MAX PLANCK SEMICONDUCTOR LABORATORY

MPG Halbleiterlabor: Precision Sensors for Basic Research

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MPS Semiconductor Laboratory (in German: MPG Halbleiterlabor - HLL)

MAX PLANCK SEMICONDUCTOR LABORATORY

At present @ Siemens Campus Neuperlach Munich

- 1000m^2 of clean room area
- 330m^2 of ISO3 area
- Full 6 inch silicon process line

From end 2023 @ Research Campus Garching

- 1500m^2 of clean room area
- 600m^2 of ISO3 & ISO4 area
- 8 inch silicon process line

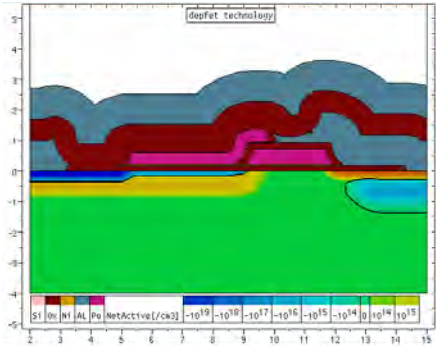
From 2023 HLL is part of Munich Quantum Valley

Central facility of the Max Planck Society
with 40 employees: scientists, engineers and technicians + guest scientists, engineers and students

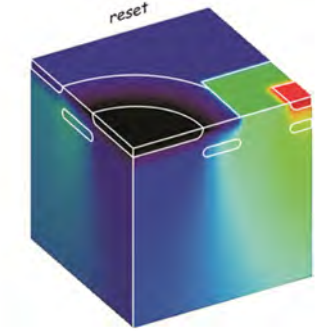
MPG HLL is developing and producing fully depleted silicon radiation sensors with integrated electronics optimized for different scientific projects

Inside HLL – Sensors and Systems : Design, fabrication & Test

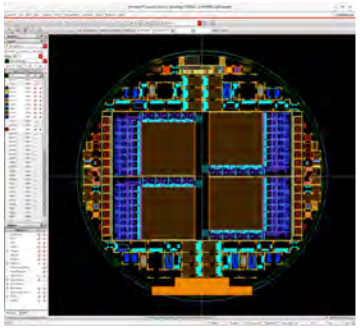
Process simulation



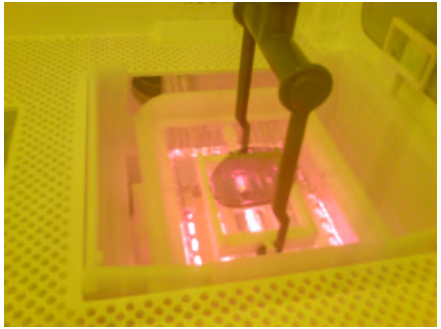
Device simulation, 2D and 3D



State-of-the-art layout tools



In house fabrication



Wire bonding, hybrid assembly

@ HLL:

- sensor design and fabrication
- interconnection
- system/camera design and test

System test facilities

Devices @ HLL

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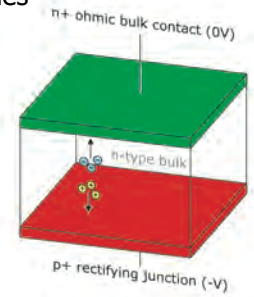
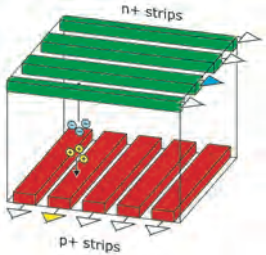
- **Building blocks**

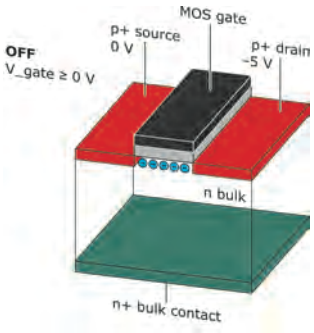
Diodes



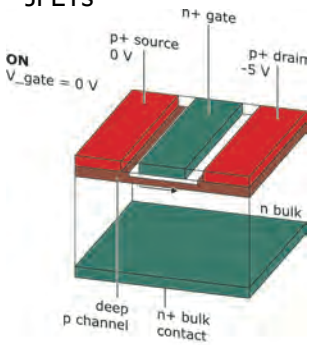
Strip detectors



MOSFETs

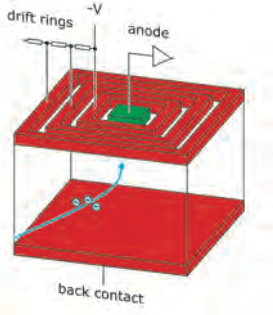


JFETs

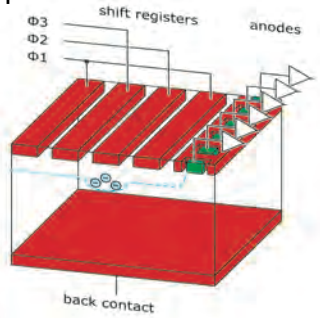


- **Devices**

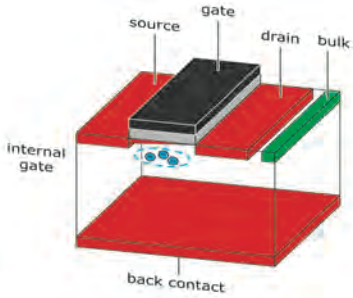
Silicon drift detectors (SDD)



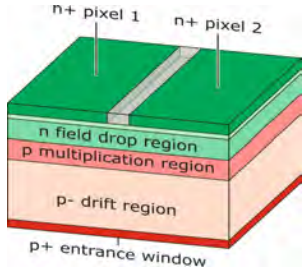
pnCCDs



DEPFETs



Avalanche devices



Highlights from SDD projects

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Mini SDD - DSSC @ EuXFEL
(imaging of X-ray diffraction patterns)

M. Porro et al., *The MiniSDD-based 1-Megapixel Camera of the DSSC Project for the European XFEL*, IEEE TNS 68(6), pp. 1334 - 1350, June 2021

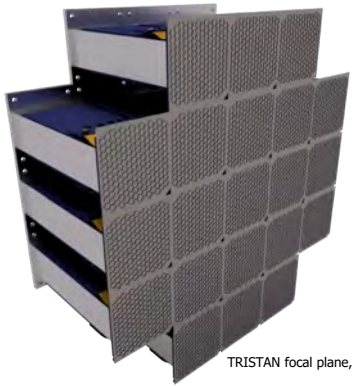
camera	**1024 x 1024 pixels** 21 x 21 cm² 32 sensor chips 4 quadrants central hole for direct beam
sensor	mini-SDD cells 128 x 256 pixels 3.0 x 6.2 cm² (chip)
hex. pixel pitch	204 µm × 236 µm
energy range	**0.25 keV – 6 keV**
noise	60 el. r.m.s.
peak frame rate	**4.5 MHz**
frame storage	800 frames

eXTP (enhanced X-ray Timing and Polarimetry)
SFA (spectroscopic focusing array)
(**space based** fast time-resolved X-ray spectroscopy)

SDD layout plot

SFA instrument	11 telescopes & sensors sensors out of focus
sensor	**19-cells SDD**
SDD cell	hexagonal 3.2 mm side length **30 mm² area**
energy resolution	< 180 eV (FWHM @ 6 keV)
time resolution	< 10 µsec

TRISTAN (tritium sterile anti-neutrino) @ KIT
sterile neutrino search by electron spectroscopy



TRISTAN focal plane, 21 modules.

system	21 sensors **20 cm diameter**
sensor	SDD with integrated FET **166 cells (~ 14 x 12 array)** **3.8 x 4.0 cm² (chip)**
SDD cell	hexagonal, 3 mm side length 7 mm² area
energy resolution	< 300 eV FWHM @ 20 keV
count rate	≤ 10^8/sec on focal plane ≤ 10^5/sec on sensor cell
dead layer	**as thin as possible**

Highlights from pnCCD projects

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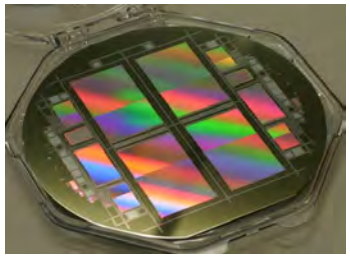
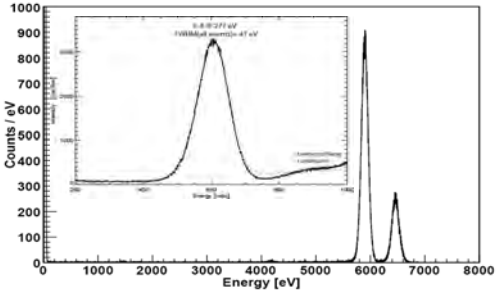
eROSITA

space based X-ray imaging & **spectroscopy**



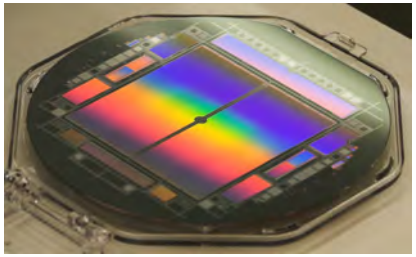
Sensor: 3 x 3 cm^2
384 × 384

Pixel size: 75 x 75 μm^2
Frame time: 50msec (20Hz)



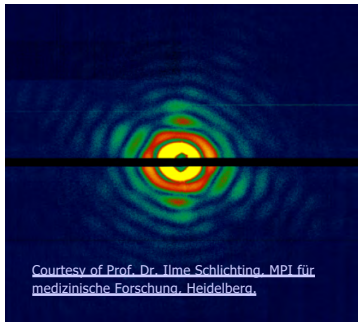
CAMP / LAMP

Soft X-ray camera for **Photon science**



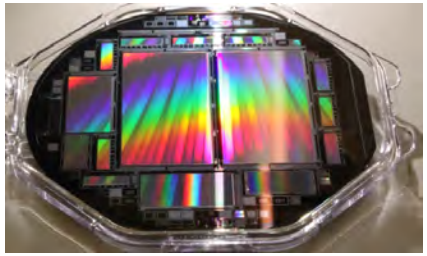
Sensor: 3.7 x 7.8 cm^2
1024 × 512 pixels.

Pixel size: 75 x 75 μm^2
Frame time: 8 msec (up to 120Hz)



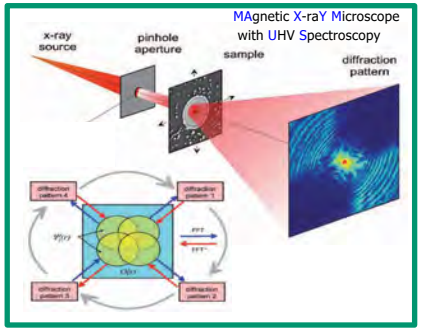
FSP – TNG for MAXIMUS@BESSY

Fast Small Pixel – The Next Generation
X-ray microscopy



Sensor: 3.7 x 7.4 cm^2
1024×1024 +(2x512) pixels

Pixel size: **36 x 36 μm^2**
Frame time: 2.5 msec (**400Hz**)



Highlights from DEPFET projects

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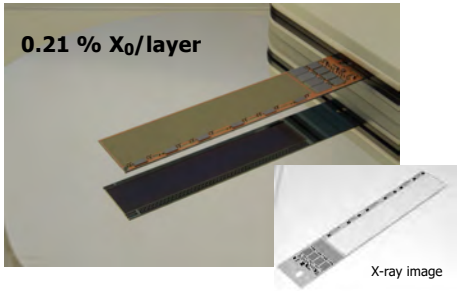
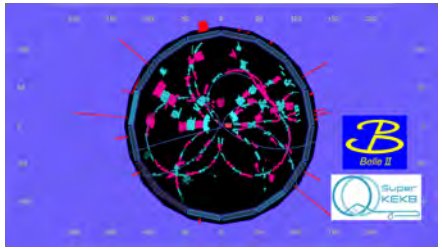
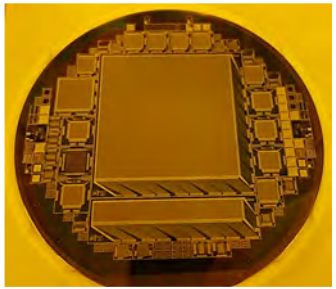
BELLE II pixel detector
High energy particle vertexing



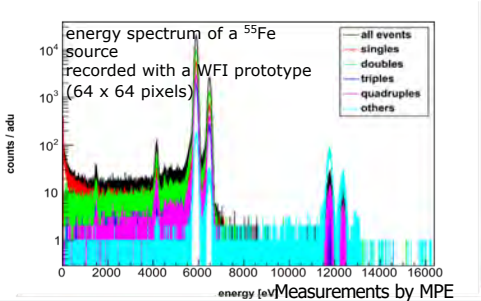
Active area 12.5 x 44.8(61.44)mm^2
250 x 800 pixels
Thickness: **75 µm**
rolling shutter mode
Pixel size: 50 x 55(85) µm^2
Frame time: 20ms (50kHz) (10MHz -row)



ATHENA Wide Field Imager
the **A**dvanced **T**elescope for **H**igh-**En**ergy **A**strophysics
as ESA's next-generation X-ray astronomy observatory

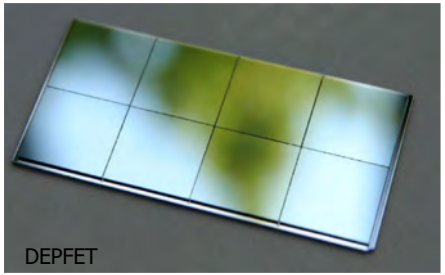


Sensor: 512 x 512 pixels
78.00 x 76.15 mm²
rolling shutter mode
Pixel size: 130x 130 µm^2
Frame time**:** **1.28 msec, i.e. 2.5 µsec / row**
with 128 eV (singles) & 136 eV (all)

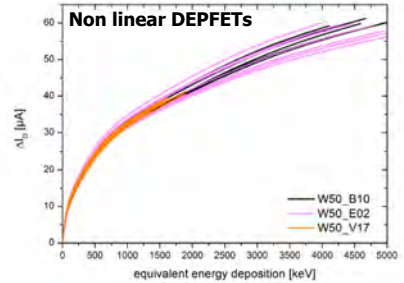


Measurements by MPE

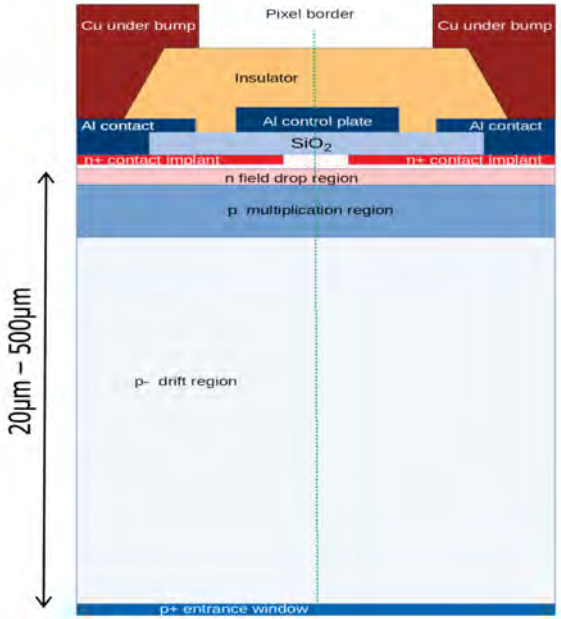
DSSC @ EuXFEL
DEPFET **S**ensor with **S**ignal **C**ompression
(imaging of X-ray diffraction patterns)



Sensor **2.56 x 10.24 cm²**
512 × 128 pixels
Hybrid detector
with 8 readout ASICs (64x64)
Pixel size: 204 x 236 µm^2
Frame time: **220ns (4.5MHz)**



Monolytic Array of Reach Through APDs (MARTHA)



operated in **proportional** mode
no inter pixel dead space
suitable for large pixel arrays

Expected features
Gain up to 20
Collection efficiencies: > 99%
Pixel pitch: given by bump bond technology and read out electronics (ATLAS 50µm)
Position resolution: << $pitch/\sqrt{12}$
Time resolution: Application dependent

- Leading edge trigger: <50ps
- Full signal formation 50ns (500µm)

DEPFETs – advanced concepts

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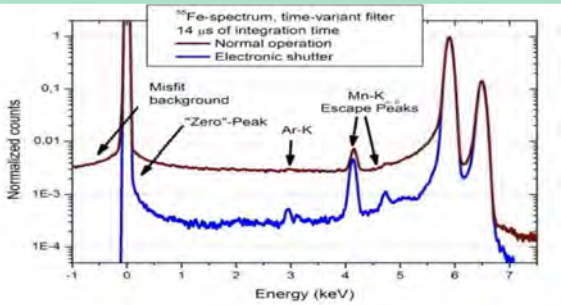
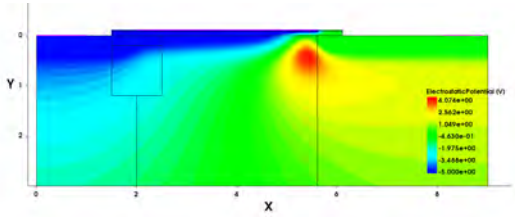
Super g_q DEPFETs – Super high S/N

- New DEPFET technology allows **improved S/N** of a factor of 3
- better S/N -> better spectroscopic applications (**ENC>1e-**)
- **High speed** readout devices
- **High precision** devices
- **High dynamic range** DEPFETs
- thinner detectors
- Smaller bias current - **less power** in pixel area
- Thinner gate isolator - **higher radiation** tolerance

Gated DEPFETs - precise timing

- allows replacement of external shutters → better timing properties
- Sensors for experiments requiring **selective sensitivity**, e.g. light curve measurements, LIDAR, AO etc.



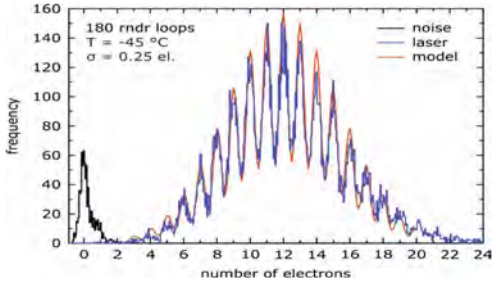


Combine different conceptual features

Create devices with multiple capabilities

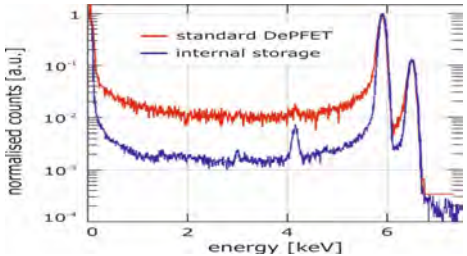
Repetitive readout – sub e$^-$ resolution RNDR DEPFETs

- an equivalent noise of 0.2 e- is achieved in ~6ms with 180 transfers
- **Extremely low noise** and background suppression
- Experiments w/ single electron sensitivity (e.g. low light level astronomy)
- Extremely low background applications (e.g. dark matter detection)



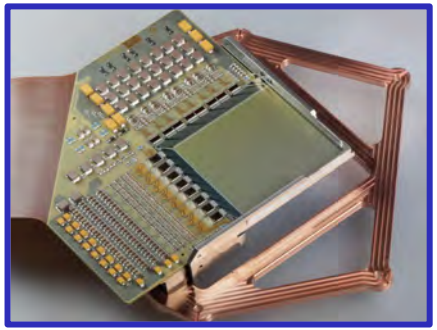
Multiple DEPFET structure – NO deadtime

- superpixel is composed of two or more standard or advanced DEPFET subpixels, which are alternately used for the detection of charge.
- one subpixel is read out, while the other one is collecting new charge

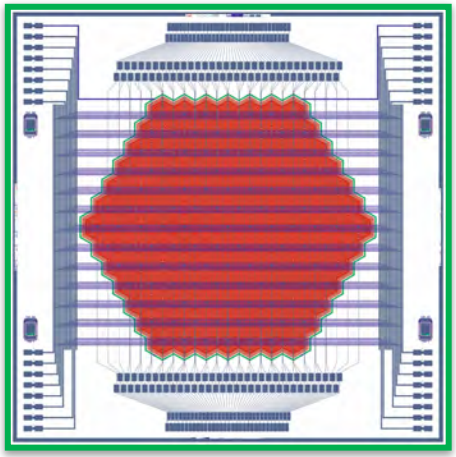


Interconnection technologies

Standard wire bonding (Al and Au)
Frame time: 1.28 msec,
i.e. 2.5 µsec / row

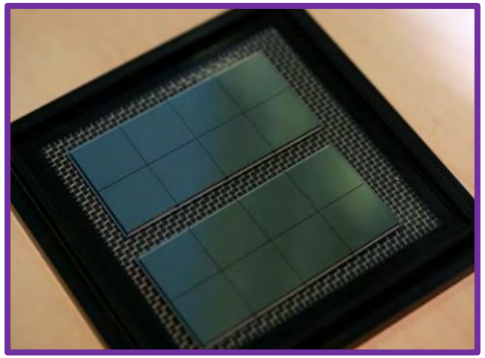


Athena WFI module
Courtesy MPE



Full parallel readout
dedicated wire routing
flip chip technology – hybrid detectors

DSSC module
With 8 CMOS chips
Frame rate: 4.5MHz



Full frame read-out DEPFET detector

application **ultra-fast X-ray timing & imaging**
frame rate **> 100 kHz**

sensor 127 hexagonal hexagonal pixels
cell diameter 800 µm

DePFET with internal storage

Interconnection technologies – All Silicon Module (ASM)

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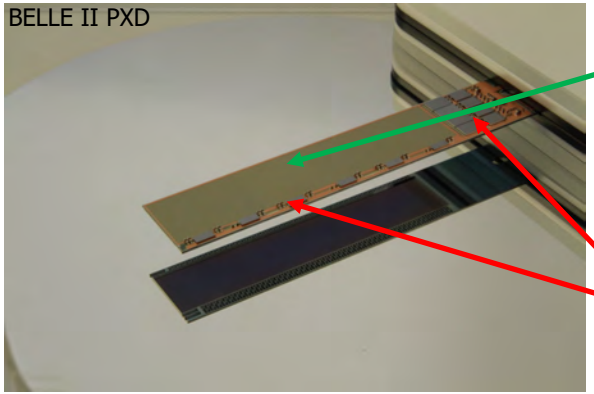
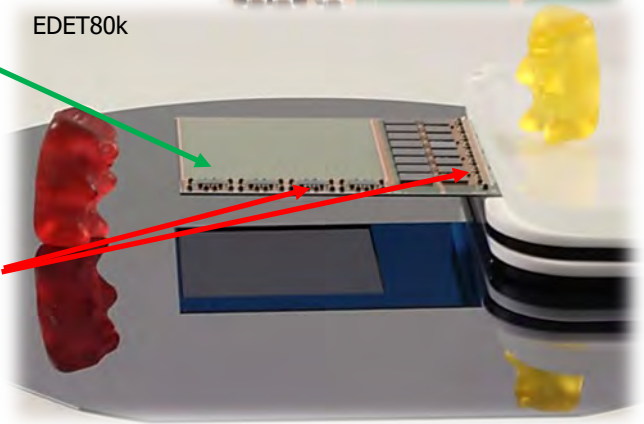
Sensor and Hybrid in one silicon piece

- Belle II Pixel detector – **tracking of high energy particles**
- EDET80k project – development of **ultra fast direct electron detectors for TEM**

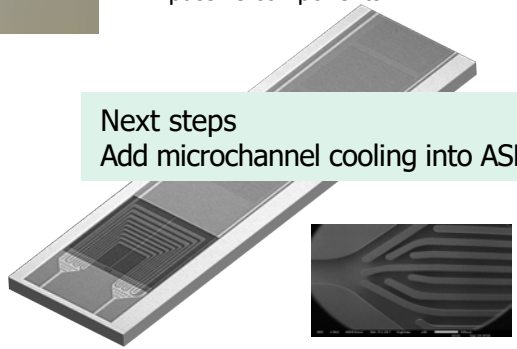


Thin sensitive area with DEPFETs

Thick silicon area for cooling and landing pads and interconnection for the read out and steering electronics and all passive components.

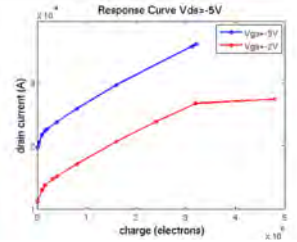


~50μm pixel size
8M pixel detector
50kHz frame time
75 μm thin detectors
Linear DEPFETs

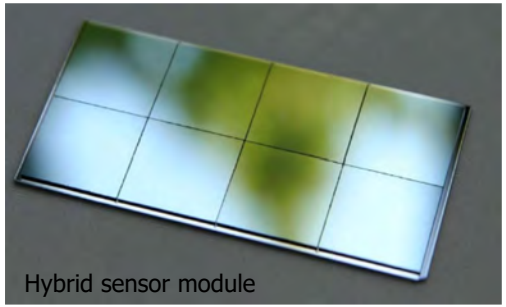


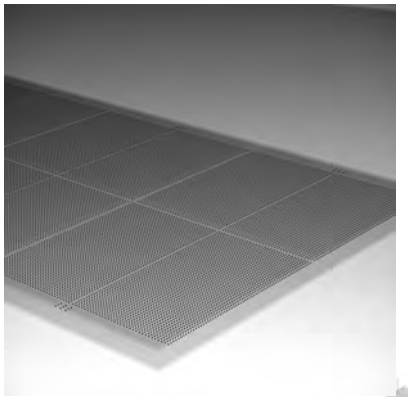
Next steps
Add microchannel cooling into ASM

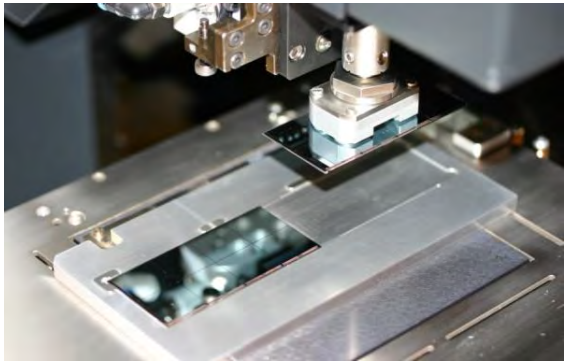
60μm pixel size
1M pixel camera
80kHz frame time
30 and 50 μm thin detectors
Nonlinear DEPFETs

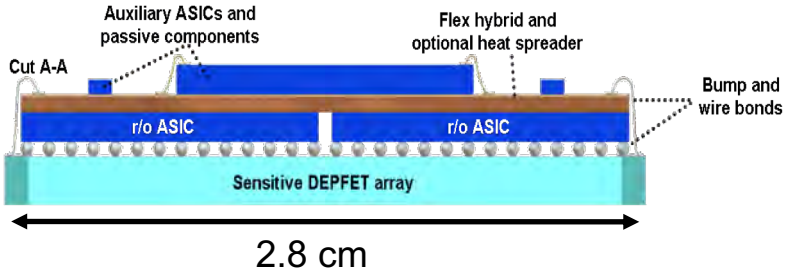


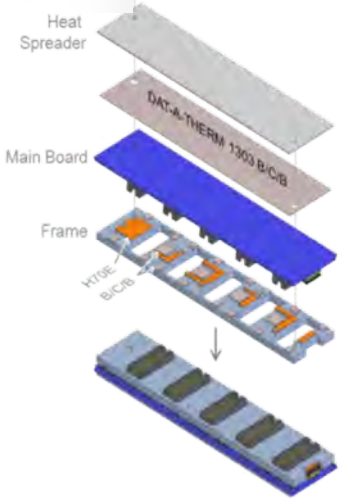
Macro/Micro assemblies

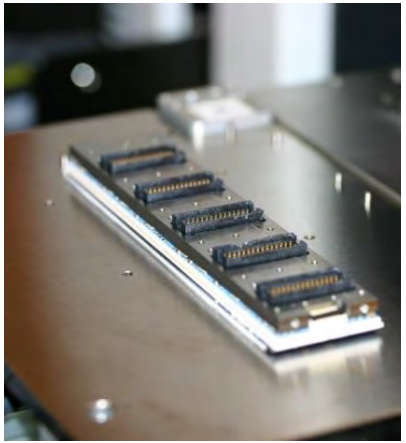




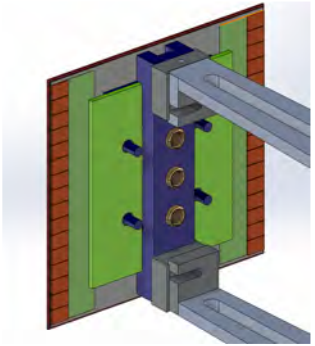


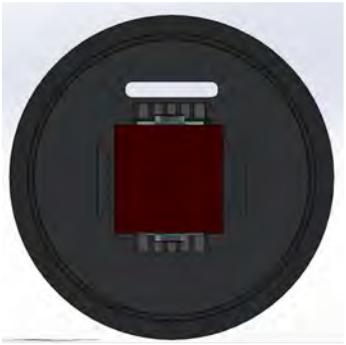


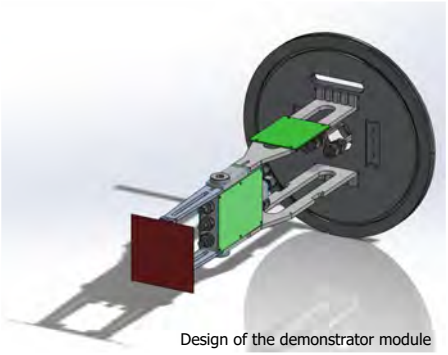




4 side buttable module development @ HLL







Design of the demonstrator module

TrueTile:

- **Novel concept** for sensor integration
- **Compact and modular** for high-density sensor integration
- **4-side buttable** devices - large sensor areas with extremely low sensitivity gaps
- Core element: **Active interposer** (AI) for frontend supply integration and cooling
- Multi-level development project

- Large area pnCCD as demonstrator device
  - 1 MPixel with 75 x 75 mm^2 pixels, 76.8 x 76.8 mm^2
- Active interposer with microchannel cooling structures
- Compact camera interior for standalone operation

See talk from S. Stadler

New MPG HLL building

MAX PLANCK SEMICONDUCTOR LABORATORY

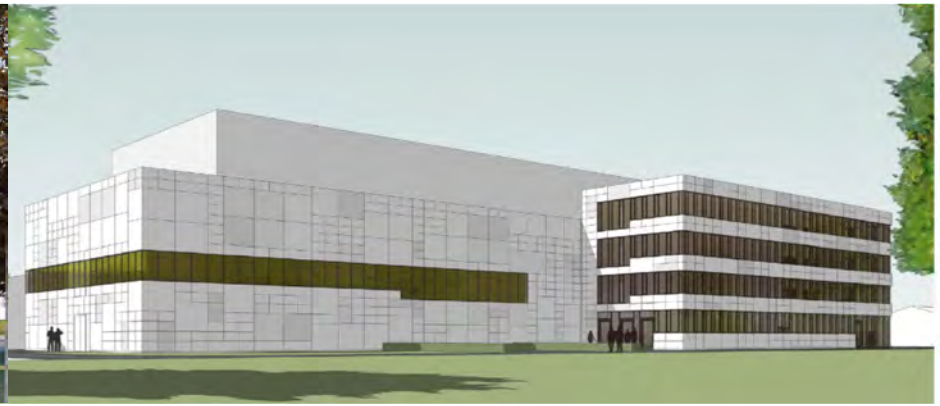
Building description

- New HLL building on research campus Garching

- Building divided into two parts:

  laboratory with technical areas & offices with meeting rooms

Front view



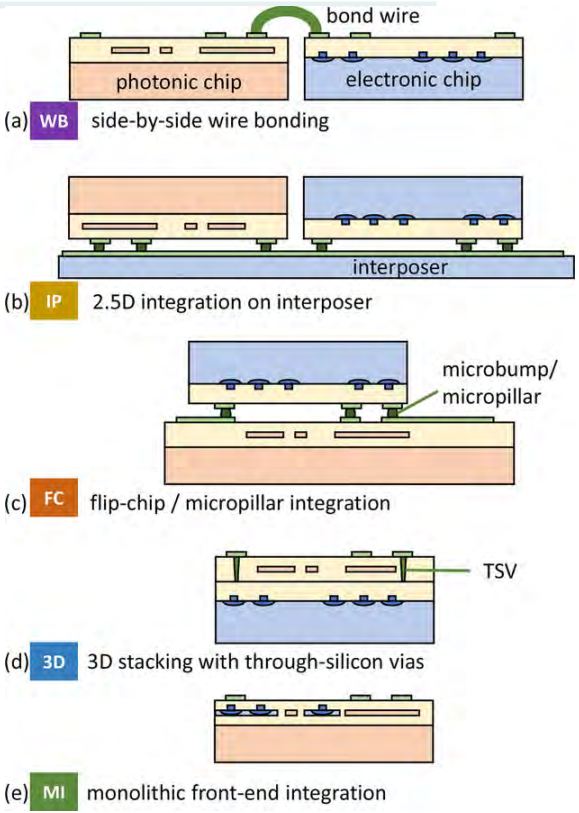
Rear view

Impressions from the site – Move in November 2023

Munich Quantum Valley : Integrated photonics @ MPG HLL

MAX PLANCK SEMICONDUCTOR LABORATORY

- Post processing of CMOS wafers
- Wafer-wafer and wafer-chip bonding
- Interconnection and assembly



See talk from L. Andricek

https://doi.org/10.1002/lpor.201700237

- Non sensor components

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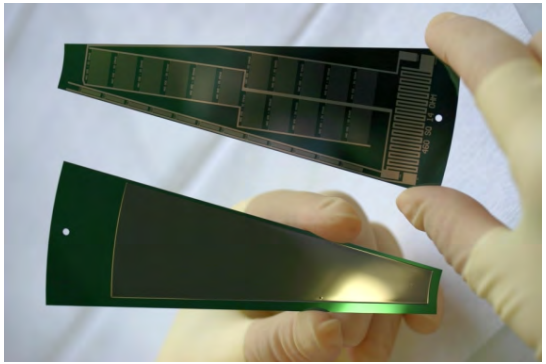
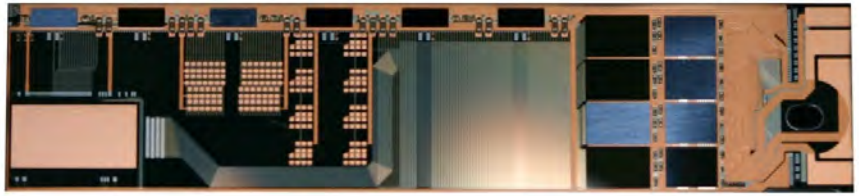
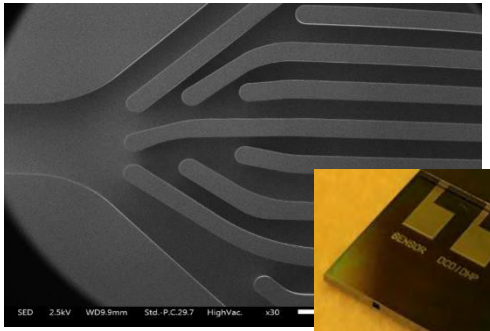
Thermo-mechanical modules

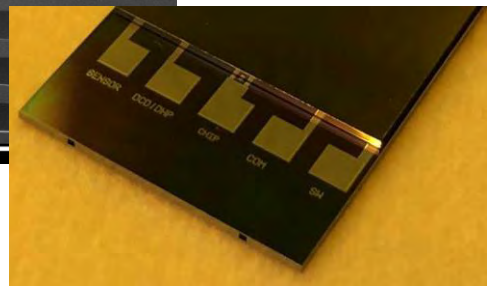


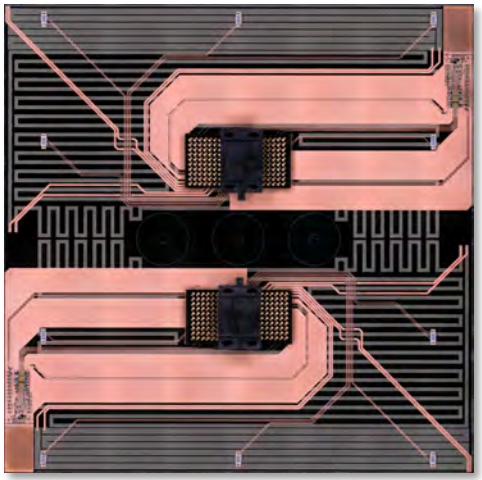
Electrical – Multi – Chip – Modules





Micro-channel-cooling





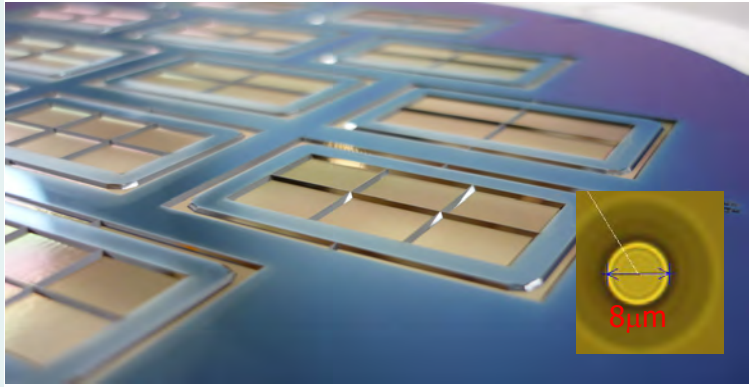
Active interposer:

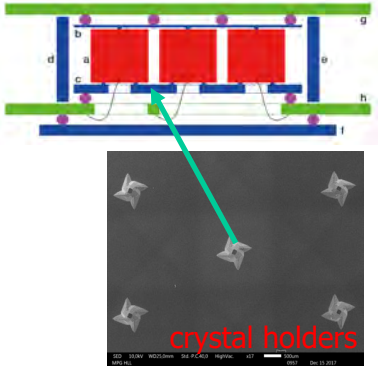
up to 3 metal layers
Micro channel cooling
TSV
UBM

Non sensor components

MAX PLANCK SEMICONDUCTOR LABORATORY

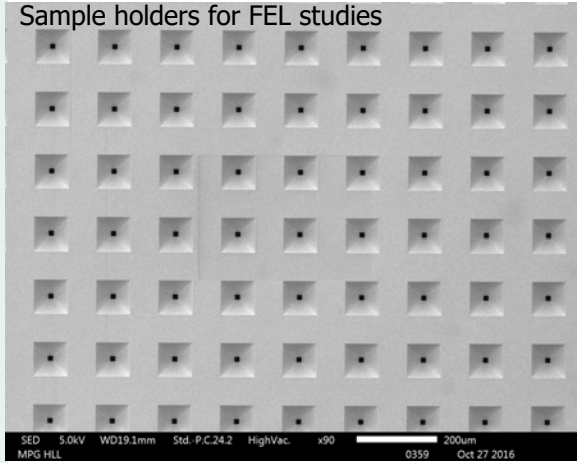
Perforated thin membranes as sample holders

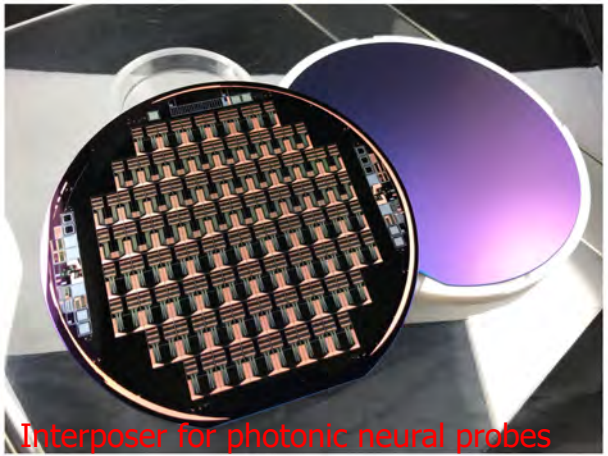


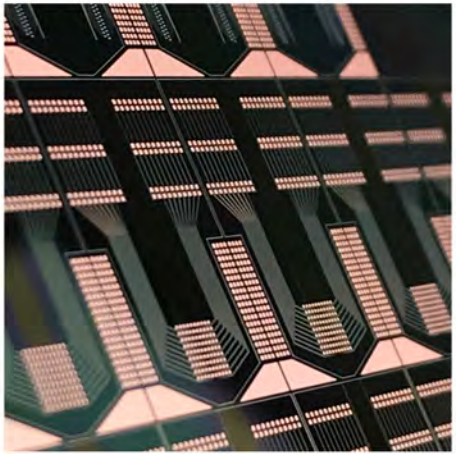


Metallization over extreme topography
"Molecular traps"

Sample holders for FEL studies







Thank you for your attention !

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