Charge Collection Efficiency of micro-strip Silicon Sensors designed for studying Charge Multiplication after Hadron irradiation

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Motivation

• For HL-LHC upgrade 2022 expect fluence for the silicon strip sensors at most $\approx 2 \times 10^{15} \text{n}_{\text{eq}}/\text{cm}^2$
• Sensors not fully depleted at these fluences below 1000V => less signal
• Charge multiplication is a beneficial effect to increase the signal
  – Multiplication due to impact ionisation in regions with high electric field (10-15 V/μm): close to the strip implants
  – but also increase noise and reduce breakdown voltage
• Create sensors to benefit from charge multiplication
Dedicated charge multiplication sensors, produced by Micron Semiconductor Ltd (UK)
  - Detectors aim to enhance the electric field near the readout strips

1cm x 1cm, n-in-p FZ strip detectors

Various strip pitch (P) and width (W)

Some sensors with floating (F) or biased (I) intermediate strips between readout strips

Sensors irradiated with neutrons (Ljubljana) to $1 \times 10^{15}$ and $5 \times 10^{15}$ $n_{eq}/cm^2$

<table>
<thead>
<tr>
<th>Serial No</th>
<th>Thickness [μm]</th>
<th>Resistivity [kΩ/cm]</th>
<th>Implant Details</th>
<th>Labelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>2935-(2,4,5,6,7,8,9)</td>
<td>305</td>
<td>13</td>
<td>Standard</td>
<td>std</td>
</tr>
<tr>
<td>2912-(2,3)</td>
<td>300</td>
<td>10-13</td>
<td>Standard, double implant energy</td>
<td>2E imp</td>
</tr>
<tr>
<td>2935-10</td>
<td>305</td>
<td>13</td>
<td>Standard, double diffusion time</td>
<td>extra diff</td>
</tr>
<tr>
<td>2885-5</td>
<td>150</td>
<td>10</td>
<td>Thin</td>
<td>thin</td>
</tr>
</tbody>
</table>
Use ALiBaVa system for charge collection measurements

• Up to 2 sensors are attached to Beetle chips for analogue read-out

• High voltage connection to bias ring on daughterboard

• $\beta$ Setup:
  – MIP’s from $^{90}\text{Sr}$ source
  – Scintillators for triggering
  – Irradiated sensors measured at temperatures between -20°C and -30°C in a freezer
Neutron Irradiation $1 \times 10^{15} \text{n}_{\text{eq}}/\text{cm}^2$

Collected Charge

No clear sign of charge multiplication

<table>
<thead>
<tr>
<th>Material</th>
<th>Treatment</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>P40-W15-F6</td>
<td>std, Liv</td>
<td></td>
</tr>
<tr>
<td>P40-W15-F15</td>
<td>std, FR</td>
<td></td>
</tr>
<tr>
<td>P40-W15-I15</td>
<td>std, FR</td>
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<tr>
<td>P40-W15-I15</td>
<td>std, Liv</td>
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<tr>
<td>P80-W6</td>
<td>std, FR</td>
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<td>P80-W6</td>
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<td>P80-W6</td>
<td>std, Liv, M2</td>
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<td>P80-W25</td>
<td>std, FR</td>
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<td>P80-W25-F10</td>
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<tr>
<td>P80-W25-F35</td>
<td>std, Liv</td>
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<tr>
<td>P80-W25-I10</td>
<td>std, FR</td>
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<tr>
<td>P80-W25-I35</td>
<td>std, FR</td>
<td></td>
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<tr>
<td>P80-W25-I35</td>
<td>std, Liv</td>
<td></td>
</tr>
<tr>
<td>P80-W60</td>
<td>std, FR</td>
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<tr>
<td>P80-W60</td>
<td>std, Liv</td>
<td></td>
</tr>
</tbody>
</table>

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Neutron Irradiation $5 \times 10^{15} \text{n}_{\text{eq}}/\text{cm}^2$

Collected Charge

Blue: std
Red: 2E imp
Green: extra diff
Orange: thin

2E imp, extra diff more charge than std

Collected Charge [ke]
Voltage [V]
Neutron Irradiation $5 \times 10^{15} \text{n}_{\text{eq}}/\text{cm}^2$

Blue: std
Red: 2E imp
Green: extra diff
Orange: thin
Width/Pitch for $5 \times 10^{15} \text{n}_{\text{eq}}/\text{cm}^2$

- Charge multiplication only observed at $V_{\text{bias}} > 600\text{V}$
- Extra diff and 2E imp show charge multiplication with respect to standard wafer
- Lower W/P ratio leads to more pronounced multiplication (as expected since fields are larger at strip edges)
Detectors with biased intermediate strips (I) show a clear deficit of charge compared to sensors with no intermediate strips or floating intermediate strips (F).

- Neutron $5 \times 10^{15}$ $n_{eq}/cm^2$
- Proton $1 \times 10^{15}$ $n_{eq}/cm^2$
• Room temperature (20°C) annealing in nitrogen cabinet
  – P80-W25-I35, std, Liv; $1 \times 10^{15} \text{n}_{\text{eq}}/\text{cm}^2$
  – P80-W25-I35, std, Liv; $5 \times 10^{15} \text{n}_{\text{eq}}/\text{cm}^2$

• Long term bias test
  – Apply high voltage for long period of time
  – Choose $U > 1000\text{V}$ because at this voltage more collected charge
  – P80-W25-I35, std, Liv; $5 \times 10^{15} \text{n}_{\text{eq}}/\text{cm}^2$
P80-W25-I35, $1 \times 10^{15}$ $n_{eq}/cm^2$

Collected Charge

Expected annealing curve

Collected charge [ke]

Annealing Time [d]

0.0 100 200 300 400 500 600 700

0 10 20 30 40 50 60 70

300 V

400 V

500 V

600 V

700 V

800 V

900 V

1000 V

1100 V

1200 V

1400 V

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Collected Charge

Collected charge [ke]

Annealing Time [d]

- 600 V
- 800 V
- 1000 V
- 1200 V
- 1400 V
- 1600 V
- 1800 V
- 2000 V

P80-W25-I35, $5 \times 10^{15} \text{n_{eq}/cm}^2$

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P80-W25-I35, $5 \times 10^{15} \text{n}_{\text{eq}}/\text{cm}^2$

SNR

Annealing Time [d]

Variations of SNR for different voltages (600 V to 2000 V) over time.
Long-term bias test
During measurement sensor reached compliance (red line) => ramp to 0V, no bias for 1d, then back to 1700V

1700V
Summary/Conclusion

• No evidence for charge multiplication can be seen for an irradiation fluence of $1 \times 10^{15} \text{n}_{eq}/\text{cm}^2$

• $5 \times 10^{15} \text{n}_{eq}/\text{cm}^2$: ‘double implant energy’ and ‘extra diffusion time’ show higher collected charge than ‘standard’ sensors
  – Low width/pitch ratio leads to pronounced multiplication
  – Intermediate strips have no benefits in terms of collected charge

• Long term annealing of $5 \times 10^{15} \text{n}_{eq}/\text{cm}^2$ sensor show increased collected charge for voltages $>1000\text{V}$
  – Annealing of second set of sensors show same behaviour

• Long term bias test show decrease of enhanced signal
  – Under investigation in collaboration with Freiburg group
• Irradiations supported by the Initiative and Networking Fund of the Helmholtz Association, contract HA-101 ("Physics at the Terascale")
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By Nathan Readioff

Please support this project: https://ideas.lego.com/projects/94885
Neutron Irradiation $1 \times 10^{15} \text{n}_{\text{eq}}/\text{cm}^2$

Noise

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SNR

Voltage [V]

Neutron Irradiation $1 \times 10^{15} \text{n}_{eq} / \text{cm}^2$

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Neutron Irradiation $5 \times 10^{15} \text{n}_{\text{eq}}/\text{cm}^2$