Silicon sensor development for the High Granularity Calorimeter of the CMS experiment at CERN via Process Quality Control

Maximilian Babeluk

ÖPG & SPS Joint Annual Meeting 2021

September 02, 2021
Endcap calorimeter highly irradiated
→ High radiation tolerance required

Up to 200 pile-up events per bunch crossing at target luminosity
→ High spatial resolution required

- New endcap calorimeter design: **High Granularity Calorimeter**
- Silicon detectors together with "conventional" scintillators
- Si sensors radiation harder and provide higher resolution
- Allows particle flow analysis

Silicon sensor development for HGCal
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HGCal Design

- Hexagonal shape ➞ tiling
- Total Si sensor area: \( \approx 500 \text{ m}^2 \)
on \( \approx 26000 \) wafers
- Three different thicknesses of sensors:
  - 120 \( \mu \text{m} \) / 432 pads each
  - 200 \( \mu \text{m} \) / 192 pads each
  - 300 \( \mu \text{m} \) / 192 pads each
- Pad sizes: 0.52 and 1.18 cm\(^2\)
HGCal Silicon Modules

- Hexagonal modules with one sensor each
- Wire-bonds from silicon to PCB
- DC coupled readout
- Readout electronics on PCB

- new 8 inch production process
  ➔ extensive prototyping necessary
Why Test-structures?

- Hexagonal (or rectangular) sensor cut out from round wafer
  → Maximises usable area
  → Still a tilable shape
- Test-structures on the cutoffs
- Electronic characterisation of production parameters via test-structures
- More information than from direct sensor measurements
What is PQC?

- Process Quality Control
- Dedicated test-structures + measurement setup
- Defined contact layout
- High throughput characterisation
- High degree of automation
- Non-destructive
- All important semiconductor parameters covered

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PQC Setup in Vienna

- Custom python software to control measurement flow
- Instruments connected software controlled

Silicon sensor development for HGCal

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What can PQC do?

PQC
High throughput characterisation

Production:
- Currently in use for the tracker
- Monitor production
- Spot deviations from specs
- Ability to test more wafers compared to other QA processes
- Procedure used and verified by 4 institutes

Prototyping:
- Currently used for HGCal
- Access to many parameters
- Spot differences of process splits
- Practical for large surveys
- Comparison with tracker possible

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Example: MOS Capacitor

- Measurement of oxide properties:
- Oxide thickness
- Flatband voltage ➔ Bound ox. charge
- Important for pad-separation
<table>
<thead>
<tr>
<th>No.</th>
<th>Diode</th>
<th>Metal VdP</th>
<th>p-edge</th>
<th>Bulk VdP</th>
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<td>i600</td>
<td>v_fd</td>
<td>rho</td>
<td>d_conc</td>
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<td></td>
<td>uA</td>
<td>V</td>
<td>kOhm/cm</td>
<td>1E12cm^-3</td>
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<td>HPK_VPX36239_002_2-S_HM_EL</td>
<td>80.6</td>
<td>295.3</td>
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PQC-tables for one Batch

Diode
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<th>i600</th>
<th>v_fd</th>
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<th>d_conc</th>
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<th>vdp_metal</th>
<th>vdp_metal</th>
<th>vdp_cb</th>
<th>vdp_cb_r</th>
<th>t_line_cb</th>
<th>vdpBulk</th>
<th>vdpBulk_r</th>
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<td>mOhm/sq</td>
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<th>vdpPoly_r</th>
<th>vdpN</th>
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<th>vdpPst</th>
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<td>kOhm/sq</td>
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<td>kOhm/sq</td>
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MOS Quarter
| i_surf | s0 | me-and_poly | lw_n | lw_pstp4 | lw_pstp2 | v_bd | pA | cm/s | MOhm | um | um | V |
|--------|----|-------------|------|---------|---------|------|----|------|------|-----|----|----|---|
| HPK_VPX36239_002_2-S_HM_EL | 80.6 | 295.3 | 2.81 | 4.95 | 233.7 | 19.0 | 18.6 | 1.17 | 1.17 | 32.0 | 57.7 | 57.7 | 2.76 |
| HPK_VPX36239_002_2-S_HM_ER | 89.0 | 298.8 | 3.19 | 4.36 | 233.4 | 18.9 | 18.6 | 1.17 | 1.17 | 33.1 | 58.1 | 57.6 | 2.77 |
| HPK_VPX36239_002_2-S_HM_WL | 99.8 | 299.3 | 2.86 | 4.86 | 240.4 | 19.3 | 19.0 | 1.16 | 1.16 | 33.3 | 57.3 | 57.5 | 2.75 |

Contact Chain
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<th>s0</th>
<th>gdc05</th>
<th>r_cont_p</th>
<th>r_cont_n</th>
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Median
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<td>Std dev.</td>
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<tr>
<td>OK/Tot.</td>
</tr>
<tr>
<td>OK (rel)</td>
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Silicon sensor development for HGCal
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HGCal

- Unprecedented large scale use of silicon detectors in a calorimeter
- Newly developed 8 inch production process
- Last prototype run in September 2021 (if everything goes well)
- Particle flow analysis possible

PQC

- Valuable tool for wide range surveys
- Cross validated by 4 institutes
- Used for production monitoring in the Tracker
- Currently used for prototyping for HGCal, will be used in production phase too
Thank You!