ATLAS ITk strip sensor quality assurance tests and results of ATLAS18 pre-production sensors

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On behalf of the ATLAS ITk Strip Sensor Collaboration
ITk Strips

- ~18,000 sensors are needed to cover the entire volume
- Expected to receive \( \sim 10^{15} n_{eq}/cm^2 \) during HL-LHC operation

**Monitoring performance of irradiated sensors during production is essential! (→Quality Assurance)**

- Pre-production was carried out in 2020 to ensure final sensor quality as well as to establish QC/QA procedures
Strip sensor QA

- Evaluate basic technological properties using dedicated pieces
  - **Mini sensor** is a 10x10 mm² strip sensor with the same structure as the main sensor; for CCE measurement
  - **MD8** is a simple 8x8 mm² diode for IV/CV measurements
  - **Test chip** has various structures to measure fundamental parameters
- 127 QA pieces were irradiated / measured during pre-production
  - Update of presentation at PSD12
    - **E. Bach, presented at PSD 12**
      (Proceedings accepted by JINST)
Flow of QA evaluation

- Irradiation for QA pieces at four facilities
  - Protons/neutrons up to $1.6 \times 10^{15} \frac{n_{eq}}{cm^2}$
  - $\gamma$-rays up to 660 kGy

\[\text{~HL-LHC (4000 fb}^{-1})\]

- \(~3\) pieces are irradiated for every batch (\(~40\) wafers)
**Mini sensor**: measure charge created by electrons from $^{90}\text{Sr}$
- Use Alibava board for DAQ

**MD8/test chip**: measurements can be performed via pads
- Either a PCB with wire-bonding or a probe station

- Measurements at -20°C after annealing at 60°C for 80 mins.

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- Normalise the plateau charge from non-irrad. sensors to 23k $e^-$
- Neutron-irradiated sensors tend to have lower collected charge
  - Different damage states from proton irradiation
- Acceptance threshold: 6350 $e^-$ at 500 V
  - All sensors have passed; $n$-irrad. samples also have sufficient headroom as significantly more than expectation is irradiated

Refer to: K. Hara et al., NIM A 983 (2020) 164422
**I–V/C–V characteristics with MD8**

- **I–V/C–V curves** are measured using MD8
  - Very consistent I–V are obtained between p and n
  - Significant increase of C is observed in n-irradiation
  - Earlier breakdowns and increase of C in γ-irrad. samples seemed to be attributed to surface currents due to measurement setup
**I–V/C–V characteristics with MD8**

- **Acceptance thresholds**
  - 100 μA/cm² at 500 V and breakdown voltage above 500 V

- **All sensors passed the thresholds**
  - No early breakdown was observed except for some γ-irrad. samples

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Results from $1.6 \times 10^{15} \text{n}_{eq}/\text{cm}^2$ irrad.

- Neutron
  - $(1.6 \times 10^{15} \text{n}_{eq}/\text{cm}^2)$

- Proton
  - $(1.6 \times 10^{15} \text{n}_{eq}/\text{cm}^2)$

Leakage current [$\mu\text{A/cm}^2$]

500 V, -20°C

QA thres.
Results from test chips

- **Bias resistances** are to be within $[1.3, 2.3]$ MΩ at $-20^\circ$C
- **Coupling capacitance** should be $>20$ pF/cm
  - All sensors passed the requirement
- **Leakage current on the coupling** should be $< 10$ nA @ 100 V
  - A few samples showed breakdown likely due to mis-handling
    → Cross-checked with other sensors from the same batches
Results from test chips

**Results from 1.6 × 10^{15} \text{n}_{\text{eq}}/\text{cm}^2 \text{ irrad.}**

- **Interstrip resistance**
  - $R_{\text{int}}$ should be $R_{\text{int}} > 10R_{\text{bias}}$ ($\sim 18 \text{ M}\Omega$)
    - $p$-irrad. sensors marginally passed due to excessive TID ($\sim 1.3 \text{ MGy}$); decided to reduce the fluence of $p$-irrad. to correspond to 660 kGy
- **Interstrip capacitance**
  - $C_{\text{int}}$ of some samples exceeded 1 pF/cm
    - Larger spread after irradiation; the threshold is being revisited
- **Punch-through voltage**
  - $V_{\text{PT}}$ should be $< 100 \text{ V}$ to protect strips from over currents

Arrows indicate acceptance ranges
Summary

• Pre-production was carried out in 2020
  – >100 QA pieces were irradiated and tested

• Overall, good performance was obtained from pre-pro. QA
  – Most of the pieces passed the QA criteria; bad results were all understood, such as bad handling before QA testing
  – QA flow was well established in terms both of quality and speed
  – Acceptance criteria were optimised towards main production
    • E.g. $n \times 10^{15} \, n_{eq}/cm^2 + \gamma$ (660 kGy) irradiation to a single sensor is chosen to be a nominal irradiation to have more realistic damages

• Based on the outcomes from pre-production, ATLAS18 sensor main production was started in July 2021
  – 3.8 year programme to produce >20,000 sensors; >5,000 sensors have been produced so far
Rbias measurement

• Use a structure with several poly-Si resistances
  – Sweep $V_{test}$ from -5 V to +5V and measure I
  → Determine $R_{bias}$ from a slope of the I-V

• Requirements
  – $1.5 \pm 0.5 \, \text{M}\Omega$ at 20°C (irradiated measurements at -20°C is normalised to 20°C)
  – $\gamma$-irradiated samples are allowed to be up to 2.2 MΩ at 20°C
• $C_{\text{cpl}}$ measurement
  – Use a square-shape capacitor with an area = 54400 $\mu$m$^2$
    → Equivalent to a strip length of 3.4 cm; square shape reduces an 'edge' effect
  – $C_{\text{cpl}}$ measurement with an LCR meter ($f = 1$ kHz); divided by 3.4 cm
  – $C_{\text{cpl}}$ leak measurement with IV up to 100 V
• Use interdigitated structure
  – 14 inter-strips in total
  – Three different structures
    • 'LOW' has \( l = 2.401 \text{ cm} \) → Use it for \( R_{\text{int}} \) measurement
    • 'MID' and 'UP' have length dependent on the sensor type → For \( C_{\text{int}} \) measurement

• Apply a bias voltage of 500 V
PTP measurement

- Punch-through protection voltage
  - Apply a bias voltage of 500 V
  - Sweep $V_{\text{test}}$ from 0 V to -40 V and evaluate $R_{\text{eff}} = V/I$ at each point
    - Define $V_{\text{PTP}}$ by $R_{\text{eff}} = R_{\text{bias}}/2$
- $V_{\text{PTP}}$ should be less than 100 V
• Each site has their own preferred testing method
  – Consistency was checked with reference samples at site-Q

CNM: probe station
Toronto: PCB
KEK/Tsukuba: PCB
Birmingham: PCB
Valencia: PCB
Ljubljana: PCB
IV in $R_{int}$ and $V_{PT}$

![Graph showing current vs. voltage and $R_{eff}$ vs. $V_{test}$ for different samples.](image)
**MD8**

- Simple 8x8 mm² diode
  - Possible to measure IV/CV with avoiding various effects from sensor structures
- Keep the bias ring to GND and apply

![Diagram of MD8 with bias and edge rings labelled as 'Bias ring (to GND)' and 'Edge ring (to GND)'](image-url)
Fluence around ITk Strips

ATLAS Radiation Simulation Public Results

ATLAS Simulation Preliminary
FLUKA Simulation Phase II

Z = [0.0-4.0] cm
- Total
- Neutrons
- Other particles

ITk Strips
### Split of QA irradiation

- Since it is very challenging to irradiate all radiation types to all QA pieces, batches are split as following table.

<table>
<thead>
<tr>
<th>Prod plan</th>
<th>QA-piece</th>
<th>Mini&amp;MD8</th>
<th>Testchip&amp;MD8</th>
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<td></td>
<td>Birmingham (66 Mrad)</td>
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<td></td>
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<td>Prague (66 Mrad)</td>
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<tr>
<td>all</td>
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<td></td>
<td>CNM (pre-irrad)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>1/6 CYRIC (66 Mrad)</td>
</tr>
</tbody>
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\[\gamma+n\]