Radiation Damage in Silicon

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TA1-SD

Alison Bates, Christian Joram, Michael Moll
Operation of a detector

Radiation creates electron and hole pairs
- holes are attracted to the p+ electrode
- electrons are attracted to the n+ electrode
Movement of charge carriers induces a signal.
Why radiation hard silicon?

Example: LHCb VELO (VErtex LOcator) detector:

- 8 mm away from the beam ($10^{14}$ 1 MeV $n_{eq}$)
- new detectors needed within ~3 years

<table>
<thead>
<tr>
<th>Radius [cm]</th>
<th>Fluence [$n_{eq}/cm^2$ per year]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$10^{14}$</td>
</tr>
<tr>
<td>2</td>
<td>$10^{13}$</td>
</tr>
<tr>
<td>3</td>
<td>$10^{12}$</td>
</tr>
<tr>
<td>4</td>
<td>$10^{11}$</td>
</tr>
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![Diagram of the LHCb VELO detector](image)
Defects in Silicon

Main (macroscopic) effects of radiation damage in silicon:

• Increased leakage current
• Increased depletion voltage
• Increased trapping
Types of Silicon

Float Zone (FZ) silicon: $1 \times 10^{15} \ O \ cm^{-3}$

Oxygenated silicon: $1 \times 10^{17} \ O \ cm^{-3}$

Czochralski (CZ) silicon: $1 \times 10^{18} \ O \ cm^{-3}$

Oxygenated silicon seems to be better than Float Zone silicon.
CV and IV measurements

Capacitance \([C]\) and Current \([I]\) vs. Voltage can be used to determine:

**CV**
- Full depletion voltage
- End capacitance

**IV**
- Full depletion voltage
- Leakage current
Results for irradiated detectors

W317 (DOFZ) oxygenated
Annealed for 4 min/80°C

Leakage current normalized to volume

$\alpha = 4.75 \times 10^{-17} \text{A/cm}$

Previous works (M. Moll):
$\alpha = 4.56 \times 10^{-17} \text{A/cm}$
Transient Current Technique

A technique to study radiation damage in silicon by measuring:

- Full depletion voltage
- Effective trapping time
- Sign of space charge
How does TCT work?

hole dominated signal
electron dominated signal
The QV-method can be used to get the full depletion voltage

\[ Q = \int_{t_0}^{t_1} I(t)dt \]
Effective trapping time

Charge gets trapped in the detector due to radiation induced defects.

The amount of charge trapped depends on the number of defects (hence on the fluence) and also on the applied voltage (over full depletion):

Higher voltage

- higher drift velocity
  - fewer charge carriers trapped
  - more charge measured
How to get the trapping time?

The corrected charge is constant with voltage \((V>V_{FD})\)

\[
Q(t) = \int I_0(t)dt = \int I(t)e^{-\frac{t}{\tau}}dt
\]
\[ \beta_e = 5.48 \pm 0.22 \times 10^{-16} \text{ cm}^2/\text{ns} \]

\[ \beta_h = 6.02 \pm 0.28 \times 10^{-16} \text{ cm}^2/\text{ns} \]

<table>
<thead>
<tr>
<th>University</th>
<th>( \beta_e \ 10^{-16} \text{ cm}^2/\text{ns} )</th>
<th>( \beta_h \ 10^{-16} \text{ cm}^2/\text{ns} )</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dortmund</td>
<td>5.16 ± 0.16</td>
<td>5.04 ± 0.16</td>
<td>O. Krasel et al., 2\textsuperscript{nd} RD50 workshop</td>
</tr>
<tr>
<td>Ljubljana</td>
<td>5.6 ± 0.2</td>
<td>7.7 ± 0.2</td>
<td>G. Kramberger et al, NIAM A481 (2002) 297-305</td>
</tr>
<tr>
<td>Hamburg</td>
<td>4.85 ± 0.15</td>
<td>5.72 ± 0.5</td>
<td>E. Fretwurst et al., 3\textsuperscript{rd} RD50 workshop</td>
</tr>
</tbody>
</table>
Type inversion

electron signal before type inversion
electron signal after type inversion
Results for Cz Silicon

From IV-CV measurements:

- **Float Zone**
- **Type inversion**
- **Oxygenated**
- **Czochralski**

Type inversion...?
TCT can determine the space charge:
(i.e. whether the bulk is still n-type or has changed to p-type)

No type inversion up to $5 \times 10^{14}$ p/cm$^2$ in CZ silicon
Conclusions

• Float Zone and Oxygenated silicon type invert

• The QV method is complementary to CV and IV to determine the depletion voltage

• Preliminary $\beta$-values for electrons agree with previous results, holes agree with Hamburg group (for W317)

• Czochralski silicon doesn't type invert up to $5 \times 10^{14}$ p/cm$^2$

QUESTIONS??????
Irradiation and annealing

The samples are irradiated with a fluence between $10^{12} - 10^{15}$ p/cm$^2$ (24 GeV protons) at IRRAD1 (PS).

Before measurements the detectors are annealed to remove movable carriers and get them all on the same damage level.
TCT Setup

Pulse Generator: Agilent 81110A
2 ns width, 0.8 ns rise time

Laser Diode: 660 nm
1.5 ns FWHM
Laser Pulse
Peltier cooled min -6°C stability ±0.5°C

Detector

Phillips preamplifier 1 GHz, 50 gain

Oscilloscope: 500 MHz, 1 GSa/s

- H.V
How to get the trapping time?

Due to trapping the current measured is lower than the actual current $I_0$:

$$I(t) = I_0(t) e^{-\frac{t}{\tau}}$$

From this relation follows for the charge

$$Q(t) = \int I_0(t) dt = \int I(t) e^{-\frac{t}{\tau}} dt$$