The performance measurements of INTPIX6 SOI pixel detector


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Outline

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2. INTPIX6
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   - 241-Am measurements
   - Iron (55-Fe) measurements
     - Gain correction

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   - Irradiation effects - results
   - Pattern image after irradiation

4. Summary
Silicon-On-Insulator

SOI is CMOS technology, which implements an insulator layer between handle wafer and epitaxial layer.

FOR ELECTRONICS:
- reduction of parasitic capacitances → power saving, higher speed,
- reduction of leakage currents → power saving,
- elimination of latch-up effects,
- better resistivity for Single Event Upsets
- smaller area - no guard rings,

FOR SENSORS:
- Possibility of designing monolithic pixel detectors
- Pitch down to few $\mu m$
- Small sensor capacitance (good SNR)
- Double SOI → may improve radiation hardness
- Wide temperature range (4 – 400K)
- Cheaper then hybrid
INTPIX6 - detector overview

INTPIX6

Large format integrating type sensor designed in 200nm Lapis SOI by group from KEK.

- Available on various wafers (CZ(n), FZ(n), FZ(p))
- Architecture based on source-follower
- 1408×896 pixel matrix, 12 × 12 \( \mu m^2 \) pixel size
- 11 parallel analog outputs
- Rolling shutter readout mode
241-Am measurements for CZ(n) sensor
241-Am measurements - CZ(n) sensor

Pixel noise: $\text{ENC} = 70.2 \, \text{e}^-$

- measurements in room temperature
- mainly 1-2 hit clusters
- linear up to 60 keV
55-Fe measurements for FZ(n) sensor
Gain variations - FZ(n)

- Probably there is some leakage: the longer we wait to read the pixel, the lower pedestal is observed.
- Affects not only pedestal but also gain.
Gain correction

- Having gain for 10×10 pixel blocks we estimate gain correction factor for the whole matrix.
- After including the correction factor the spread of peak position was eliminated.
Iron spectrum - results

**BEFORE CORRECTION**

1hit cluster energy

<table>
<thead>
<tr>
<th>hClusterEnergy[1]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entries</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Std Dev</td>
</tr>
<tr>
<td>Underflow</td>
</tr>
<tr>
<td>Overflow</td>
</tr>
<tr>
<td>$\chi^2 / \text{ndf}$</td>
</tr>
<tr>
<td>Constant</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Sigma</td>
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</tbody>
</table>

**AFTER CORRECTION**

1hit corrected cluster energy

<table>
<thead>
<tr>
<th>hCorrClusterEnergy[1]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entries</td>
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</tbody>
</table>

$\sigma_{bc} = 2.44$ [ADC]

$\sigma_{ac} = 2.27$ [ADC]

The noise ENC:

- from pixel fluctuations: $\approx 70 \text{ e}^-$
- from peak width: $\approx 100 \text{ e}^-$
radiation hardness
Pedestal after irradiation

High dose is obtained irradiating the chip with high intensity (425 MBq) 55-Fe Xray source.

- The plots show pedestal after irradiation at 60 krad dose.
- The visible pattern is due to the X-ray source size.
Dose in SiO$_2$ recalculation

From the data analysis we know the number of hits in detector. From this value the BOX-dose can be calculated.

\[
\Delta l_n = l_{n+1}(e^{x_{BOX}} - 1)
\]

\[
\Delta l_n = 7 \frac{\text{particles}}{\mu s} \cdot (e^{0.2\mu m} - 1)
\]

\[
\Delta l_n = 0.14 \frac{\text{particles}}{\mu s}
\]

Mass and dose recalculation:

\[
D = \frac{\Delta l \cdot E_\gamma \cdot t}{m}
\]

\[
m = 2830\mu m \cdot 2830\mu m \cdot 0.2\mu m \cdot \rho = 3.7 \text{ nkg}
\]

\[
D = 60 \text{ krad (24 h)}
\]

Final dose

The dose after 24h is:

\[
D = 60 \text{ krad}
\]
Data analysis from irradiated detector

- Up to $\sim30$ krad detector works properly
- Above $\sim30$ krad the efficiency drops but energy resolution remains on the same level
Data analysis from irradiated detector

- The pixel RMS spectrum after irradiation changes because more pixels pass the criteria for bad pixel.
- Up to $\sim 30$ krad number of bad pixels below 1%
- Above $\sim 30$ krad number of bad pixels (highly fluctuating) is rapidly increasing.
Iron spectrum during irradiation

- **0-24 krad**
  - Entries vs. Energy (ADC) graph showing the distribution of energy for different cluster sizes.
- **24-36 krad**
  - Similar graph as 0-24 krad.
- **36-48 krad**
  - Similar graph as 0-24 krad.
- **48-60 krad**
  - Similar graph as 0-24 krad.

These graphs illustrate the spectral distribution of energy for different irradiation levels, highlighting changes in cluster sizes and their contributions to overall energy distribution.
Patterns

- defocused laser 1060 nm
- average of 100 frames
- pattern visible even after 60 krad irradiation on CZ(n)
Summary

- Large (1408×896) INTPIX6 SOI detector with very small (12×12μm²) integrating type pixels is fully functional.
- ENC of about 70 electrons (100e⁻ from FWHM) is obtained at room temperature.
- The detector is operating up to at least 60 krad dose.
- Good S/N ratio is maintained up to 30 krad.
- For higher doses S/N decreases and number of bad pixels increases rapidly, however the imaged pattern is seen well.

- **With recent modification in SOI transistor LDD dose and introduction of double SOI wafer, radiation tolerance more than 10 Mrad is foreseen now.**