Measurement of E_{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:

$$I(T) = A \cdot T^2 \exp\left(\frac{E_{\mathrm{eff}}}{2 \cdot kT}\right)$$

- E_{eff} is the effective band gap (literature value: $E_{\mathrm{eff}} = 1.21\,\mathrm{eV}^1$)
- Prediction of power dissipation for different temperatures requires scaling

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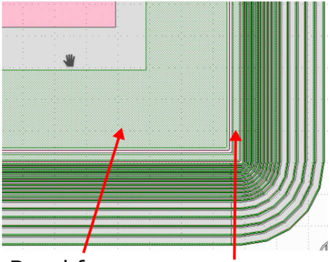
[1] A. Chilingarov, https://doi.org/10.1088/1748-0221/8/10/p10003

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

Diode	Irradiation Facility	Fluence n_{eq}/cm^2	Annealing Range min at 60 °C
P1	PS	0.5e15	780
P3	PS	0.5e15	0-1200
P4	PS	3e15	0-780
P5	PS	1e15	0-1200

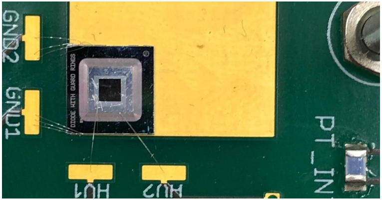


Bond for bulk current

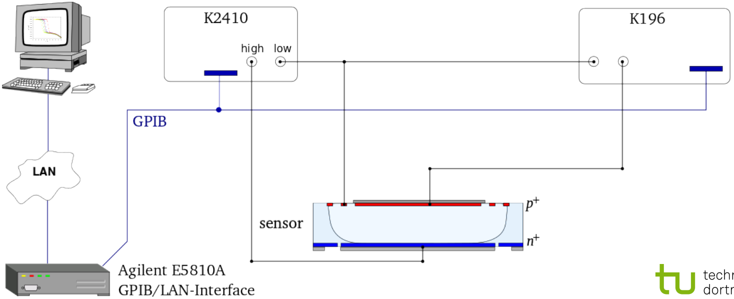
Bond for edge current

- 250 µm thick n-bulk diodes
- 9 mm^2 active area
- Bulk separated from surface current

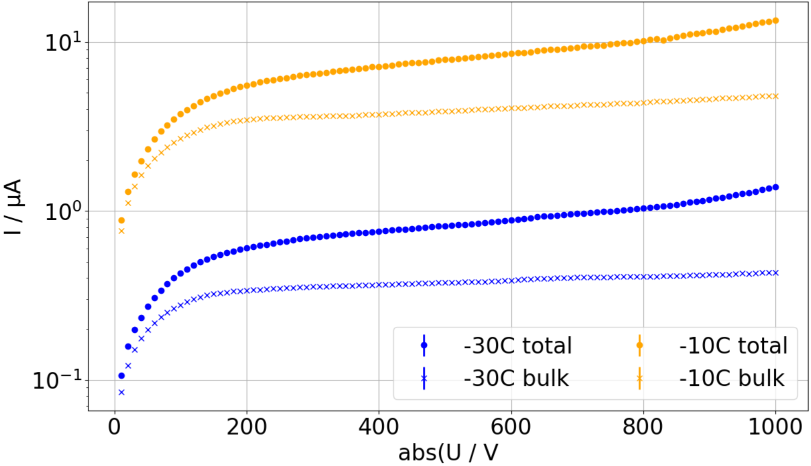
Setup



- 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)

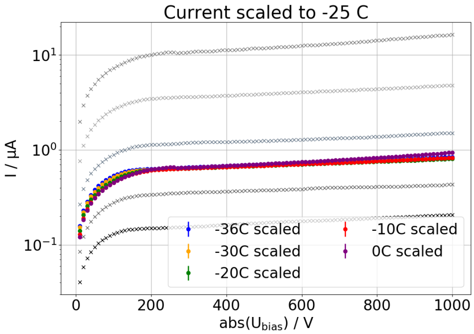


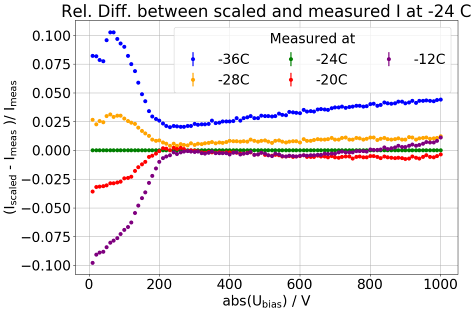
Total current vs bulk current



→ E_{eff} determined with bulk current

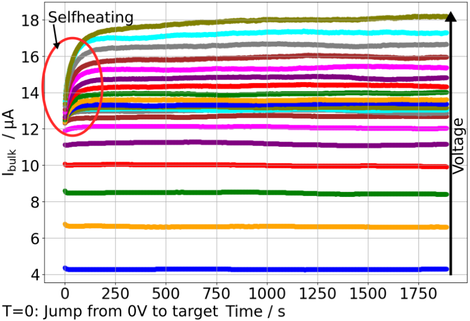
Scaling with Fixed Literature Value $E_{\mathrm{eff}} = 1.21\,\mathrm{eV}$

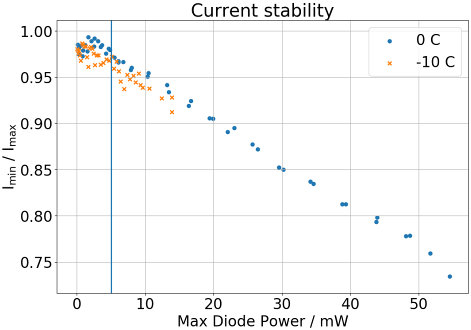




- Good agreement in plateau region
- Bad scaling below plateau (here: $\lesssim 200\,\mathrm{V}$)
- Offset in plateau region

Power limit

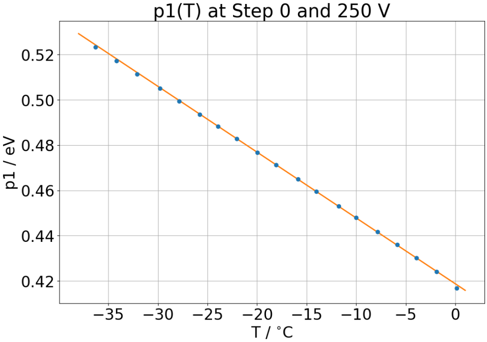




- Goal: Determining suitable power limit
- Self-heating induces a change in bulk current after jump to target voltage
- Set limit at 5 mW to exclude areas with clear correlation between power and I_{min}/I_{max}

Determining E_{eff}

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



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

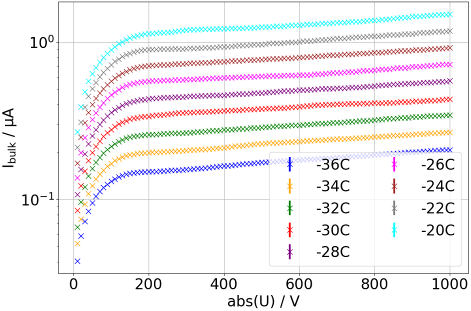
$$\Longrightarrow -2 \cdot kT \ln\left(\frac{I(T)}{T^2}\right) = p_1(T) = B + 2C \cdot kT$$

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

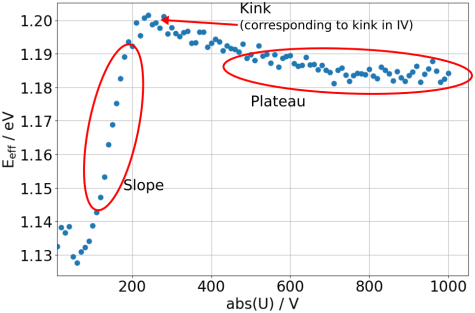
E_{eff}-V Curves

- E_{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_{eff} is not determined for that voltage

Used IV curves



Example E_{eff}-V curve



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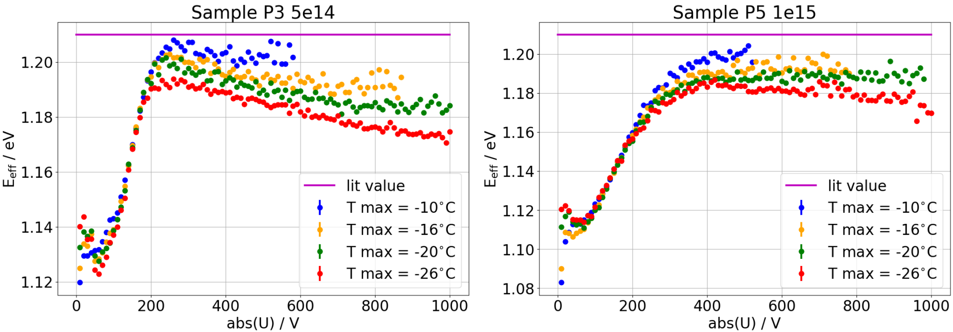
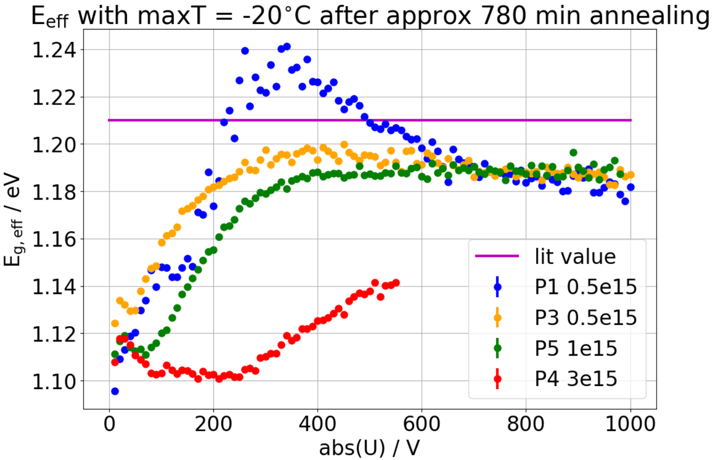
Variation of Maximum Temperature



- Lower maximum temperatures result in a lower measured E_{eff}
- Feature locations remain the same

Fluence Dependence



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

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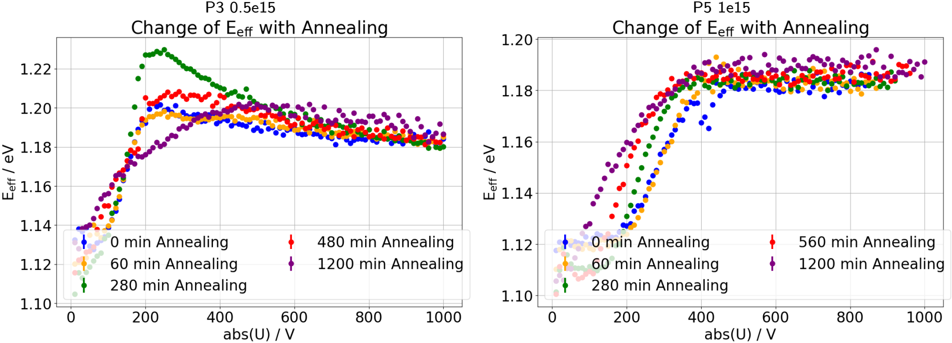
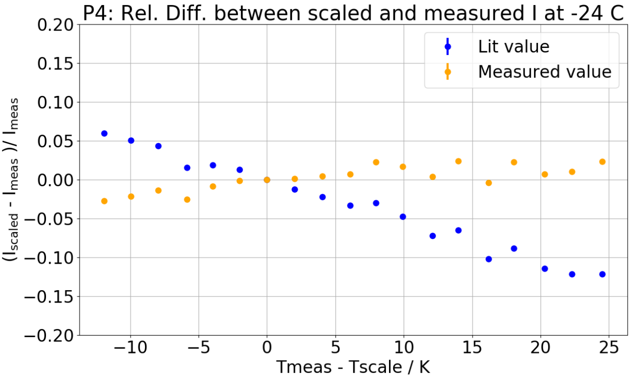
Annealing Dependence



- E_{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_{eff} of the device at a given voltage

Conclusion and Outlook

- Dependence of E_{eff} on voltage investigated for irradiated and annealed samples
- E_{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