Characterization of CMOS Active Pixel Sensor featuring non-epitaxial substrate with different radioactive sources.

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Outline

• Description of RAPS/SHARPS INFN experiments: aimed at the exploitation of standard CMOS technology (0.18µm, twin-tub, 1P6M) to fabricate ionizing particle detector based on Monolithic Active Pixel Sensors.

• The Pixel architectures.

• Characterization with IR Laser, β and γ from $^{55}$Fe.

• Conclusions.
Technology options: 0.25μm vs. 0.18μm

∆VA swing greater than ∆VB!

∆VA 0.18μm swing greater than ∆VA 0.25μm!

The 0.18μm technology A has been selected! (non-epitaxial technology).
Pixel APS

Sensitivity time

Interval

RESET width

Area del fotodiodo

NMOS del reset

NMOS di selezione della riga

NMOS del source-follover

4.4 µm

MRST

MSEL

MSF

4.4 µm

4.4 µm

n-well

p-well

p-sub

PRD06 - Siena, October, 1-5 2006
**Signal Analysis: MIP (simulation)**

Pixel

Circuitry transfer function simulated within CADENCE environment (Spectre)

Column line

Output swing ≈ 800mV

Photodiode voltage drop estimated using 3D physical simulation (~ 80mV, depending on the impact point)

Programmable gain column amplificator

Photon-induced PhD voltage drop estimated using 3D physical simulation (80mV, depending on the impact point)

Output swing ≈ 800mV

**Graphs**

- Radiation-induced PhD voltage drop (V)
- Photodiode voltage drop (V)
- Output voltage (V)
- Photodiode voltage (V)

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Sensor layout (32 x 32 matrix)
Radiation Active Pixel Sensor (RAPS)

UMC 0.18\(\mu\)m MM 1P6M CMOS technology (twin-tub, no-epi)

- high-gain, in-pixel ampl.
- pMOS & nMOS;
- 10x10\(\mu\)m\(^2\) pixel size;
- self-reset operation (event-triggered).

- 3T architecture;
- pMOS & nMOS;
- 10x10\(\mu\)m\(^2\) pixel size;
- sparse read-out.

- 3T architecture;
- 4.4x4.4\(\mu\)m\(^2\) pixel size.
Optical workbench

- Mirror
- Lens
- Beam-splitter
- Objective
- IR laser ($\lambda = 1060$nm)
- DUT (RAPS02)
Laser spot size (1)

Single pixel output evaluation

Voltage [V]

X [µm]

4.4 µm

2.7 µm

~1.0 µm

0.06 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5

0 5 10 15 20 25 30 35
Laser spot size (2)

Two pixels output evaluation

Voltage [V] vs. X [µm]

- Laser spot Diameter ~3.5µm
- 4.4µm
- 2.7µm
- ~1.0µm

After deconvolution
Cluster response analysis (IR)

4.4µm
Linearity analysis (using IR Laser)

Good linearity
### Noise Analysis (No source)

#### Average

![Graphs of Noise Analysis](image)

- **Sample**: [Graph showing noise variations over time]
- **Average**: [Graph showing average noise levels]

#### Rumore [mV]

<table>
<thead>
<tr>
<th>Value (mV)</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1000</td>
</tr>
<tr>
<td>1</td>
<td>800</td>
</tr>
<tr>
<td>2</td>
<td>600</td>
</tr>
<tr>
<td>3</td>
<td>400</td>
</tr>
<tr>
<td>4</td>
<td>200</td>
</tr>
</tbody>
</table>

**Average**:
- μ = 0 µV ± 9.9 µV
- Deviazione: 0.699 mV ± 9.9 µV

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**Single pixel noise evaluation (kTC)**

**Transfer Function**

- **Output [V]**
  - **Output Noise**
    - SATURATION
    - HIGH-GAIN
    - LINEAR

**Noise**

- **SATURATION**
  - Value: -20 [µV ± 9.9 [µV]
  - Deviation: 0.699 [mV ± 9.9 [µV]

- **HIGH-GAIN**
  - Value: -0.36 [mV ± 0.62 [mV]
  - Deviation: 17.4 [mV ± 0.62 [mV]

- **LINEAR**
  - Noise: 0.96(±0.08) [mV]

**INFIN**
**Time response analysis (X-ray)**

![Graph showing time response analysis with time in nanoseconds (ns) on the x-axis and pixel voltage drop in volts (V) on the y-axis. The graph illustrates a single pixel output with a voltage drop of approximately 100 V in about 100 ns.](image-url)
**Signal Analysis**

For every pixel we define:

\[
\text{Signal}(i) = \text{V}_{\text{pixel}}(i) - \text{Ped}(i) \quad \text{(single pixel signal)} \quad \text{and:}
\]

\[
\text{S/N}(i) = \frac{\text{Signal}(i)}{\text{Noise}(i)} \quad \text{(single pixel signal normalized to pixel noise)}
\]

**Cluster Signal:**

Look at the 3x3 pixel matrix centered in the pixel with maximum voltage drop. If pixel > 2.5 the pixel noise add to total cluster signal.
Test with $^{55}$Fe X-ray source

Single pixel Signal

Single pixel Voltage Drop

Single Pixel noise

Pixels with effects from X-ray

$c^2 / ndf = 854.9 / 106$

Constant $= 6.501e+04 \pm 103$

Mean $= -0.002767 \pm 0.001916$

Sigma $= 1.496 \pm 0.001$
Test with $^{55}$Fe X-ray source

Cluster Signal

34 mV => 5.9 keV
Test with $^{55}\text{Fe}$ X-ray source

![Graph showing the distribution of S/N ratios with statistical parameters. The graph highlights the mean and sigma values with uncertainties.]
Test with $^{90}$Sr/$^{90}$Y $\beta^{-}$ source

Example of signal for $^{90}$Sr/$^{90}$Y($\beta$) source.

Single pixel Signal/Noise distribution. The gaussian fit should have \( \sigma = 1 \) in absence of any source.
Test with $^{90}\text{Sr}/^{90}\text{Y}$ $\beta^-$ source

Cluster Signal

$C^2 / \text{ndf} = 22.98 / 23$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>$74.29 \pm 10.20$</td>
</tr>
<tr>
<td>MPV</td>
<td>$20.96 \pm 0.31$</td>
</tr>
<tr>
<td>Sigma</td>
<td>$1.734 \pm 0.231$</td>
</tr>
</tbody>
</table>

Events with Non-MIP Energy release

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Test with $^{90}\text{Sr}/^{90}\text{Y}$ $\beta^-$ source

<table>
<thead>
<tr>
<th>$\chi^2 / \text{ndf}$</th>
<th>59.68 / 19</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>103.7 ± 12.6</td>
</tr>
<tr>
<td>MPV</td>
<td>11.97 ± 0.21</td>
</tr>
<tr>
<td>Sigma</td>
<td>1.066 ± 0.117</td>
</tr>
</tbody>
</table>

Cluster Signal/Noise

Events with Non-MIP Energy release
Test with $^{90}\text{Sr}/^{90}\text{Y}$ $\beta^-$ source

- A MIP ($\beta^-$ from $^{90}\text{Sr}/^{90}\text{Y}$) is clearly visible by our detector.

- A S/N of $\sim 12$ is feasible.

- Using the $^{55}\text{Fe}$ calibration, we can derive the number of electrons collected by our detector ($\sim 1000$).

- This implies an equivalent collection depth of 13-15 microns, in agreement with our simulations.
Conclusions

• The suitability of standard CMOS technology (0.18\(\mu\)m, twin-tub, no-epi) for Active Pixel Sensors fabrication for particle detection has been investigated through extensive experimental characterization.

• Different pixel layout and read-out schemes have been devised and implemented.

• ...as well as different test strategies and workbenches.

• Test results have shown satisfactory responses to \(\beta\), IR, and X-rays stimuli and promising performance in terms of S/N.

• Future works:
  - test beam analysis of the existing devices;
  - radiation hardness evaluation;
  - next run (still CMOS 0.18\(\mu\)m) foreseen this autumn.