Precision radiation detectors for cutting edge research projects developed at the MPS Semiconductor Lab (MPG HLL)

Jelena Ninkovic for the MPG HLL team

- MPS Semiconductor Lab
- Devices & Selected Applications
Inside MPG HLL

assembly and test  flip chip  Cu line  complete 6” processing line

- flip chip
- Cu line
- assembly and test
- complete 6” processing line

- System test
- Chip storage & assembly
- cutting & wire bond
- Cu back-end & flip chip
- R&D lab
- Water probe stations Q/A

- LPCVD
- Oxidation
- Thermal processes
- Wet Chemistry I
- Wet Chemistry II
- Entrance
- Implanter
- Inspection
- Lithography
- ~ 112 m² System Test
- ~ 256 m² R&D/back-end/assembly
- ~ 309 m² Service area
- ~ 330 m² Main Clean Room
Devices @ MPG HLL

**Building blocks**

- **Diodes**
  - n+ ohmic bulk contact (0V)
  - p+ rectifying junction (-V)

- **Strip detectors**

- **MOSFETs**
  - OFF: V_gate ≥ 0 V
  - ON: V_gate = 0 V

- **JFETs**
  - p+ source
  - p+ drain
  - n+ gate
  - deep p channel

**Devices**

- Silicon drift detectors (SDD)
- pnCCDs
- DEPFETs
- SiMPI
Entrance window engineering – application optimization

- anti-reflective coating (ARC)
  - sequence of dielectric layers deposited on the entrance window
  - variation of material and thickness
  - transmittance tuning to application needs

- polymer passivation
  - mechanical protection
  - optical coupling
pnCCDs

- definition of potential pockets by differently reverse-biased diodes
- charge transport by periodic clocking of shift registers
- **column-parallel readout** → high frame rate (5 msec @ 200 pixel)
- integrated 1st FET (1 / column) → low noise (3el. ENC)
- backside illuminated, **fully depleted** → high quantum efficiency

- format  ~ cm²  ... wafer scale
- thickness  450 µm
- **pixel size  36 ... 150 µm**

Applications
- X-ray imaging & spectroscopy
- optical light imaging

- XMM Newton Mission (1999 - )
- EROSITA (2017 - )
- ATHENA (2028 - )
Small pixel pnCCDs @ HLL

Motivation: development of a sensor for Fast Solar polarimetry (collaboration partner MP Solar System Research)

Device characteristics:

- **pnCCD concept:**
  - Backside illuminated,
  - frame store,
  - split frame,
  - column-parallel readout
- **Format:** 1k x 1k storage, 2 x 1 k x 0.5 k framestore
- **Pixel size:** 36 x 36 µm²
- **Total sensitive area:** 36.8 x 73.3 mm²
- **Total chip size:** 4.2 x 8.1 cm²
- Optimized for **optical wavelength** using ARC
- **Operating temperature:** -35°C (target)
- **Target operating frame rate:** 400 Hz (~4 µs /row)
- **Data rate:** 840 Mbyte / s (16 bit)

Compact vacuum-tight camera housing ~ 18 x 25 x 10 cm³
FSP pnCCDs
DEPFETs

p-MOSFET on fully depleted n-substrate

- **fully depleted** sensitive volume
  - fast signal rise time (~ns), small cluster size
  - no stitching, 100% fill factor
- **Charge collection in "off" state**, read out on demand
  - potentially low power device
  - Non destructive readout
- **internal amplification**
  - charge-to-current conversion (300 pA/el.)
  - large signal, even for thin devices
  - r/o cap. independent of sensor thickness (20 fF)
- Usually read out in rolling shutter mode, but hybrid devices also available

**Applications:**
- unit cell of active pixel sensor
- integrated readout device of SDD, pnCCD, ...
DEPFET classes

**Thin & small pixel: vertex, low E electron detectors (TEM)**
- Pixel size: 20µm...75µm
- Read out time per row: 25ns-100ns
- Noise: ≈100 el ENC
- Thin detectors: 50µm...75µm → still large signal: 40nA/µm for MIP

**Low noise: Spectroscopic X-Ray imaging**
- Pixel size: 100µm, with drift rings several 100s of µm
- Read out time per row: few µs
- Noise: ≈4 el ENC
- Fully depleted, the thicker the better → large QE for higher E

**High Dynamic range**
- **DEPFET Sensor with Signal Compression**
- Sensitivity to single photons and high dynamic range
- Pixel size: 60 - 200 µm
DEPFETs for **Vertex detectors: BELLE II**

**Thin & small pixel: vertex, low E electron detectors (TEM)**

- pixel size: 20µm...75µm
- read out time per row: 25ns-100ns
- Noise: \(\approx100\) el ENC
- thin detectors: 50µm...75µm → still large signal: 40nA/µm for MIP

**Characterization of the first full-sized DEPFET PXD Module for the Belle II Pixel Detector**

8 Aug 2016, 18:30
Riverwalk A/B

**Poster by L. Andricek**

Low mass vertex detectors with at present highest possible integration!
**DEPFETs for Vertex detectors: BELLE II**

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**Characterization of the first full-sized DEPFET PXD Module for the Belle II Pixel Detector**

8 Aug 2016, 18:30
Riverwalk A/B

~ 0.1‰ masked pixels

outer backward module, 200k pixel, 7.7cm²
Future all silicon modules – going towards ILC

Integrated micro-channels

Forward tracking disks in ILD

Collaborative work with: University of Bonn and IFIC Valencia
DEPFETs for Spectroscopic X-Ray imaging

Low noise: Spectroscopic X-Ray imaging

- pixel size: 100µm, with drift rings several 100s of µm
- read out time per row: few µs
- Noise: ≈4 e ENC
- fully depleted, the thicker the better → large QE for higher E

MIXS – Ready for launch
First Imaging X-ray spectrometer for planetary X-ray fluorescence

- Format
  - 1.92 x 1.92 cm²
  - 64 x 64 pixels
  - 300 x 300 µm² pixel size

- Energy resolution
  - 200 eV FWHM @ 1 keV
  - QE > of 80 % @ 500 eV

- Time resolution
  - < 1 ms due to dynamics

- Radiation hardness
  - ~ 20 krad ionizing
  - 3 x 10¹⁰ 10 MeV p/cm²
  - equivalent to 1.11 x 10¹¹ 1 MeV n/cm²

next large X-ray observatory ATHENA
DEPFETs with high dynamic range

**High Dynamic range**

DEPFET Sensor with Signal Compression
Sensitivity to single photons and high dynamic range
pixel size: 60 - 200 µm

- The internal gate extends into the region below the source
- Small signals assemble below the channel, being fully effective in steering the transistor current
- Large signals spill over into the region below the source. They are less effective in steering the transistor current.
- 200 x 200 µm pixel has been designed and produced
- 60 x 60 µm pixel has been designed and is being produced now

DSSC - DEPFET Sensor with Signal Compression
DEPFETS with signal compression

DSSC for EuXFEL: hybrid detectors

<table>
<thead>
<tr>
<th></th>
<th>DSSC</th>
<th>Edet</th>
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<tr>
<td>size</td>
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<td>1MPixel</td>
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<tr>
<td>Pixel size</td>
<td>200 µm</td>
<td>60 µm</td>
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<tr>
<td>Thickness</td>
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<td>30 and 50 µm</td>
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<tr>
<td>Total area</td>
<td>21x21cm²</td>
<td>6x6 cm²</td>
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<tr>
<td>Frame rate</td>
<td>4.5MHz</td>
<td>80kHz</td>
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Summary

I showed:

- Some very attractive devices developed and produced at MPS Semiconductor Laboratory
- Some of the potentials of those devices are used in current projects
- Still space to explore much more …

Thank you for your attention!
Fully assembled MIXS module
X ray imaging using small pixel pnCCDs

Imaging of a collimated Fe$^{55}$ Source through a mask + goldwire

Mikroscope Image of mask and wire in front of the pnCCD.

Frame as obtained by integrating Photons per pixel

Frame as obtained by cluster reconstruction and integration per subpixel (32x32 subgrid)

Frame Integrated
Image Resolution for Cluster Imaging @ 5.9 keV

- Width of goldwire = 23.6 Micron
- Edge spread function = 1.5 Micron (1 sigma)