Development of a characterization set-up for testing position sensitive silicon micro-strip sensors at the University of Delhi

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Outline

- Motivation & Introduction
- Sensor qualification center for outer tracker upgrade
  - Quality Assurance Scheme
  - Preliminary specifications
  - Measurements performed using the Qualification System
- Sensor qualification facility at DU
  - Electrical Instruments and Probe Station
  - Master Connection Diagram
- Silicon strip sensor
- Measurements results
- Summary and Future outlook
Motivation and Introduction

Predictions of the maximum 1MeV $n_{eq}$ fluences normalized to 3000fb$^{-1}$ of HL-LHC

Expected particle fluence in the **Tracker volume**

LHC Runs 1, 2

- Peak $L \sim 1.5 \times 10^{34}$ cm$^{-2}$s$^{-1}$
- Expected Integrated $L = 500$ fb$^{-1}$ (10 yrs of operation)

HL-LHC Phase

- Peak $L \sim 5-7 \times 10^{34}$ cm$^{-2}$s$^{-1}$
- Integrated $L = 3000$ fb$^{-1}$ (10 yrs of operation)

Need to upgrade the outer tracker by using more radiation hard silicon sensors !!

Expected particle fluence in **End cap calorimeter**

<table>
<thead>
<tr>
<th>Region</th>
<th>Maximum Fluence (1 MeV $n_{eq}$ cm$^{-2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer tracker</td>
<td>$1.1 \times 10^{15}$</td>
</tr>
<tr>
<td>Endcap Calorimeter</td>
<td>$1.5 \times 10^{16}$</td>
</tr>
</tbody>
</table>
Upgrade of tracker and endcap calorimeter of CMS experiment

Present

| η | < 2.7 |
| η | < 4.0 |

Phase 2 Upgrade

| p-on-n | n-on-p |
| 3 Discs of Pixel | 10 Discs of Pixel |
| ~124 millions pixels | ~218 millions pixels |
| ~10 millions Strip detectors | ~50 millions strip detectors |
| Active area ~200 m² Pixels : 2 m² Strips : 198 m² | Active area ~215 m² Pixels : 4 m² 2S & PS modules : 150+60 m² |

These sensors have to be extensively tested, prior to their installation, under the controlled environment of SQC.
Sensor Qualification Center
Quality Assurance Scheme for OT strip sensors

Sensor Fabrication Center

100%

CERN - Distribution Center

100%

SQC 1

5%

SQC 2

5%

SQC 3

5%

SQC 4

5%

SQC 5

5%

Sensor Production Committee

Results Reported

Process Quality Control (PQC) + Irradiation Test Center (IT)

Accepted %

Module Assembly Center

100% of the accepted sensors are bonded
Preliminary Specifications*

• Environmental conditions
  ➢ Have to be monitored during measurements and should be within the following range:
    ▪ Temperature: 22±2°C
    ▪ Humidity: < 40% rH

• Global measurements on sensors
  ➢ Extracted from I-V and C-V curves on the full sensor (bias voltage between bias ring and backplane) from 0 V – 700 V
    ▪ Full depletion voltage Vfd: < 150 V for 200 μm (LCR settings: < 1 V and 1 kHz)
      < 300 V for 300 μm
    ▪ Current @500V I_{500}: ≤ 2 nA/mm³ (< 5 μA for 100 x 100 x 0.2 mm)
    ▪ Breakdown voltage Vbreak: > 700 V (un-irradiated), I_{700} < 3 x I_{500}
      > 1000 V (for F ≥ 5e14neq/cm²), I_{1000} < 4 x I_{700}
    ▪ Long-term stability: |ΔI_{500}/I_{500}|< 48% in 48 h @ 500 V bias

• Measurements on each strip
  ➢ Measurements to be performed on each strip of a sensor at Vbias=300 V
    ▪ Strip current I_{strip}: < 2 nA/cm
    ▪ Bias resistor R_{poly}: mean(R_{poly}): 1.5 ± 0.3 MΩ RMS(R_{poly}) : 5%
    ▪ Coupling capacitance C_{ac}: > 1.2 pF/cm μm
    ▪ Inter-strip resistance R_{int}: > 10 GΩ cm
    ▪ Inter-strip capacitance C_{int}: < 1 pF/cm
    ▪ Pinhole check: Idiel < 1 nA@10 V

• Bad Strips : Max. Number of bad strips: < 0.5 % per sensor (10/2032) Strips are considered as bad strips if any of the criteria from Measurements on each strip are not fulfilled for the respective strip.

*These specs are getting evolved : CMS Technical Design Report
To ensure the performance and quality of each detector certain tests have to be performed on few samples on each batch.

**Electrical Characterizations tests**

1. **IV**  
   Sensor current vs Bias
2. **CV**  
   Sensor capacitance vs Bias
3. **I_{leak}**  
   Strip leakage current
4. **R_{bias}**  
   Strip bias resistor
5. **C_{Coup}**  
   Coupling capacitance
6. **I_{dieel}**  
   Dielectric current
7. **R_{int}**  
   Interstrip resistance
8. **C_{int}**  
   Interstrip capacitance
Sensor Qualification Facility at DU
Basic Requirements for SQC (1/2)

<table>
<thead>
<tr>
<th></th>
<th>Clean Room</th>
<th>Source Measuring Units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Class 10,000, Area ~40 m²</td>
<td>K2657A (single channel)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Voltage range: 5 mV to 3 kV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Current range: 30 fA to 120 mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>K2636B (Dual channel)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Voltage range: 5 μV to 200 V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Current range: 20 fA to 10 A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>E4980A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Capacitance: 1e-18 to 1e18 F</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AC Voltage: 100 μVrms to 2 Vrms</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frequency range: 20 Hz to 2 MHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DC Voltage: 330 μV to 40 V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Isolation Box</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Customized from CERN</td>
</tr>
</tbody>
</table>
## Basic Requirements for SQC (2/2)

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light-tight humidity controlled chamber</td>
<td>MPI TS2000 DP</td>
</tr>
<tr>
<td>Chuck (200 mm)</td>
<td>Provision of Vacuum holes, temperature range: 13-200 °C</td>
</tr>
<tr>
<td></td>
<td>XY stage: 210 X 340 mm (2 μm step)</td>
</tr>
<tr>
<td></td>
<td>Z translation: 10 mm (1 μm step)</td>
</tr>
<tr>
<td></td>
<td>θ stage: ±5 (Resolution = 0.0004)</td>
</tr>
<tr>
<td>Microscope</td>
<td>2x, 5x and 10x magnification</td>
</tr>
<tr>
<td>Storage cabinet</td>
<td>Low temperature cabinet, humidity Cabinet</td>
</tr>
<tr>
<td>Air Compressor</td>
<td>Anest Iwata SLPM-371EE (up to 1 Mpa or 10 bar)</td>
</tr>
</tbody>
</table>

### Additional Equipments

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protection Module</td>
<td>K2657A-PM-200</td>
</tr>
<tr>
<td>LO Interconnect Module</td>
<td>K2657A-LIM-3</td>
</tr>
<tr>
<td>Switching Matrix</td>
<td>K707B</td>
</tr>
<tr>
<td>Low voltage switching card</td>
<td>K7072 Matrix card</td>
</tr>
<tr>
<td>High voltage switching card</td>
<td>K7072-HV</td>
</tr>
</tbody>
</table>
Electrical Instruments and Probe Station

HV power supply: K2657A
- V source: ±3kV
- I measure: 1nA
- I resolution: 1fA

ACS (Automated Characterization Suite)
Interfacing software to Keithley instruments & MPI probe station

K707B matrix + K7072 card
- 8 X 12 matrix
- Relay settling time: < 15ms

LV power supply: K2636B
- dual channel
- V source: ±200V
- I measure: 100pA

LCR meter: E4980A
- Freq: 20 Hz to 2 MHz
- AC voltage: 5mV-2V

Touch screen
Sentio software

Keyboard & mouse

Humidity & temperature readout

Vibration free table

Vacuum pump

MPI TS 2000-DP Probe Station
*details in next few slides
Probe Station: In SQC lab

- Silicon Strip Sensor (BEL fabricated)
- XYzt Chuck
- Micro-positioner
- XYZ Microscope
- Camera
- Humidity sensor
- SHV, Coaxial cables
- Platen
- Micro-positioner attached to chuck
- XYZT Chuck
Measurements on strip sensor
**Silicon strip sensor**

**Indigeously developed in an Indian foundary***

**CMS Mini Strip Sensor for Phase 1**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector geometry</td>
<td>6.43 cm × 3.25 cm</td>
</tr>
<tr>
<td>Resistivity</td>
<td>2–5 kΩ · cm</td>
</tr>
<tr>
<td>Number of strips</td>
<td>512</td>
</tr>
<tr>
<td>Strip width</td>
<td>30 μm</td>
</tr>
<tr>
<td>Strip pitch</td>
<td>55 μm</td>
</tr>
<tr>
<td>Strip length</td>
<td>6 cm</td>
</tr>
<tr>
<td>Detector thickness</td>
<td>300 ± 20 μm</td>
</tr>
<tr>
<td>Metal overhang</td>
<td>5 μm on both sides of the strip</td>
</tr>
<tr>
<td>Number of guard rings</td>
<td>4</td>
</tr>
<tr>
<td>Width of guard rings</td>
<td>50 μm for innermost, 25 μm for others</td>
</tr>
<tr>
<td>Spacing between strip and guard ring</td>
<td>25 μm</td>
</tr>
<tr>
<td>Spacing between guard rings</td>
<td>25, 30, 40 μm</td>
</tr>
<tr>
<td>Aluminium contacts</td>
<td>DC and AC pads</td>
</tr>
</tbody>
</table>

**p-on-n**

# strips = 192
Strip Pitch = 120 μm

**Measurements are shown in the next slides for CMS mini strip sensors from Phase 1**

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Measurements using the Qualification System

Temperature = 20 °C
Relative Humidity < 10 %
Environmental Conditions

**Temperature vs Time**

Stable temperature observed throughout the measurements

**Relative Humidity vs Time**

RH% of ~ 10% maintained during measurements
Strip Measurements

\[ V_{\text{Bias}} = 250 \, \text{V} \]
Inter-strip Measurements

$V_{\text{Bias}} = 250 \text{ V}$

Interstrip Resistance

Interstrip Capacitance

$R_{\text{int}}$

$C_{\text{int}}$

$f = 1 \text{ MHz}$
### Expected Measurement Duration

<table>
<thead>
<tr>
<th>2S</th>
<th>Measurement</th>
<th>Multiplicity</th>
<th>Duration (min)</th>
<th>Total (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IV to 1000 V</td>
<td>1</td>
<td>0.84</td>
<td>0.84</td>
</tr>
<tr>
<td></td>
<td>CV to 400V</td>
<td>1</td>
<td>1.33</td>
<td>1.33</td>
</tr>
<tr>
<td></td>
<td>Strip ( (C_{\text{Coup}}, I_{\text{strip}}, R_{\text{poly}}, I_{\text{diel}}) )</td>
<td>2032</td>
<td>0.25</td>
<td>508</td>
</tr>
<tr>
<td></td>
<td>Inter-strip ( (R_{\text{int}}, C_{\text{int}}) )</td>
<td>406</td>
<td>0.25</td>
<td>102</td>
</tr>
<tr>
<td></td>
<td>Alignment</td>
<td>2</td>
<td>10</td>
<td>20</td>
</tr>
</tbody>
</table>

**Total time ~ 632 min (~10.5 h)**
Summary and Future Outlook

- The silicon sensor automated characterization facility is developed in the University of Delhi, India.

- Measurements are performed on strip sensors of CMS mini strip sensors.

- Measurement results are found to be reproducible and within the tolerance limits for specific parameters.

Future Outlook

- This facility is proposed to be used for characterization and qualification of the 2S sensors during the production phase of the CMS Outer Tracker Phase II Upgrade in HL-LHC phase.
Thank You