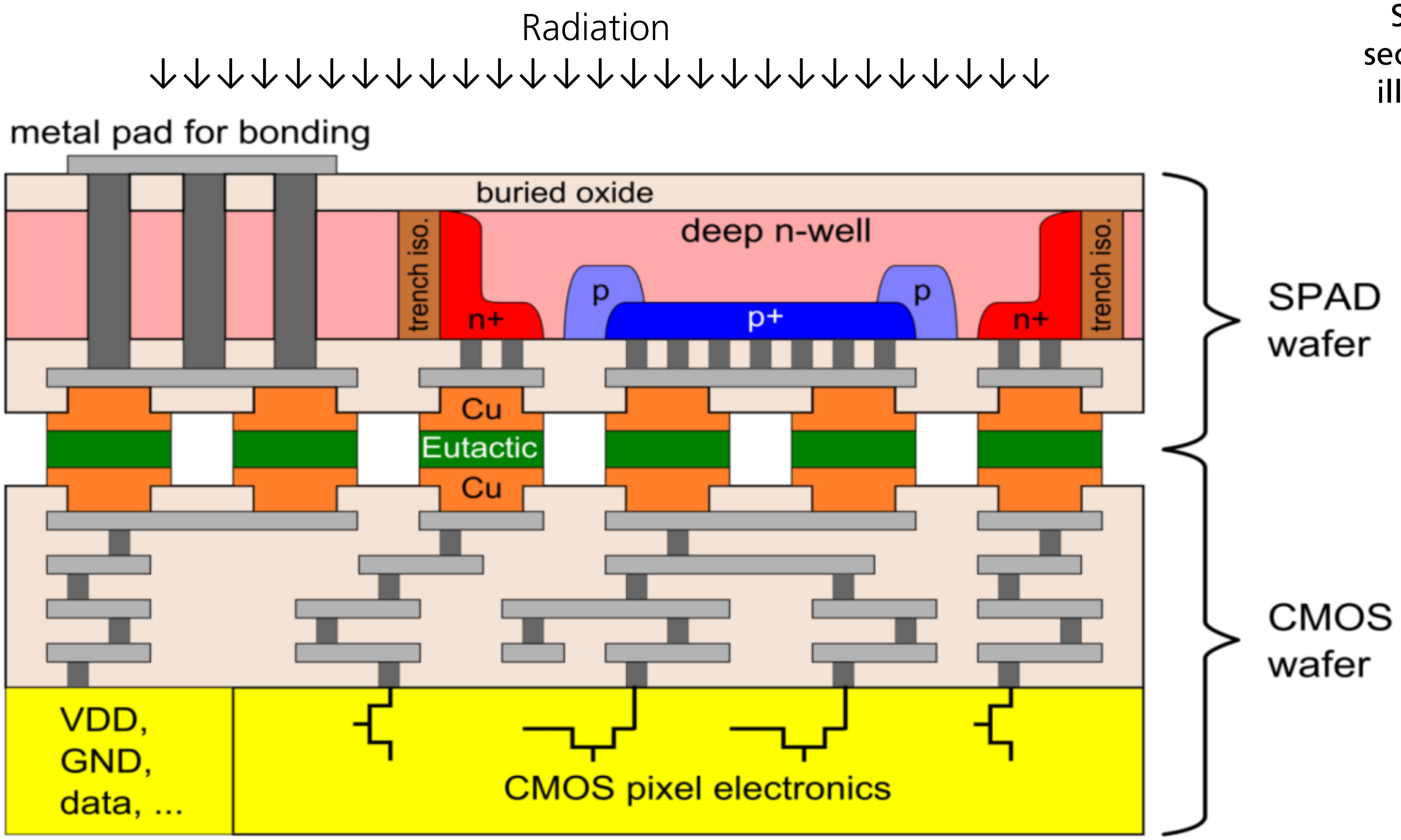
Dark count rate (DCR)	< 50 cps at room temperature
Timing response	< 140 ps FWHM
Uniformity	95% of pixels have close to avg. DCR
Breakdown voltage (V_{BD})	26 V
Temperature drift of V_{BD}	37.8 mV/K
Afterpulsing probability	< 1% at dead time > 50 ns
Pixel pitch	As low as 10 µm
Spectral range	300 nm – 1000 nm
Dynamic range	106 dB
Noise-equivalent Irradiance @ 905 nm	11 pW/cm²







BackSPADs



Schematic cross section of backside illuminated SPAD sensor after integration

SPAD Linear Sensor

Technology: 0.35µm Standard CMOS Prozess

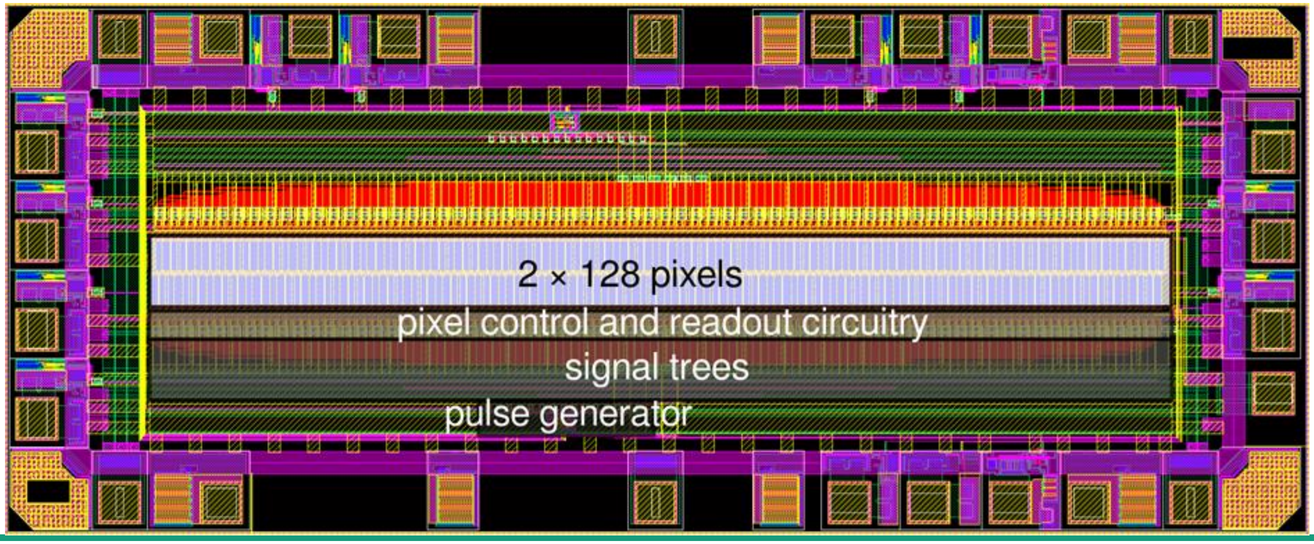
2×128 SPAD-pixel

3.3V Digital output and control

60% Fillfactor @20µm pixel pitch

Applications:

- Time-resolved spectroscopy (e.g. Raman spectroscopy)
- ToF/LIDAR (with adaption of readout electronics)



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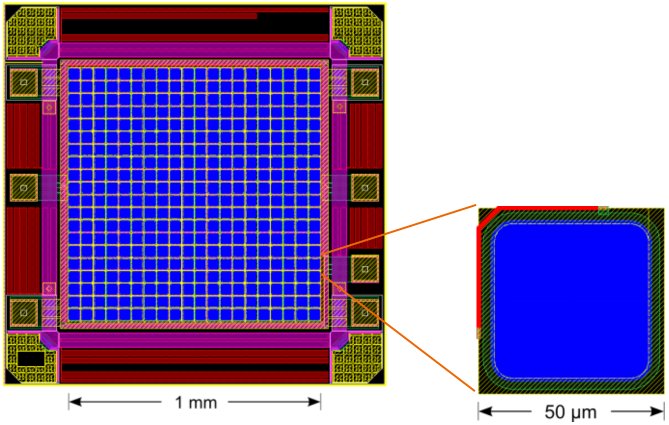
IMS design examples: Silicon Photomultiplier (SiPM)

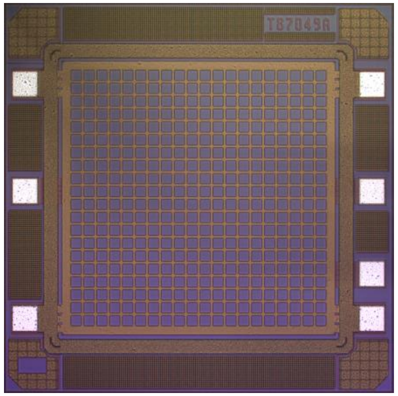
20×20 SPAD-elements on
1×1 mm² active area

Geometric fillfactor: 68%
@ 50µm pitch

Applications:

- Detector in high-energy particle physics
- Scanning-LIDAR
- PET-detector (medicine)





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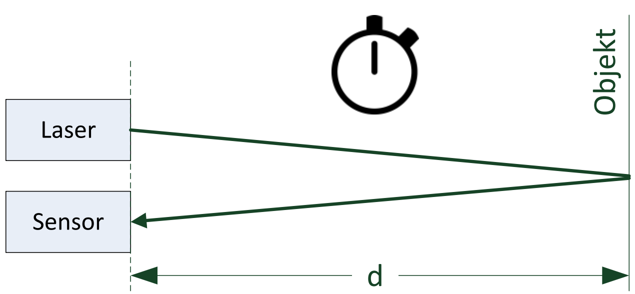
Time-of-Flight methods

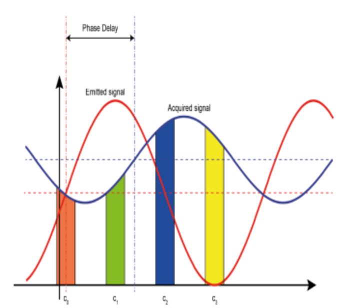
Direct

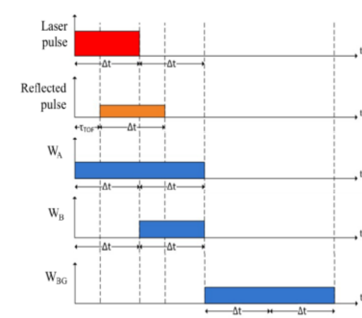
- Direct time measurement
- Jitter is limiting precision
- High optical power density in short pulses
- Complex analog circuitry (TDC)
- High precision possible

Indirect

- Calculation of distance from # photons
- Photon statistics limits precision
- Lower optical power density
- Digital circuitry (counters)
- Dead time limits counting rate



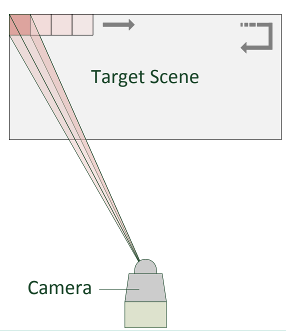




LIDAR-Methods - Benchmarking

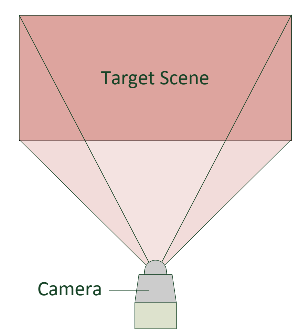
Scanning LIDAR

- Subsequent pointing to object area points
- Only one object point at a time
- Mechanical scan
- High optical power density
- High distance range
- Single detector element
- Low framerate



Flash LIDAR

- Complete scene is take in a flash
- Solid state solution possible
- No moving parts
- Low optical power density
- Low distance range
- Detector array required
- High Framerate



Challenges for Automotive LIDAR

Background light suppression

- 20…40 klux are realistic
- For short ranges120 klux seem possible

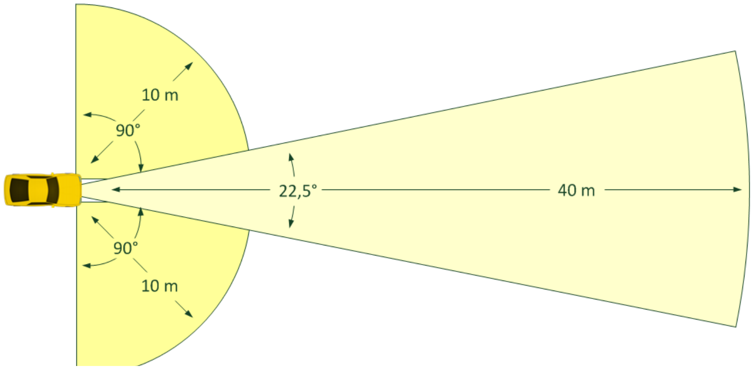
Limits for Flash LIDAR

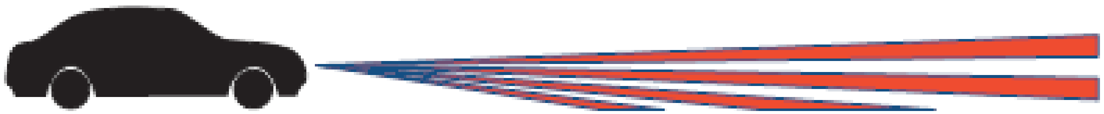
- For long ranges flash LIDAR is not very efficient
- Trade-off: laser power / range / FOV
- Long ranges are covered with video and radar

Example of Flash LIDAR

SPAD linear sensor for ADAS

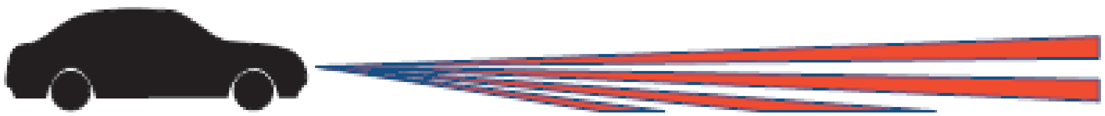
- Pedstrian detection
- Parking Assistance
- Flash LIDAR-System with 3 SPAD line sensors for short and medium ranges



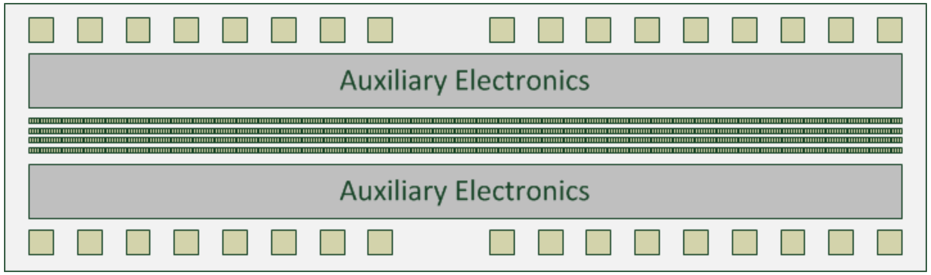


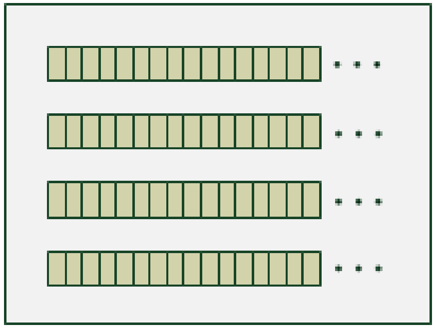
Example of Flash LIDAR

Approach: Detection of target area by 4 lines



Detector allows high fillfactor





Summary

- SPADs in CMOS Technology allows for highly efficient LIDAR sensors
- Backgroung light suppression is still an issue in outdoor applications
- New signal processing methods and algorithms enable extension of dynamic range