Sensor production readiness

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for the USCMS FPIX group

PMG review 02/25/2005
**Outline**

- **Sensor requirements**
  - Geometry
  - Radiation hardness

- **Development**
  - Guard Rings
  - P-stops

- **The final design (performance)**
  - Laser measurements (CCE)
  - FNAL test beam results
  - CERN test beam results

- **Conclusions**
Pitches are set by the ROC design
- 150 μm x 100 μm pitch
- 100-200 x 100 bonding pitch

Dimensions are set by the blade design
- 7 different sensors are needed for a blade
  - 5 different geometries

<table>
<thead>
<tr>
<th>Sensor geometry</th>
<th>Active area X [μm]</th>
<th>Active area Y [μm]</th>
<th>Edge to Edge X [μm]</th>
<th>Edge to Edge Y [μm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2x1</td>
<td>16200</td>
<td>8100</td>
<td>18594</td>
<td>10494</td>
</tr>
<tr>
<td>3x2</td>
<td>24300</td>
<td>16200</td>
<td>26694</td>
<td>18594</td>
</tr>
<tr>
<td>4x2</td>
<td>32400</td>
<td>16200</td>
<td>34794</td>
<td>18594</td>
</tr>
<tr>
<td>5x2</td>
<td>40500</td>
<td>8100</td>
<td>42894</td>
<td>18594</td>
</tr>
<tr>
<td>5x1</td>
<td>40500</td>
<td>16200</td>
<td>42894</td>
<td>10494</td>
</tr>
</tbody>
</table>
Sensor requirements

Radiation hardness

All components of the pixel detector are specified to remain operational up to a particle fluence of at least $6 \times 10^{14}$ mip/cm$^2$.

- $n^+$-on-$n$ sensor for potential partially depleted operation post bulk-inversion
  - Double sided process with 10 masks (5 per side)
- Foreseen HV operations above 300 V
  - Need for multi-guard-rings at the sensor periphery
Finalized in 1999 with the engineering run
- PSI-JHU-PURDUE-BTeV
- Two vendors
  - Sintef
  - CSEM (later Colibris later out of business)
- $V_{dep} \sim 180\text{-}200$ V

10+1 Guard-rings add $\sim 1.2$ mm on each edge of the sensor
- Holds $>1000$V before irradiation
- Holds $>800$V after $6 \times 10^{14}$

P-stops edges are the points with high electric field

- Shapes and distances strongly affects the maximum HV reachable

2001: submission with Sintef with

- Only 2 design left for large sensors
  - PSI30 Honeywell (irradiated and bumped at PSI)
  - PSI43 DMILL (bumped at MCNC and IZM)
  - PSI46 $\frac{1}{4}$ μm (bumped at IZM and VTT)

- Assembly experience
- CCE measurements
- Test beam
1064 nm laser (goes through more than 300 μm of Si)
Beam size ~10 μm
Scans in ≥2 μm steps
Technique allows:
- One to one comparison on the CCE performance of the 2 design (F and FM).
- Dependence on Vbias

Implanted n+ pixel (also metalized)
- ~98 μm square
P-stops ring 8 μm wide with 12 μm gaps
Metal grid on the p-side
Contact between the Al and the n+ implanted pixel
F vs FM

direct comparison

F design at 320 V
FM design at 320 V

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The decision to move to a higher resistivity (90-100 V depletion on diodes versus the 180-200 V of the 2001 submission) allows for more over depletion to be applied and so better CCE (lower inefficiencies) in the corner regions.
Can we squeeze it even more?

**Graph:**
- X-axis: Voltage Breakdown
- Y-axis: Number of Sensors
- Data points:
  - 2x1T
  - 3x1B
  - 4x2T
  - 5x2T
  - 6x2T
  - 5x2

**Images:**
- FM
- FMM

**Note:**
- Sintef 2004 Wafer 22 N-Side

**Date:**
- 2/23/2005

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FNAL Test beam

strip pixel strip

120Gev Proton
• beam: 120GeV Proton,
  6-12 spills/min, few 1000 trgs/spill, 300 events/spill,
• 4 strip planes (upstream) + pixel + 4 strip planes (downstream)
• Operation temperature: -20.4°C
Beam telescope
- 8 strip planes (4X + 4Y)
- 1 plane = 2 ROC’s = 2 x 128 ch
- Strips pitch: 50um

- Single cluster is used for tracking
- Alignment variables: theta, offset
- track_residual < 3um
Months of data taking with the DMILL PSI43
- Unstable performance
12/20/04 switched to ¼ μm PSI46v1
- Reliable operation and robust efficiency measurements
- No charge information: a binary chip

Pixel detector
- Sensor design: FM
- 4160 pixels/ROC
- Chip: PSI46v1, 1x2 chip
  → 1 chip has 52 columns and 80 rows
  → 8.1 mm x 8.1 mm
  → No charge information
- Pixel size: 150um(col) x 100um(row)
<table>
<thead>
<tr>
<th>run</th>
<th>Bias Volt.</th>
<th>Data Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>2635*</td>
<td>-350</td>
<td>250k</td>
</tr>
<tr>
<td>2643</td>
<td>-250</td>
<td>250k</td>
</tr>
<tr>
<td>2644</td>
<td>-400</td>
<td>250k</td>
</tr>
<tr>
<td>2645</td>
<td>-300</td>
<td>250k</td>
</tr>
<tr>
<td>2646</td>
<td>-200</td>
<td>250k</td>
</tr>
<tr>
<td>2648</td>
<td>-250</td>
<td>250k</td>
</tr>
<tr>
<td>2649*</td>
<td>-350</td>
<td>250k</td>
</tr>
<tr>
<td>2650*</td>
<td>-350</td>
<td>250k</td>
</tr>
<tr>
<td>2653*</td>
<td>-350</td>
<td>250k</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>run</th>
<th>Bias Volt.</th>
<th>Data Size</th>
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</thead>
<tbody>
<tr>
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<td>-350</td>
<td>250k</td>
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<tr>
<td>2665</td>
<td>-300</td>
<td>250k</td>
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<tr>
<td>2666</td>
<td>-250</td>
<td>250k</td>
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<tr>
<td>2667</td>
<td>-200</td>
<td>250k</td>
</tr>
<tr>
<td>2668</td>
<td>-400</td>
<td>250k</td>
</tr>
<tr>
<td>2669</td>
<td>-350</td>
<td>250k</td>
</tr>
</tbody>
</table>

Runs with the * have been combined to get a high statistic sample.
### Cuts

Number listed here for the 1M evts (4 runs combined)

<table>
<thead>
<tr>
<th>Cut</th>
<th>Number of events</th>
<th>System/Sensor efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>~ 1M</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single track from the telescope</td>
<td>699299</td>
<td>30% have multiple tracks</td>
</tr>
<tr>
<td>Track quality</td>
<td>483700</td>
<td>15% with single tracks have poor track resolution</td>
</tr>
<tr>
<td>Pointing to the pixel array</td>
<td>309534</td>
<td>18% are pointing outside of the pixel array</td>
</tr>
<tr>
<td>BAD TBM trailer</td>
<td>306263</td>
<td>A small percentage have DAQ troubles</td>
</tr>
<tr>
<td>Find pixel hits</td>
<td>304990</td>
<td>99.6 ± 0.3 %</td>
</tr>
<tr>
<td>Trk-pixel residual</td>
<td>304022</td>
<td>99.3 ± 0.3 %</td>
</tr>
</tbody>
</table>
No tilt Efficiency: \(99.3 \pm 0.3\%\)

- Inefficiency is dominant at the corner of 4 pixels
- Consistent with the laser results
## Rotation: 0° vs 20°

<table>
<thead>
<tr>
<th>Bias Voltage</th>
<th># of Events</th>
<th>Good trk</th>
<th>Good hits</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>-200</td>
<td>250k</td>
<td>70348</td>
<td>68002</td>
<td>96.7 %</td>
</tr>
<tr>
<td></td>
<td>250k</td>
<td>74938</td>
<td>73005</td>
<td>97.4 %</td>
</tr>
<tr>
<td>-250</td>
<td>250k</td>
<td>76221</td>
<td>75553</td>
<td>99.1 %</td>
</tr>
<tr>
<td></td>
<td>250k</td>
<td>75618</td>
<td>75013</td>
<td>99.2 %</td>
</tr>
<tr>
<td>-300</td>
<td>250k</td>
<td>70868</td>
<td>70394</td>
<td>99.3 %</td>
</tr>
<tr>
<td></td>
<td>250k</td>
<td>71511</td>
<td>71046</td>
<td>99.3 %</td>
</tr>
<tr>
<td>-350</td>
<td>1M</td>
<td>306268</td>
<td>304022</td>
<td>99.3 %</td>
</tr>
<tr>
<td></td>
<td>250k</td>
<td>76304</td>
<td>75820</td>
<td>99.4 %</td>
</tr>
<tr>
<td>-400</td>
<td>250k</td>
<td>70370</td>
<td>69185</td>
<td>99.5 %</td>
</tr>
<tr>
<td></td>
<td>250k</td>
<td>73734</td>
<td>73310</td>
<td>99.4 %</td>
</tr>
</tbody>
</table>
Post irradiation: CERN

- CERN test beam data from fall 2004
- Different ROC
  - PSI30 (Honeywell from late 90s)
    - Different pitch 125μm x 125 μm
    - Analog charge available
    - Threshold-less
- Pre-bump irradiation at CERN (6 \(10^{14}\))
- Bumped at PSI (indium)
  - Single die metallurgy
  - Many un-bonded pixels
- Post irradiation efficiency measurements
Illumination

Data set

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Bias Volt.</th>
<th>Dose</th>
<th># of events</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>-300</td>
<td>Unirradiated</td>
<td>1424700</td>
</tr>
<tr>
<td>FM</td>
<td>-450</td>
<td>$6 \times 10^{14}$</td>
<td>1400000</td>
</tr>
<tr>
<td>FM</td>
<td>-600</td>
<td>$6 \times 10^{14}$</td>
<td>1040000</td>
</tr>
</tbody>
</table>

No un-irradiated FM design to be compared with the results from FNAL
Efficiency measurements

![Graph showing efficiency measurements](image)

- Efficiency measurements at 3000 e⁻, with 97% efficiency.

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Other results

- Signal to noise ratio of \( \sim 44 \) post \( 6 \times 10^{14} \) irradiation (\( \sim 45 \) for the p-spray as a comparison)
- No evidences of micro-discharges up to 600 V on irradiated device
  - True also around un-bonded pixels

![Graph showing signal-to-noise ratio and threshold curves]

4 Corners
4 Sides
Conclusions

- Sensors for the CMS FPIX project have been developed.
- The geometry is driven by the other components of the system.
- High voltage operation are guaranteed according to the TDR specification.
- The particle detection efficiency is >99% before any irradiation and after $6 \times 10^{14}$ is still above 97%.
- The designed sensors are fully compatible with the goals of the project.
- Daniela will present the results from the preproduction run.