Measurement of $E_{\text{eff}}$ for Irradiated and Annealed Diodes

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Temperature scaling

- Power dissipation: important factor for highly irradiated silicon sensors
- Leakage current is dependent on temperature:
  \[ I(T) = A \cdot T^2 \exp \left( \frac{E_{\text{eff}}}{2 \cdot kT} \right) \]
- \( E_{\text{eff}} \) is the effective band gap (literature value: \( E_{\text{eff}} = 1.21 \text{ eV}^1 \))
- Prediction of power dissipation for different temperatures requires scaling

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1 A. Chilingarov, https://doi.org/10.1088/1748-0221/8/10/p10003
Temperature scaling

- Temperature scaling model assumes depleted bulk
  → Validity for highly irradiated sensors?
  → Dependent on applied voltage?

- Affected by annealing due to change in defects?
## Samples

<table>
<thead>
<tr>
<th>Diode</th>
<th>Irradiation Facility</th>
<th>Fluence $n_{eq}/\text{cm}^2$</th>
<th>Annealing Range min at 60 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>PS</td>
<td>0.5e15</td>
<td>780</td>
</tr>
<tr>
<td>P3</td>
<td>PS</td>
<td>0.5e15</td>
<td>0-1200</td>
</tr>
<tr>
<td>P4</td>
<td>PS</td>
<td>3e15</td>
<td>0-780</td>
</tr>
<tr>
<td>P5</td>
<td>PS</td>
<td>1e15</td>
<td>0-1200</td>
</tr>
</tbody>
</table>

- 250 µm thick n-bulk diodes
- 9 mm² active area
- Bulk separated from surface current
Setup

- n-bulk diodes glued on PCB and contacted via wirebonds
- Measurements performed in climate chamber
- Temperature monitoring via Pt1000 on PCB (used as reference for scaling)
Total current vs bulk current

\[ \rightarrow E_{\text{eff}} \text{ determined with bulk current} \]
Scaling with Fixed Literature Value $E_{\text{eff}} = 1.21\,\text{eV}$

- Good agreement in plateau region
- Bad scaling below plateau (here: $\lesssim 200\,\text{V}$)
- Offset in plateau region
Goal: Determining suitable power limit

Self-heating induces a change in bulk current after jump to target voltage

Set limit at 5 mW to exclude areas with clear correlation between power and $\frac{I_{\text{min}}}{I_{\text{max}}}$
Determining $E_{\text{eff}}$

- IV curves measured every 2 K from 0 °C to −36 °C
- For every voltage, $E_{\text{eff}}$ is determined from scaling behaviour extracted from IV curves
- Linearized data is fitted

\[ I(T) = A \cdot T^2 \exp \left( \frac{E_{\text{eff}}}{2 \cdot kT} \right) \]

\[ \Rightarrow - 2 \cdot kT \ln \left( \frac{I(T)}{T^2} \right) = p_1(T) = B + 2C \cdot kT \]

with $A = \exp(-C)$ and $B = E_{\text{eff}}$
$E_{\text{eff}}$ -V Curves

- $E_{\text{eff}}$ is determined from curves up to a selected maximum temperature (here: $-20^\circ$C)
- If the power limit is exceeded at a single temperature, $E_{\text{eff}}$ is not determined for that voltage

**Used IV curves**

**Example $E_{\text{eff}}$ -V curve**
Variation of Maximum Temperature

- Lower maximum temperatures result in a lower measured $E_{\text{eff}}$
- Feature locations remain the same
**Fluence Dependence**

- $E_{\text{eff}}$-V curves seem to converge for high voltages (more data needed)
- Slope moves to higher voltages with fluence
Annealing Dependence

- $E_{\text{eff}}$-$V$ curve similar in plateau
- Different behaviour
  - Height at start of plateau changes with annealing for P3
  - Slope moves to lower voltages for P5
Scaling accuracy with $E_{\text{eff}} = 1.21 \text{eV}$

Scaling error in a worst case scenario ($E_{\text{eff, meas}} = 1.137 \text{eV}$):
- $\leq 12\%$ for literature value
- $\leq 3\%$ for measured value

- Scaling over large temperature scaling requires knowledge of $E_{\text{eff}}$ of the device at a given voltage
Conclusion and Outlook

- Dependence of $E_{\text{eff}}$ on voltage investigated for irradiated and annealed samples.
- $E_{\text{eff}}$-V curves stretched towards higher voltage with fluence.
- For highly irradiated samples, voltage dependence is not negligible at typical operation voltages.

- Measurement of more samples for statistics as well as neutron irradiated samples.