CMOS Image Sensors and Electronics at Fraunhofer IMS Duisburg

Fraunhofer Institute Microelectronic Circuits and Systems, Duisburg
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2nd Annual MT Meeting, KIT, March 8th, 2016

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Agenda

- Motivation
- Infrastructure at Fraunhofer IMS
- Optical Sensors in Standard CMOS Process
- Examples of Optoelectronic Devices
- Summary

Motivation

- Optical semiconductor sensors and detectors play an increasing role in various niche markets.
- Requirements are often very different from mainstream image sensor applications.
- Demanded production volume is typically low or medium (i.e. few 1000 / a).
- Long-time availability is requested
- Only few semiconductor manufacturers left in Europa.

➔ Use Fraunhofer Technology Portfolio

Fraunhofer IMS
Facts & Figures

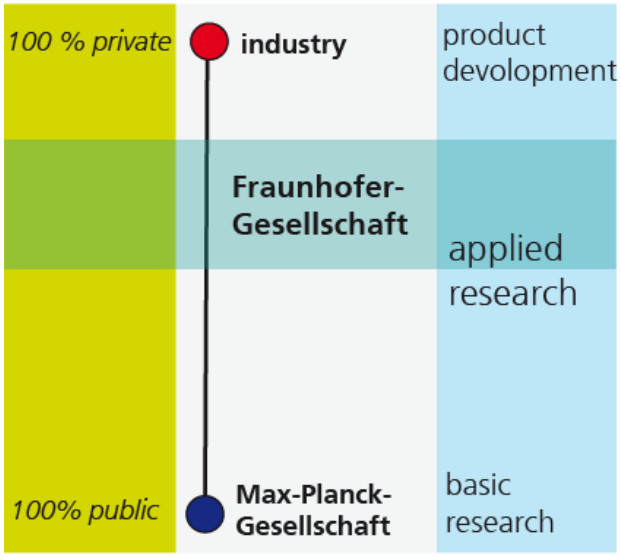
Foundation: 1984/85

Staff: > 250

8 Business units

Budget: (24,4 million EUR for 2014)

- 25 % basic funding for corporate research and administration
- 25 % publicly funded projects
- 50 % projects funded by industry



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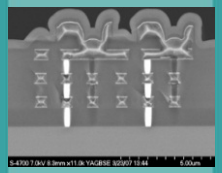
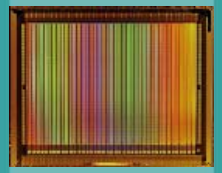
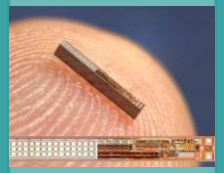
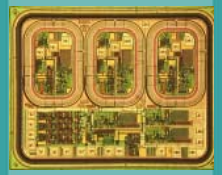
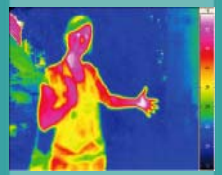
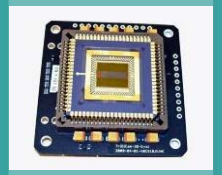
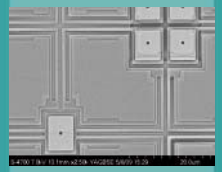
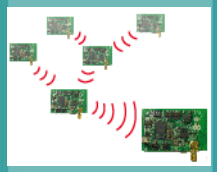
Business Fields

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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CMOS Fab

Total area:	1300 m^2
Wafer size:	200 mm
Operations:	24h/7d
Capacity:	70.000 wafers p.a.

- Automotive certified
- 0.35µm CMOS, 0.35µm 250°C on SOI, 600V/1200V on SOI, integrated pressure and optical sensors
- Cooperation with ELMOS AG (automotive circuits)
- Cooperation with Infineon (600/1200V driver circuits)
- ICs from a few 100 ASICs to several millions for IMS customers

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, chip-to-wafer, chip-scale packaging.

MST Lab&Fab

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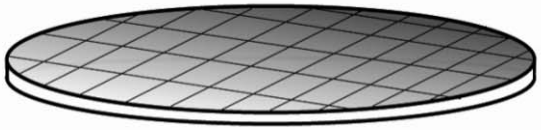
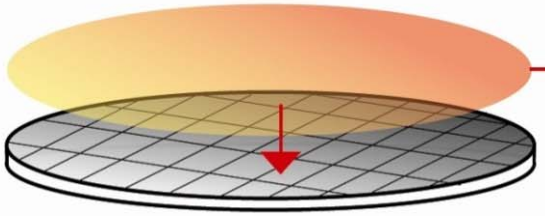
„More than Moore“ at IMS: CMOS + Post-Processing

CMOS Fab

MST Lab&Fab

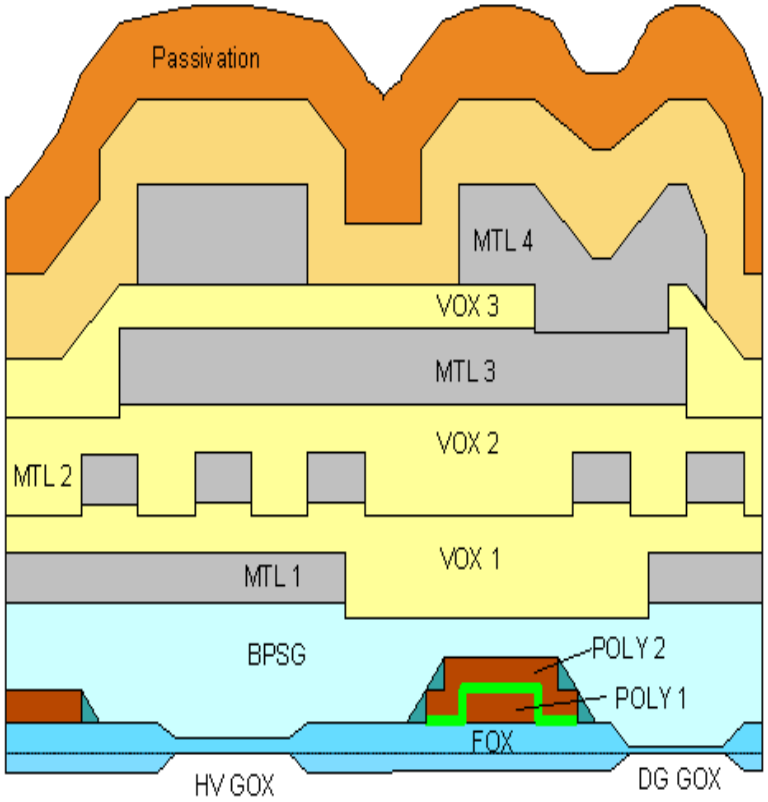
CMOS Processing	Post-Processing	Applications
		▶ IR-Application ▶ Biohybrid-Applications ▶ Opto-Applications
CMOS as „intelligent“ substrate	Post-Processing: Prepare layers, structures, and devices on this substrate	Compact, intelligent micro systems

CMOS Process

0,35µm, automotive qualified

combines high voltage capability up to 120V with scaled devices for integration of mixed signal functions

- 4 metal layers
- 2 poly layers
- 3.3V for 0.35µm devices
- transistors with Uth~0V
- voltage independent capacitor
- poly-poly capacitor
- High-resistivity Poly
- EEPROM
- Flash
- DIMOS 80V
- HV PMOS 60V



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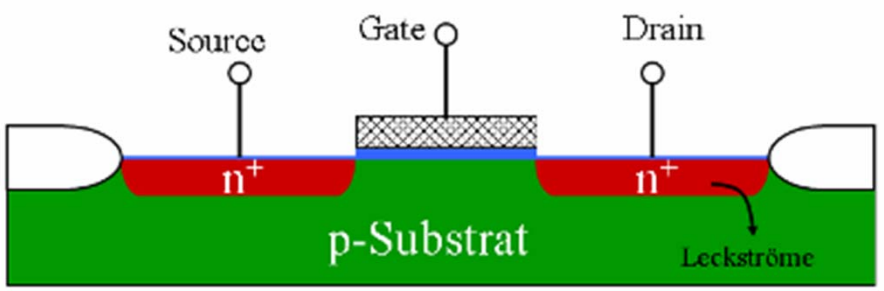
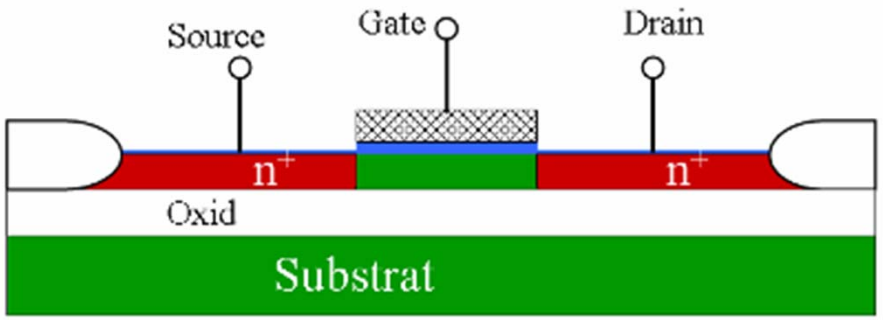
SOI CMOS Process



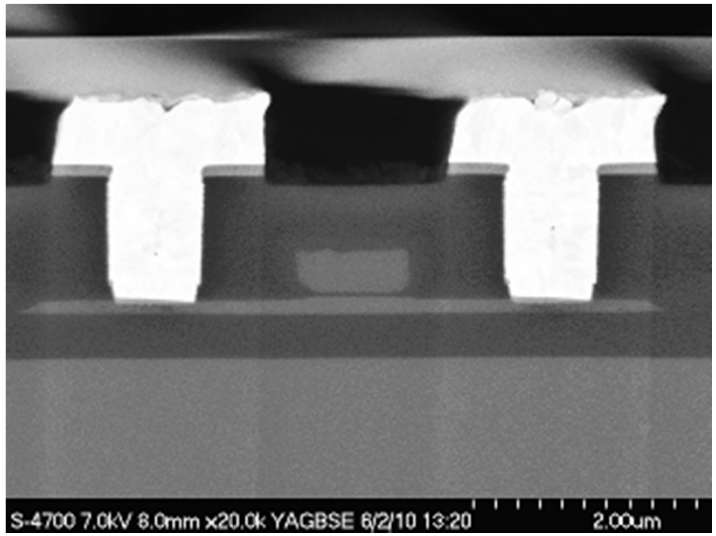
For:

- High temperature (200 – 300 °C)
- High voltage (600 – 1200 V)

Bulk CMOS, o.k. up to about 150°C, limited by junction leakage and metal degradation



SOI = Silicon on Insulator



CMOS for 250°C with EEPROM memory.
Partially depleted on thin film SOI wafers.
Dielectric isolation reduces leakage currents.
Tungsten metal reduces electromigration.

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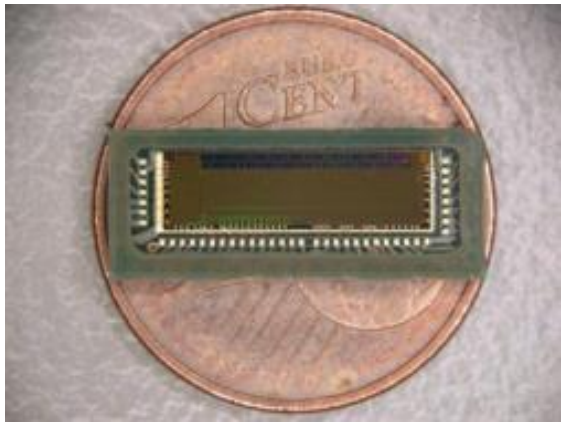
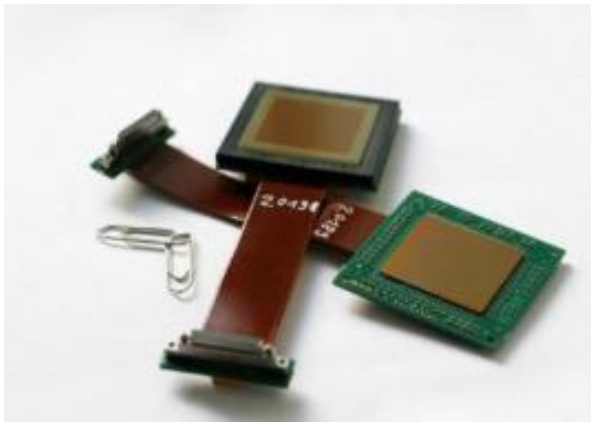
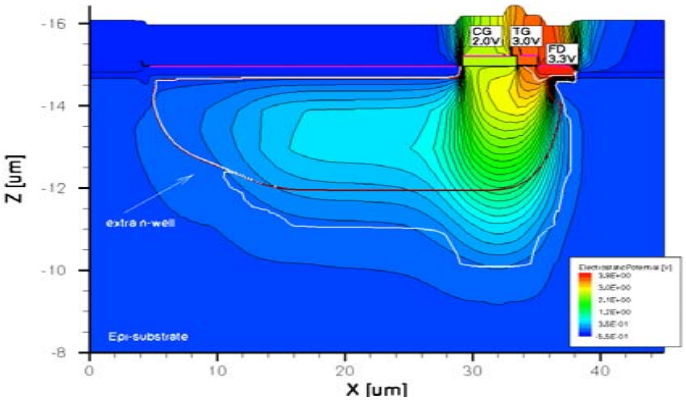
Business Field: CMOS Image Sensors

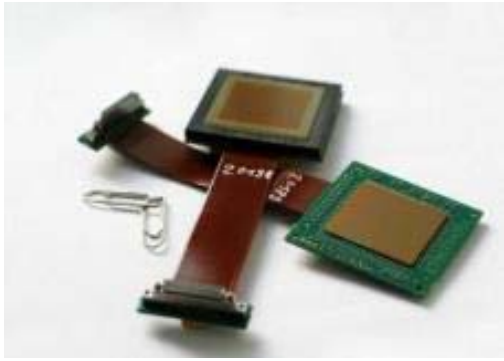


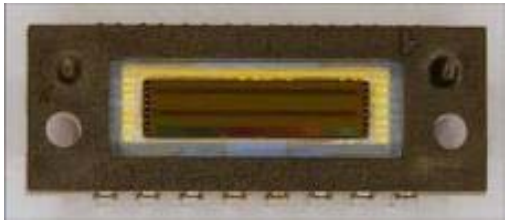




Service and Know-how - Optical CMOS Sensors

Optical CMOS Sensors



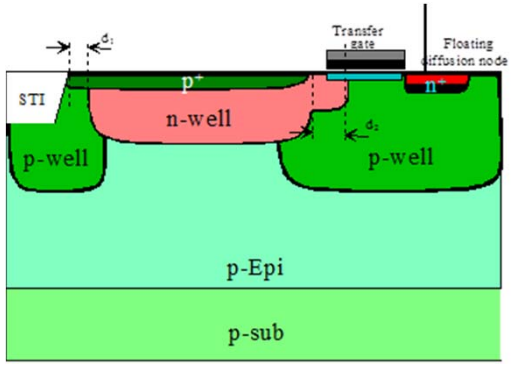


Service and Support

- 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

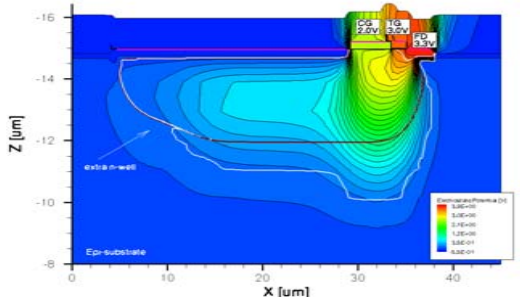
Service and Know-how - Optoelectronic Devices

Optoelectronic Devices



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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Technology - CMOS 0.35µm Process “Opto”

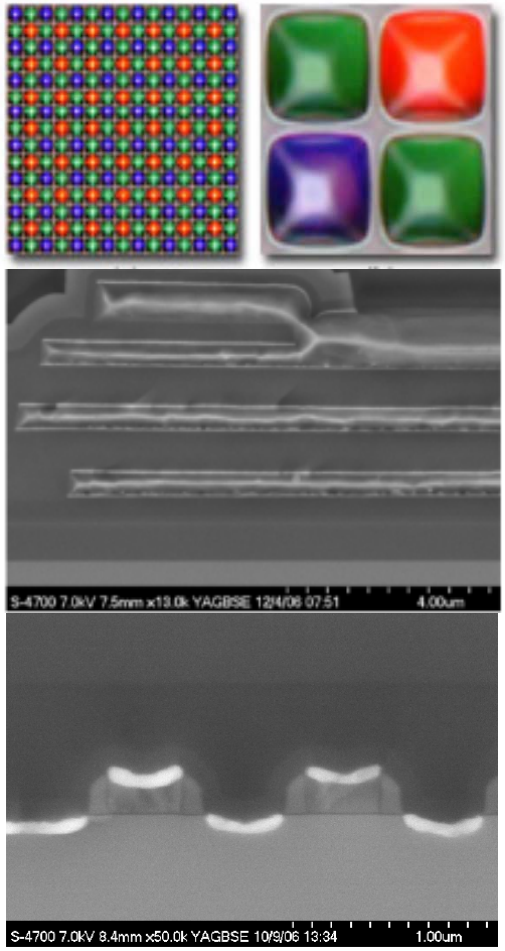
The IMS 0.35µm CMOS process “Opto” is providing:

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
- Dot array photodiodes
- Lateral Drift-Field Photodetectors (LDPD)
- Single-Photon Avalanche Diodes (SPADs)
- Embedded CCD



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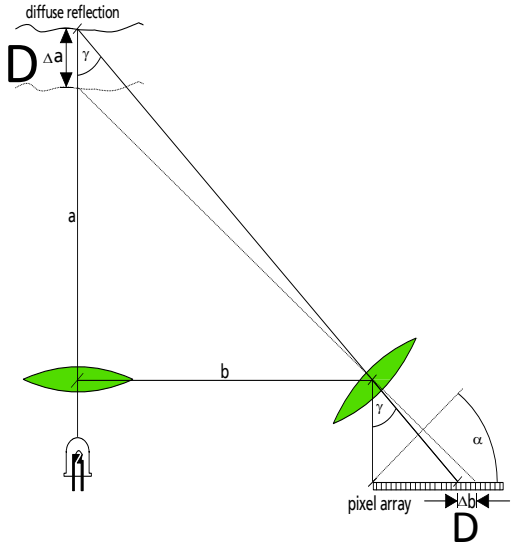
Reference Projects - Triangulation Sensor

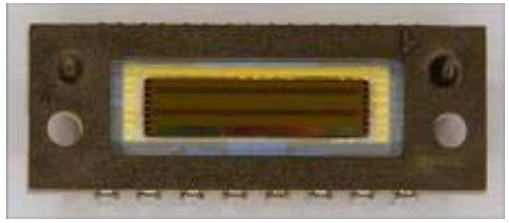
Design and Development

- Designed for high speed range sensing in industrial environment

Unique Selling Points

- High speed overexposure detection
- 512 Pixel with random access
- High NIR sensitivity: 70% QE @700nm





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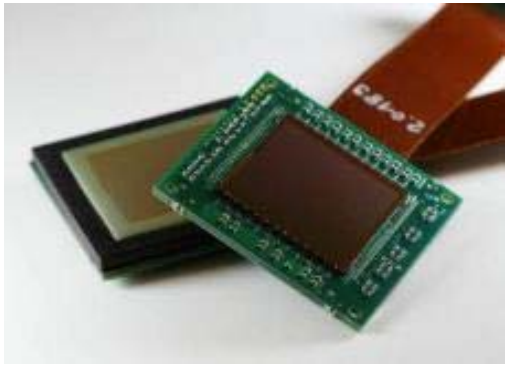
Reference Projects - High Temperature Image Sensor

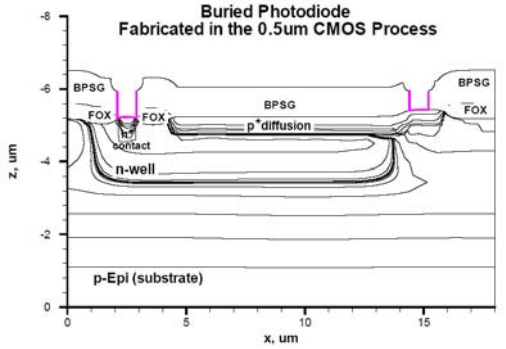
Design and Development

- Designed for imaging in harsh environment with high temperature



Unique Selling Points

- 778mm^2 imager with 256 x 256 pixels
- Temp. range: -40°C .... +110°C
- Binning, ROI readout, 50fps



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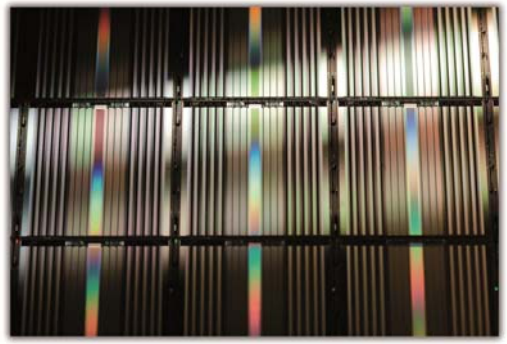
Reference Projects – RGB Line-Scan Sensor

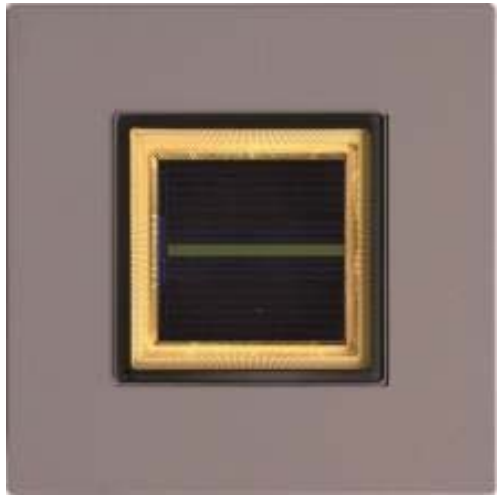
Design and Development

- 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



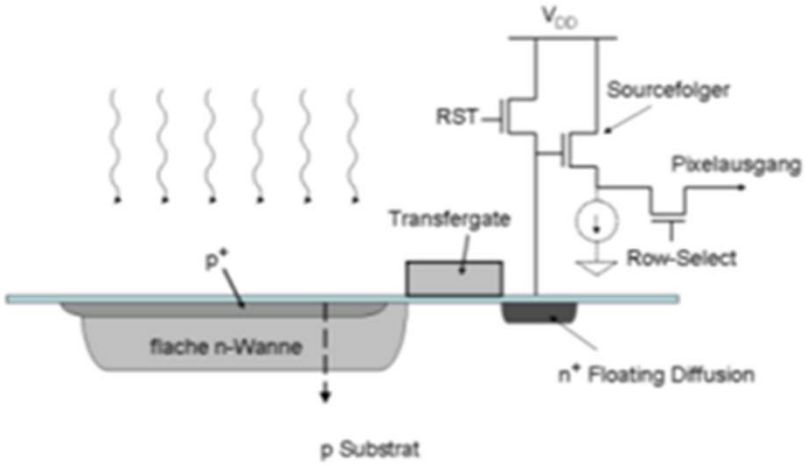
Opto Devices - Pinned Photodiode (PPD)

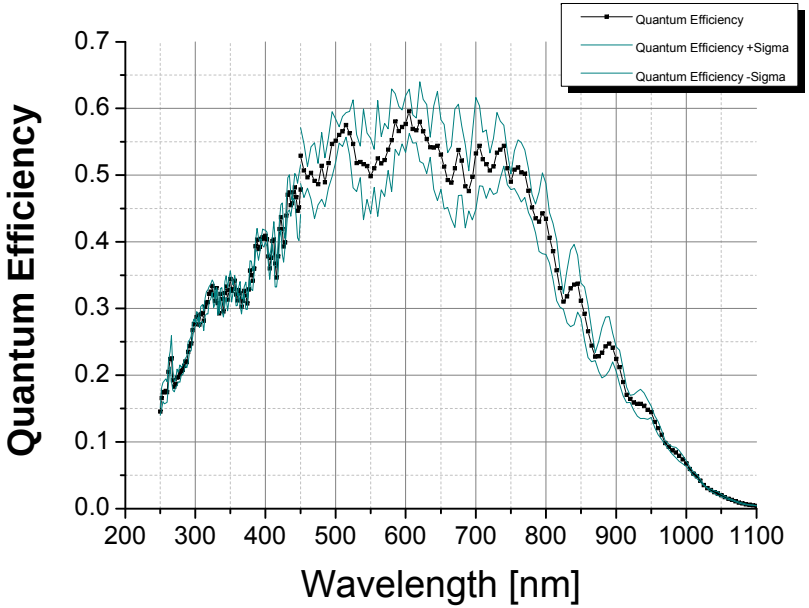
Technology

- CCD-like pixels based on charge transfer
- Integrated into standard 0.35µm CMOS process

Key Features

- Low-noise and low leakage currents
- In-pixel storage
- Spectral range from UV to NIR





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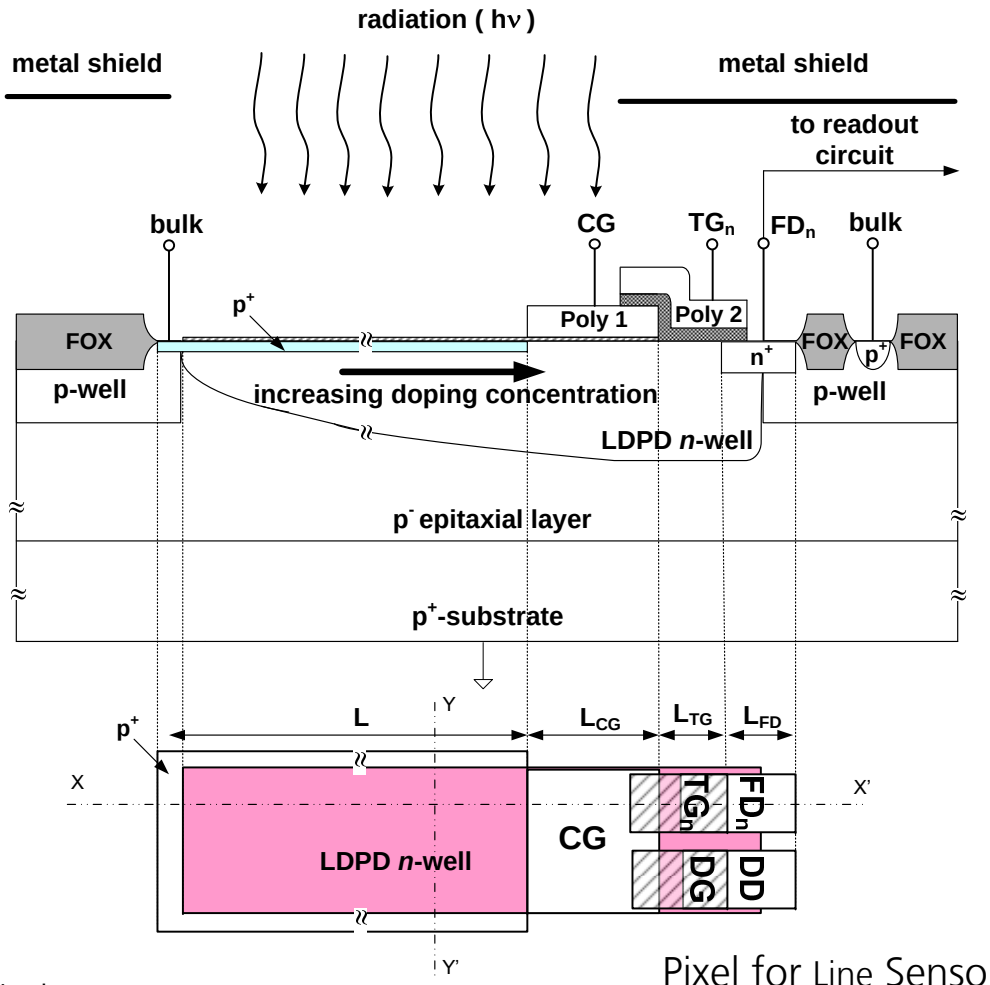
Lateral Drift-Field Photodetector (LDPD)

Key Features

- CCD-like pixels based on charge transfer
- 0.35µm CMOS Technology
- Low Noise / High sensitivity (high SNR)
- Non destructive readout
- Time-Dependent Charge Separation (multiple floating diffusions)
- Individual Pixel Reset
- Multiple Shutter Integration
- Correlated double sampling feature



Pixel for Line Sensors

5 Pixels, 10µm x 1000µm

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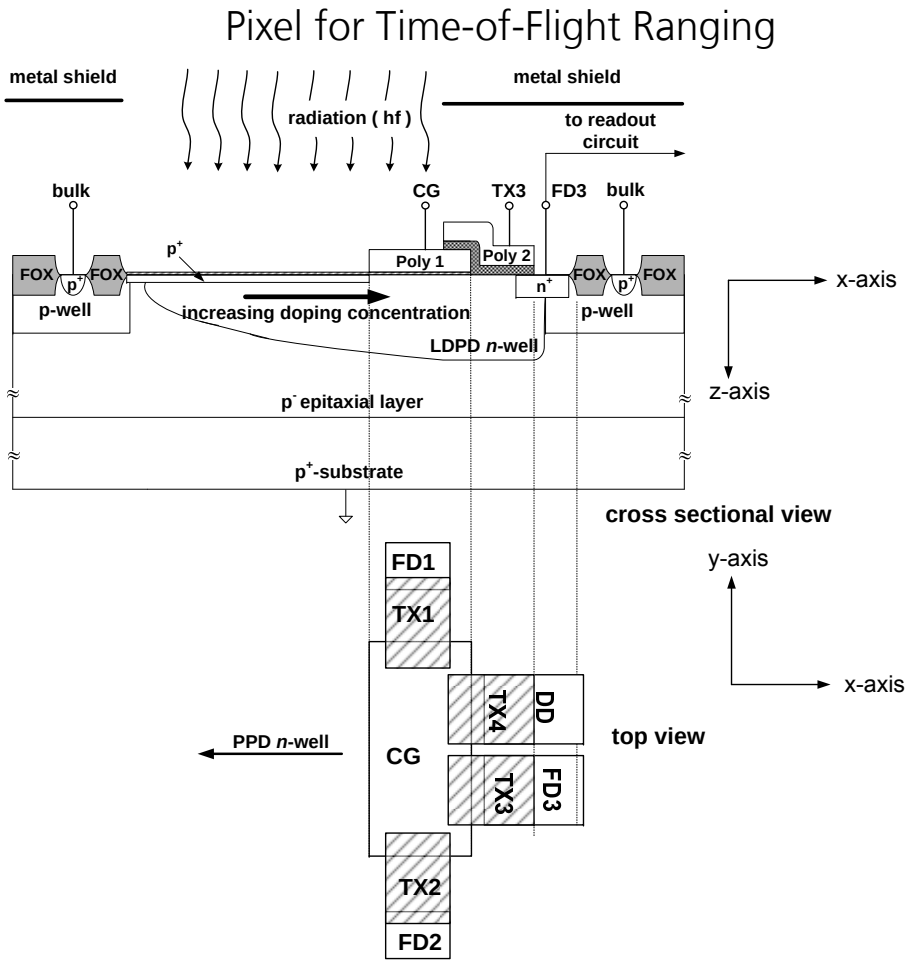
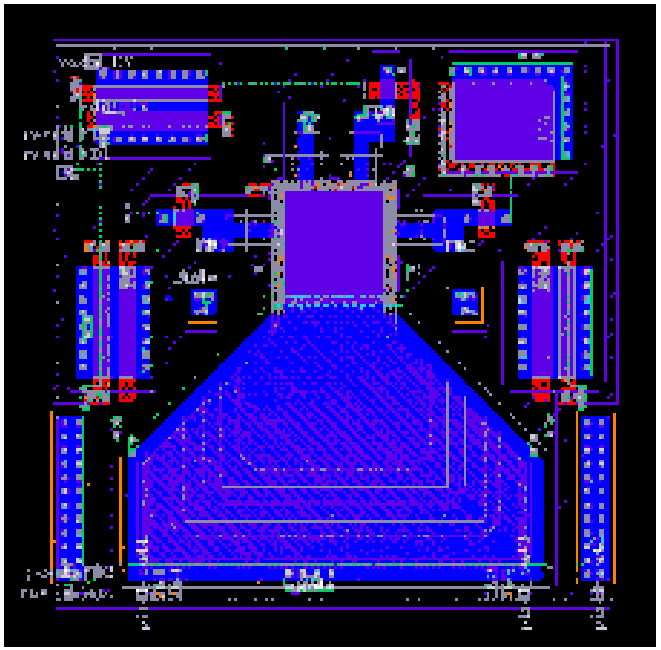
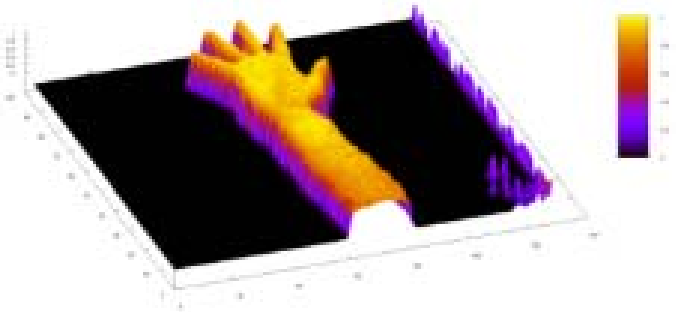
Lateral Drift-Field Photodetector (LDPD) for ToF







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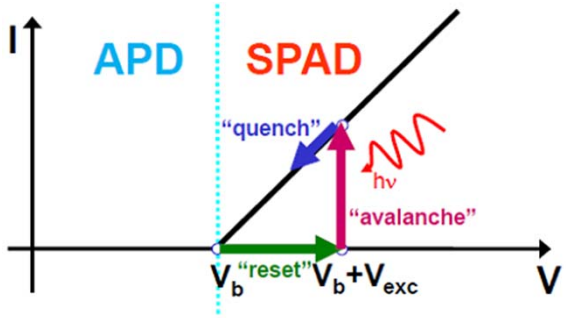
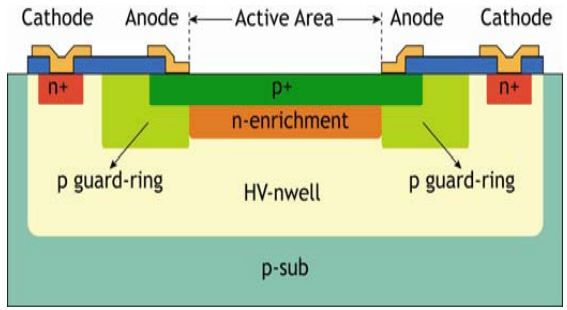
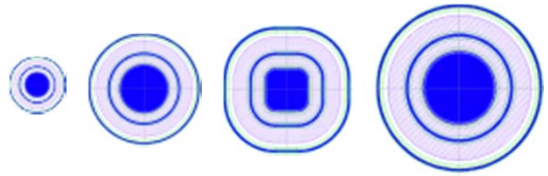
Single-Photon Avalanche Diodes (SPADs)

Technology

- Avalanche Photodiode (APD) operated in Geiger mode
- Smart frontside illuminated pixels integrated into standard 0.35µm CMOS process





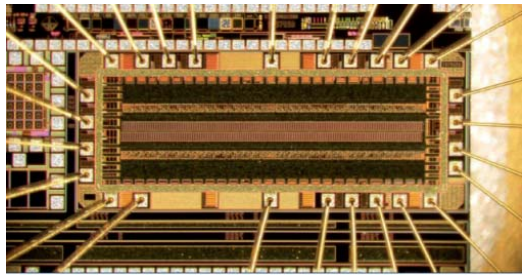


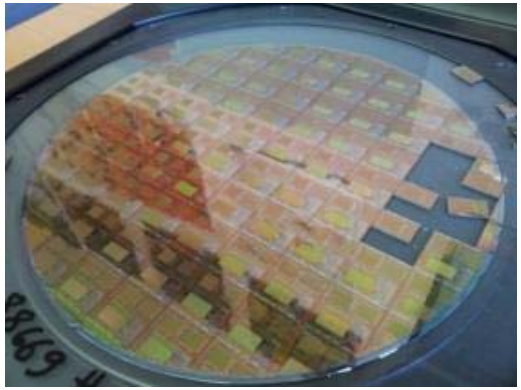
Unique Selling Points

- Lowest Dark-Count-Rate
- High uniformity
- Picosecond time resolution
- High sensitivity in blue and UV

SPAD Performance

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-equiv. Irradiance @905nm	11 pW/cm^2

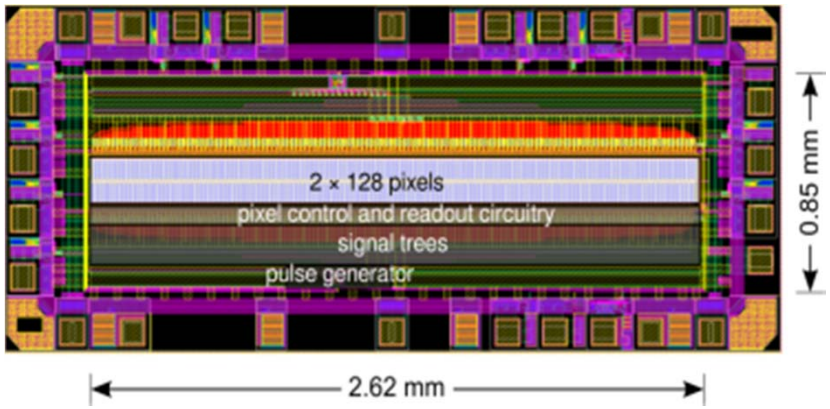




Linear Sensor and SiPM

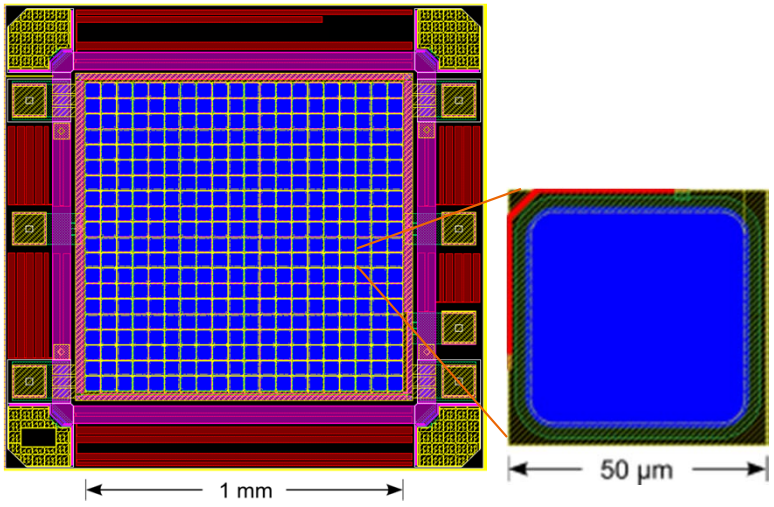
Linear sensor

- 256 pixels (20µm x 80µm)
- clock trees for time critical signals
- digitally controlled front-end and shift-register-based readout
- variable gating time



SiPM

- SiPM array with 400 cells of 1x1mm²
- 50µm x 50µm element size
- single photon resolution
- on-chip TIA



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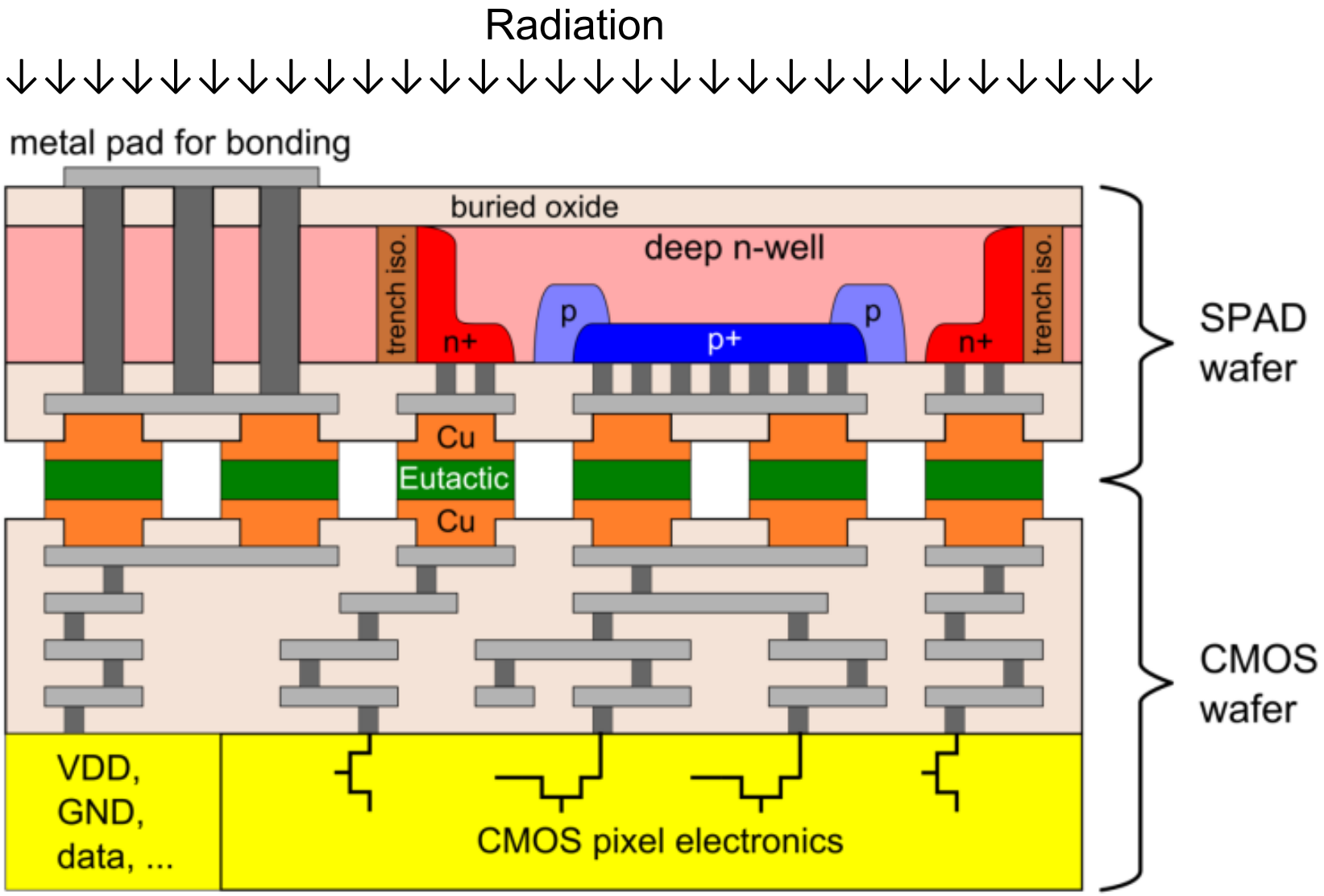
BackSPADs

Schematic cross section of backside illuminated SPAD sensor after integration



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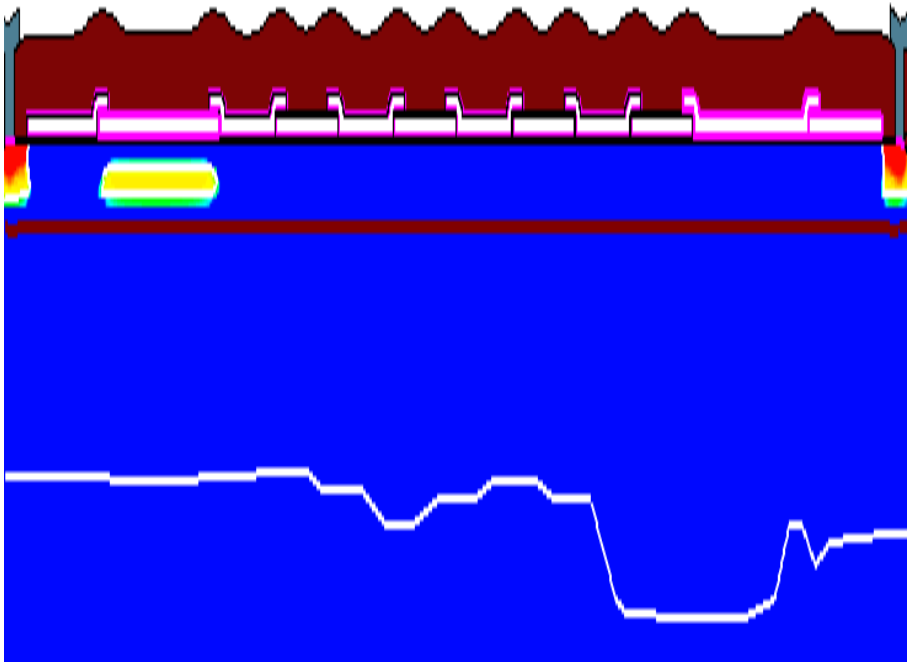
Embedded CCD

Application

- CMOS/CCD TDI sensor for earth observation and high resolution scanning



Important data

- High full-well capacity 150 000 e^-
- Fast TDI integration 100 000 fps
- Transfer efficiency > 99.99%
- On-chip CDS and multiplexing

DOSE (deep optical stack etching)

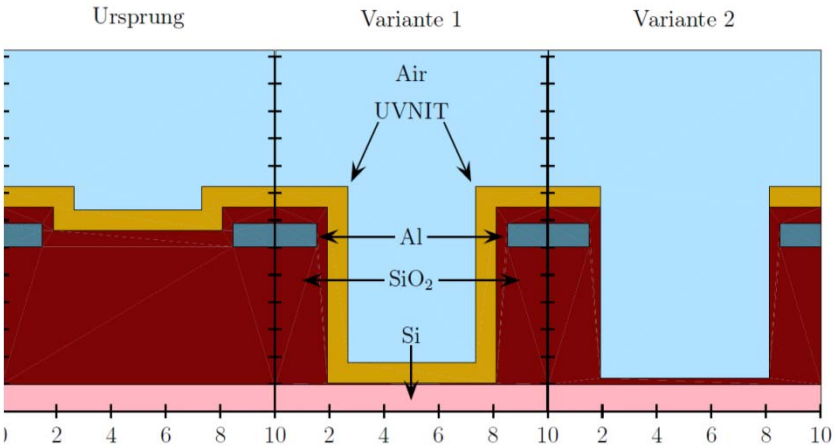
Deep UV and EUV Detectors

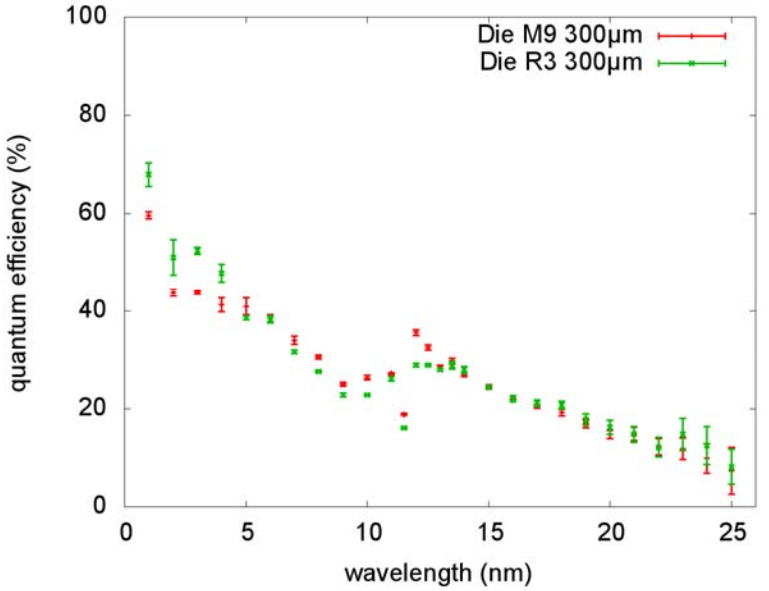
Technology

- Removal of dielectric stack in the photosensitive area

Unique Selling Points

- High sensitivity in deep UV and EUV
- No spectral distortion by unwanted interference effects in dielectric stack
- No absorbtion losses
- Less optical crosstalk



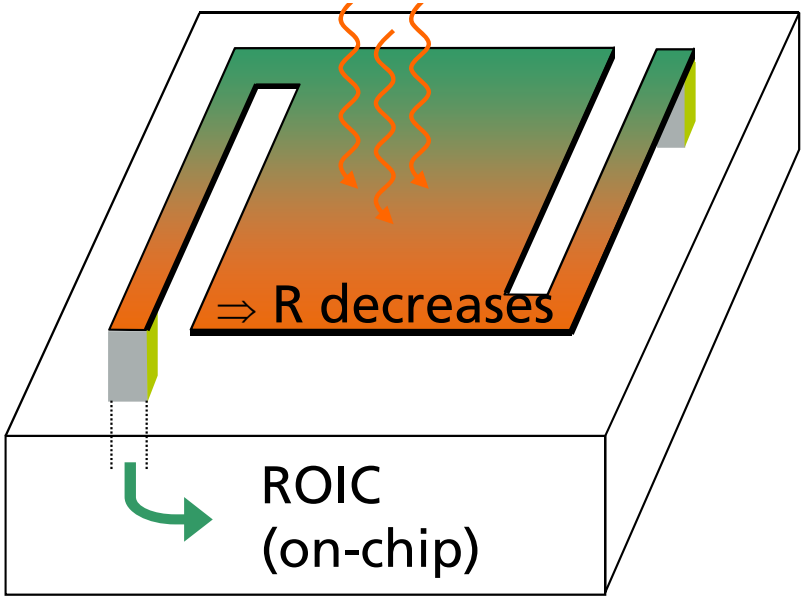


Fraunhofer IMS

Mikrobolometer Array on CMOS

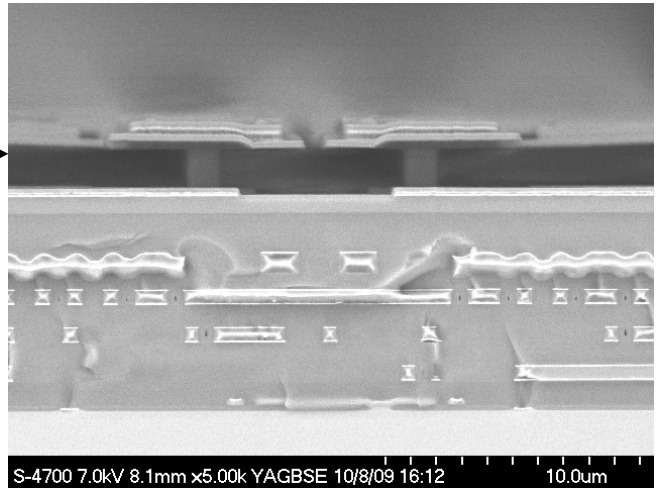
IR emitter
8 – 14 µm

IR radiation causes
temperature rise

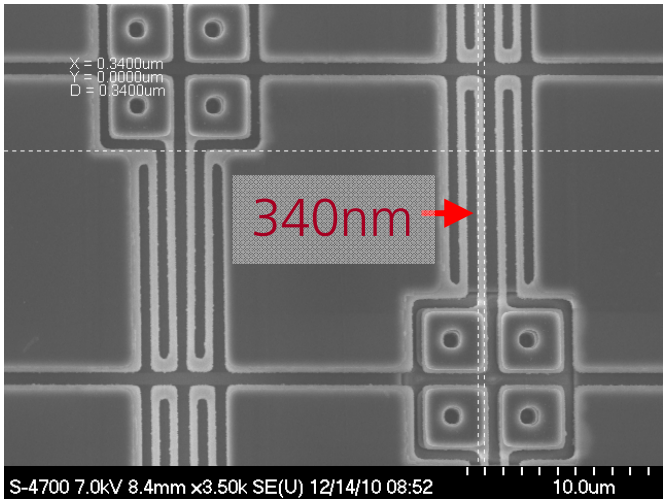


Mikrobolometer
(Post Processing)

CMOS



Cross section

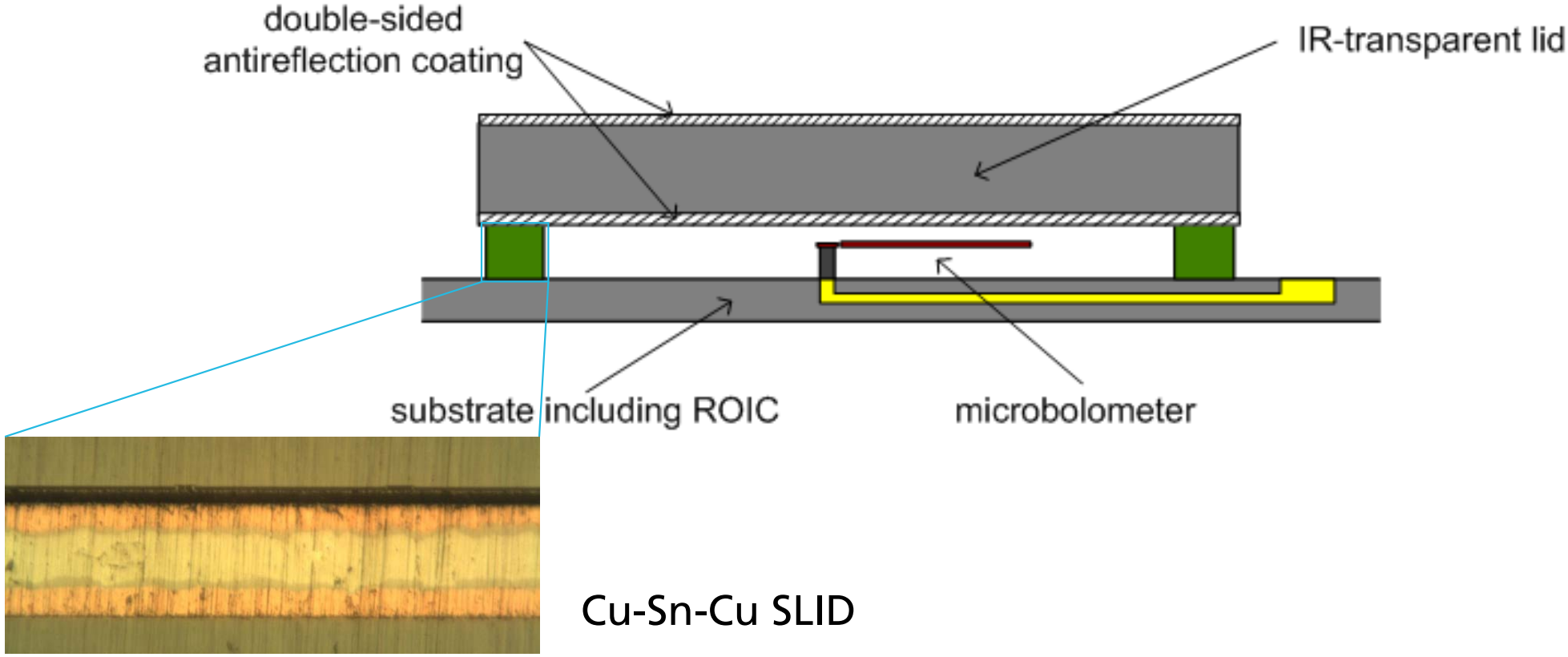


Top view (single pixel)

Fraunhofer IMS

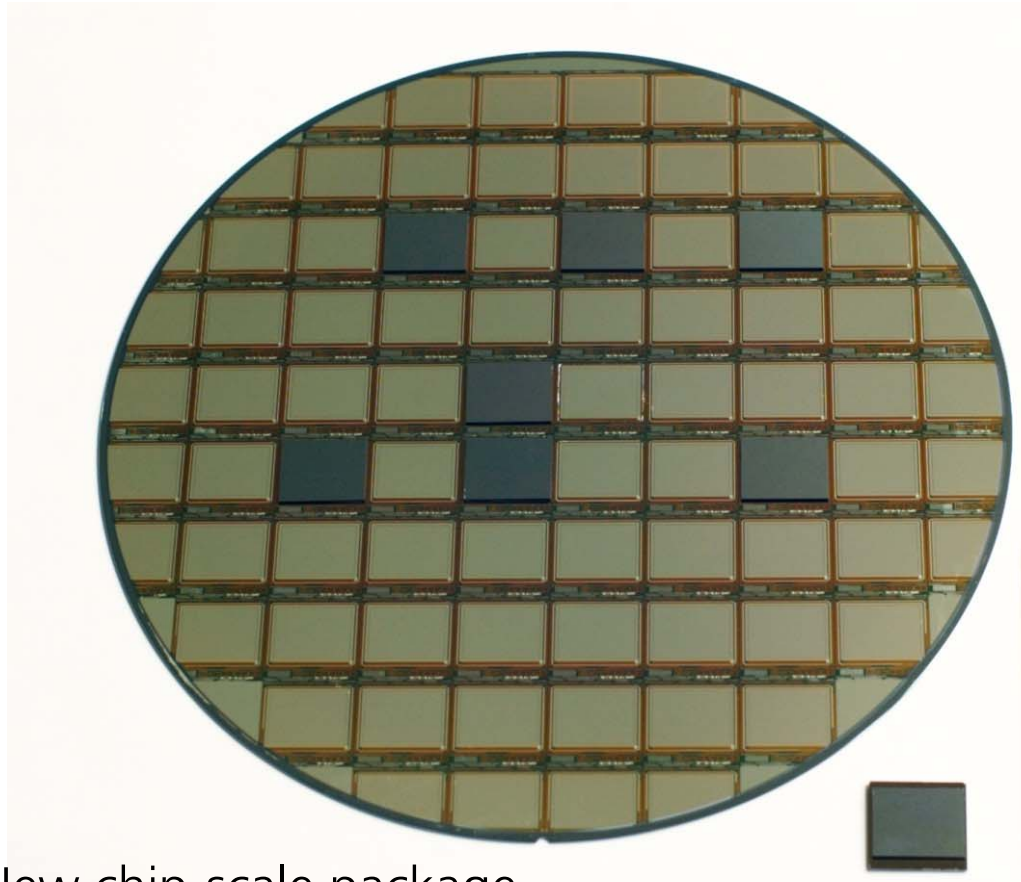
Vacuum Chip Scale Package

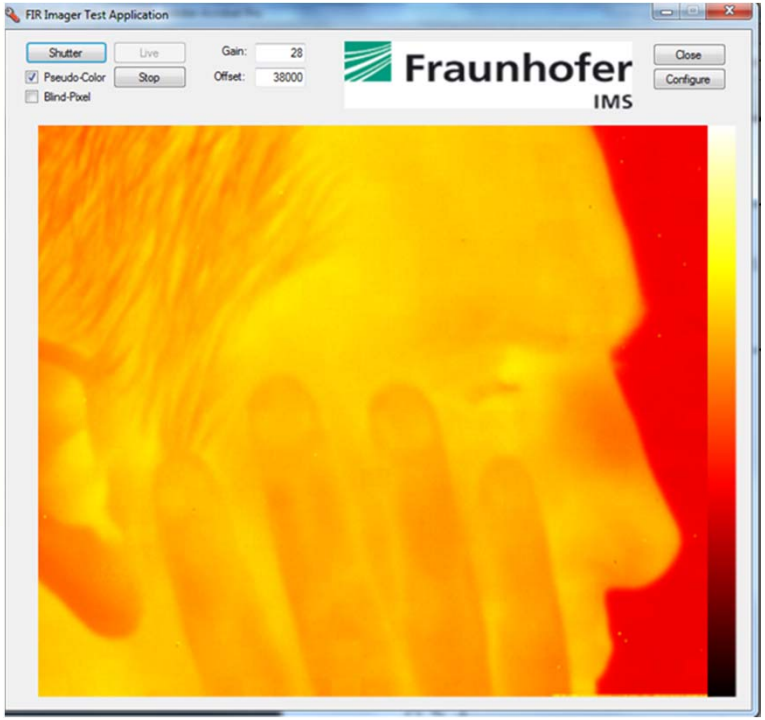
- Cost reduction
  compact, all silicon, wafer-scale, no ceramic or metal package
- Package requirements
  Vacuum inside to reduce thermal losses from gas convection
  IR-transparent window



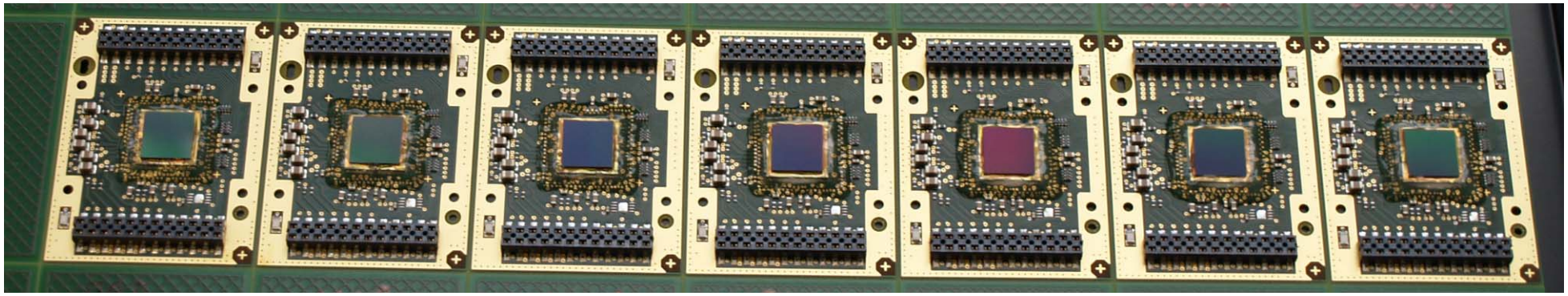
Cu-Sn-Cu SLID

MEMS Chip Scale Packaging





New chip-scale package



Fraunhofer IMS

DEPFET

DEpleted **P**-channel **F**ield **E**ffect **T**ransistor

PNSensor

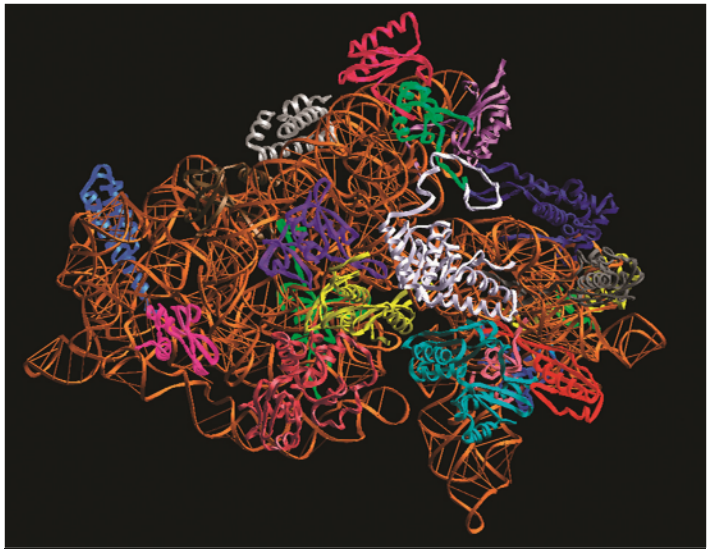
Process development and manufacturing of a DEPFET sensor chip

Goal

- Detection of X rays (λ = 0,05 nm bis 4,7 nm)
- Sensing element in a new detector for the free electron laser **XFEL**
- High frame rate (4,5 MHz for > 3000 frames)

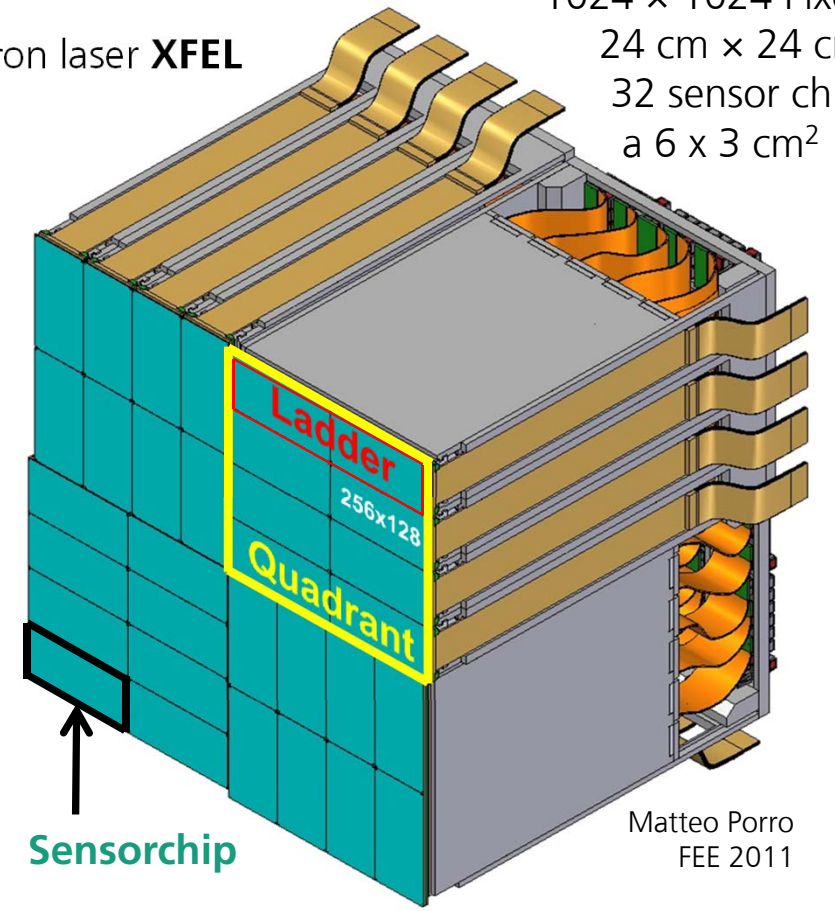
Application examples

- Structure analysis of bio molecules (e.g. ribosomes)
- Process sequences of chemical reactions



Ribosom (www.xfel.eu)

Detektor:
1024 × 1024 Pixel
24 cm × 24 cm
32 sensor chips
a 6 x 3 cm^2



Matteo Porro
FEE 2011

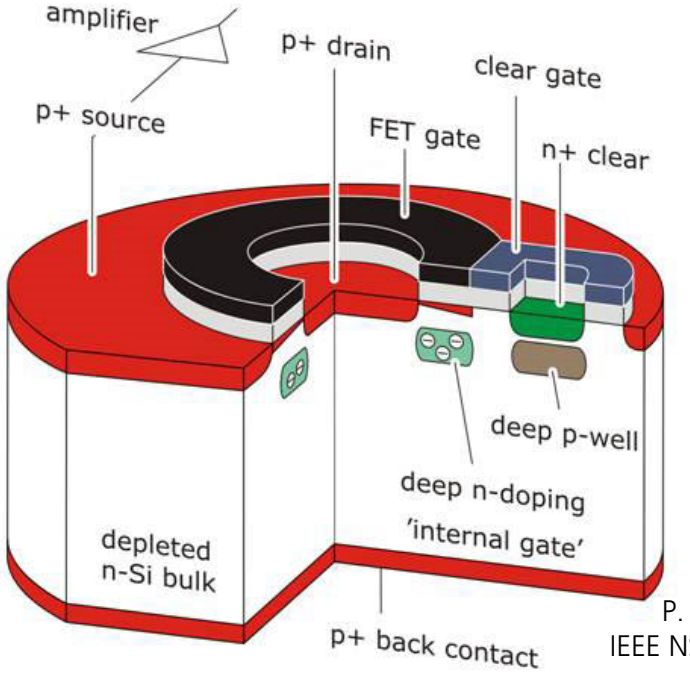
Fraunhofer IMS

DEPFET

DEpleted **P**-channel **F**ield **E**ffect **T**ransistor

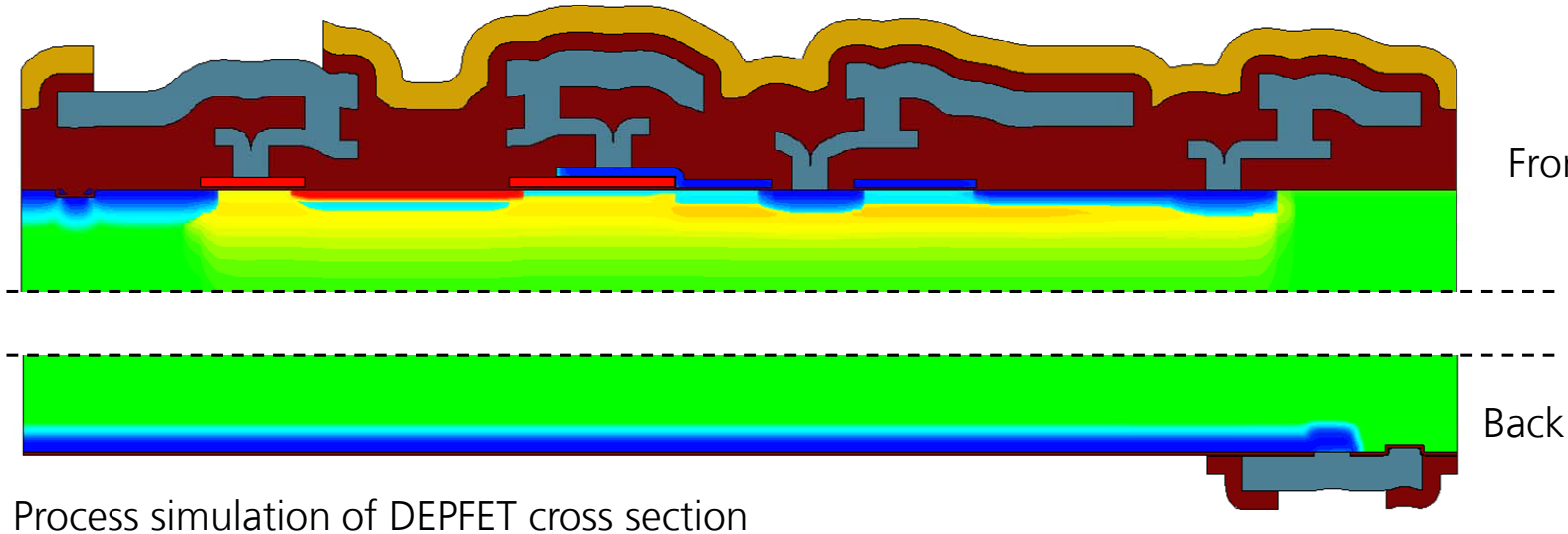
Special features

- High resistivity silicon substrate
- Fully depleted wafer during operation
- Double sided processing in a CMOS fab
- Chip size ca. 6 cm × 3 cm



P. Lechner
IEEE NSS 2011

Schematic cross section of a DEPFET pixel



Process simulation of DEPFET cross section

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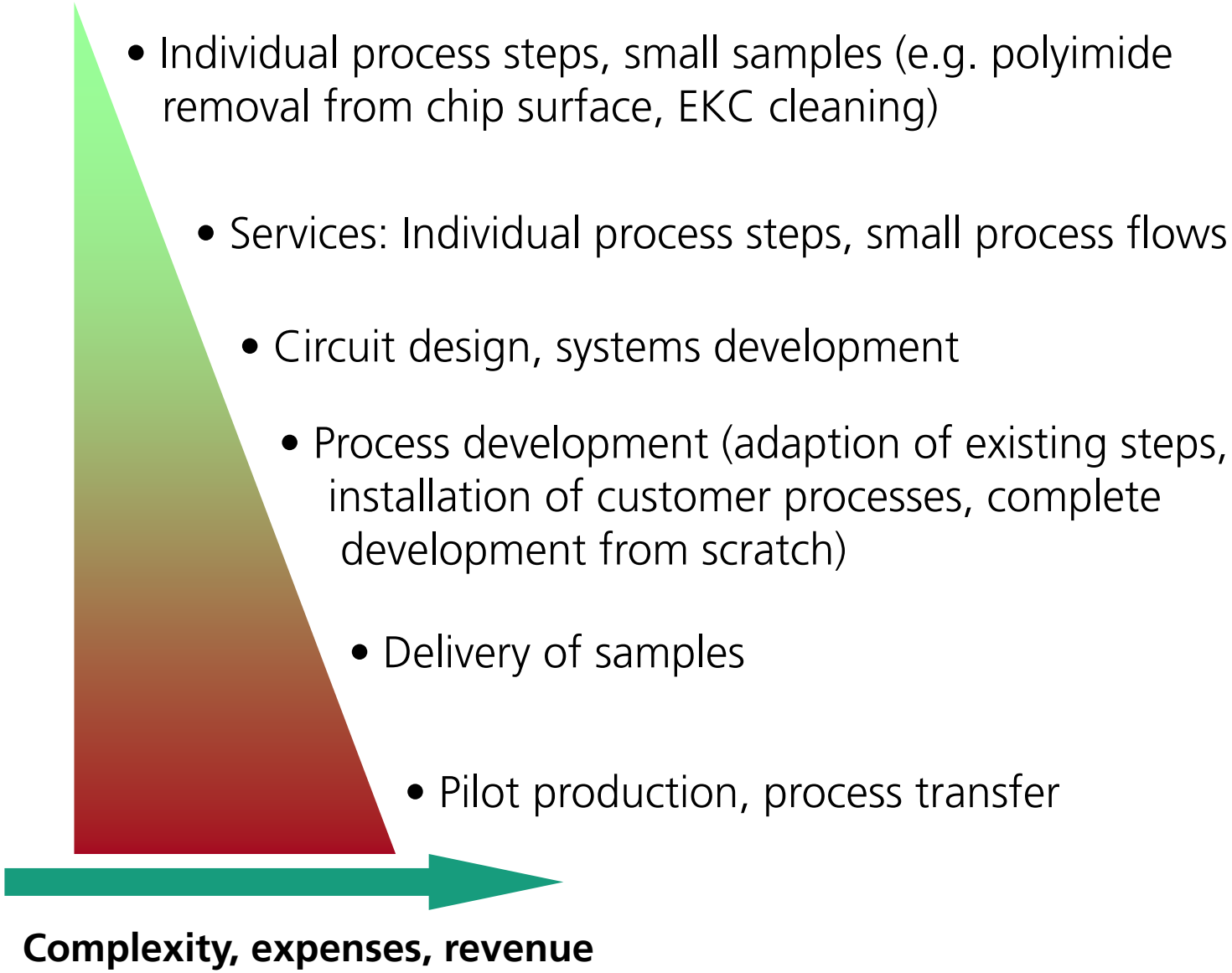
Projects and Services by IMS



Fraunhofer IMS

Summary

- Application specific CMOS sensors enable high performance electro-optical detector Systems.
- Dedicated optical sensors have been integrated in an standard CMOS process.
- Fraunhofer IMS bridges the gap to the semiconductor industry which is only interested in high production volumes.
- Fraunhofer IMS services include concept development, prototyping, and pilot production.

Thank You !

Contact

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!!! Registration open: 8th CMOS Image Sensor Workshop: May 9th &10th, 2016 !!!

Fraunhofer IMS