Characterisation of Crystalline Defects in 4H Silicon Carbide using DLTS and TSC

Niels G. Sorgenfrei[1,2], Elias Arnqvist[3], Yana Gurimskaya[1], Michael Moll[1], Ulrich Parzefall[2], Faiza Rizwan[1], Moritz Wiehe[1]
[1]CERN, Switzerland; [2]University of Freiburg, Germany; [3]Uppsala University, Sweden

Introduction

- Silicon is well understood and widely used, but suffers strongly from radiation damage
- Future HEP experiments require either a leap in radiation hardness (difficult) or frequent replacement of detector (costly)

⇒ New materials?

- Wide-bandgap materials have certain advantages over Silicon, like their extremely low leakage currents
- High grade 4H-Silicon Carbide has become more readily available in the last years, due to industry driven interest

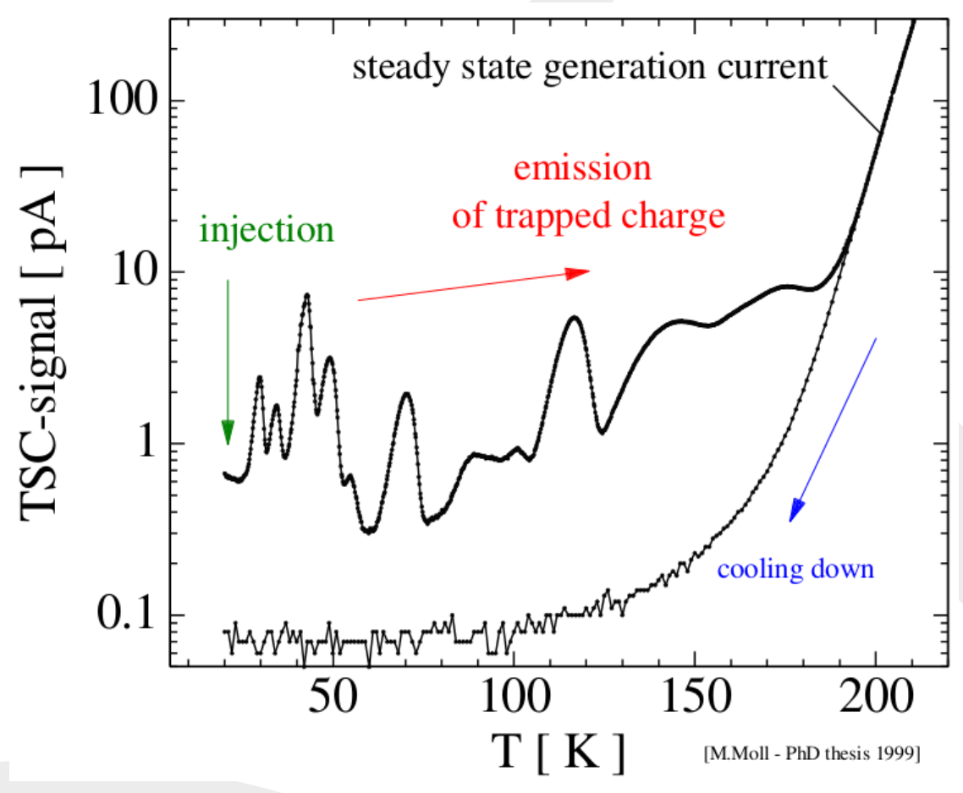
Objectives

- Are there defects present in non-irradiated material?
- Which defects are caused by radiation and what are their effects?
- What are the properties and constituents of the uncovered defects?
- How can the creation of defects detrimental to detector performance be mitigated?

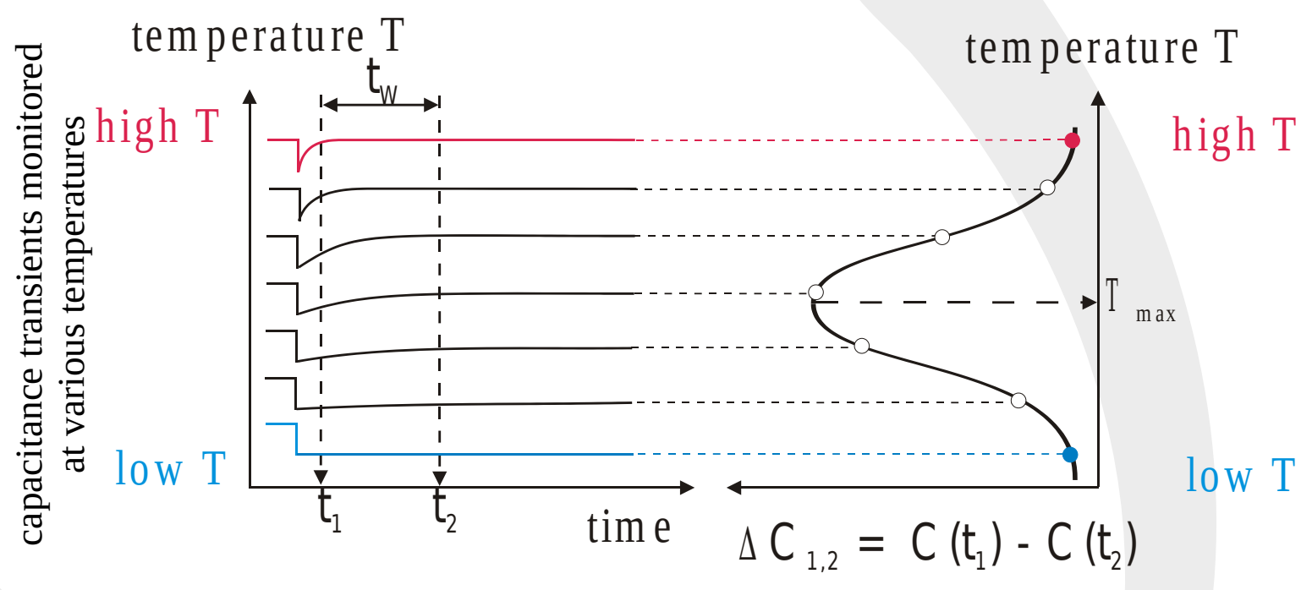
Methods

Spectroscopical measurement techniques based on injection of charge carriers while monitoring capacitance transients or current responses as a function of temperature:

- Thermally Stimulated Currents (TSC)



- Deep-Level Transient Spectroscopy (DLTS)



Simulation framework using DLTS values to simulate TSC measurement spectra:

$$I_{\mathrm{TSC}}(t) = q_0 A \sum_{i=1}^{n} \left[\sum_{\mathrm{defects}} \frac{e_n(t)n_{\mathrm{T}}(t) + e_p(t)p_{\mathrm{T}}(t)}{2}\right] \Delta z_i$$

Acknowledgements

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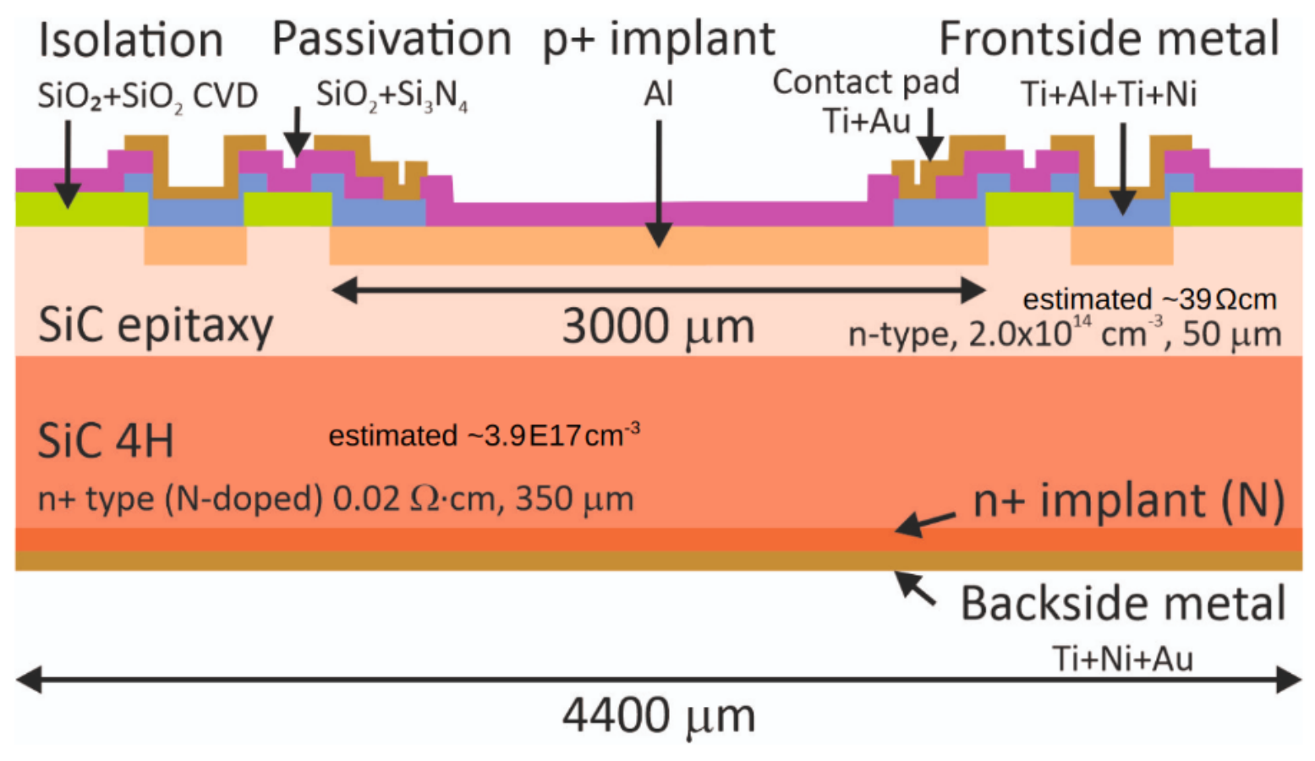
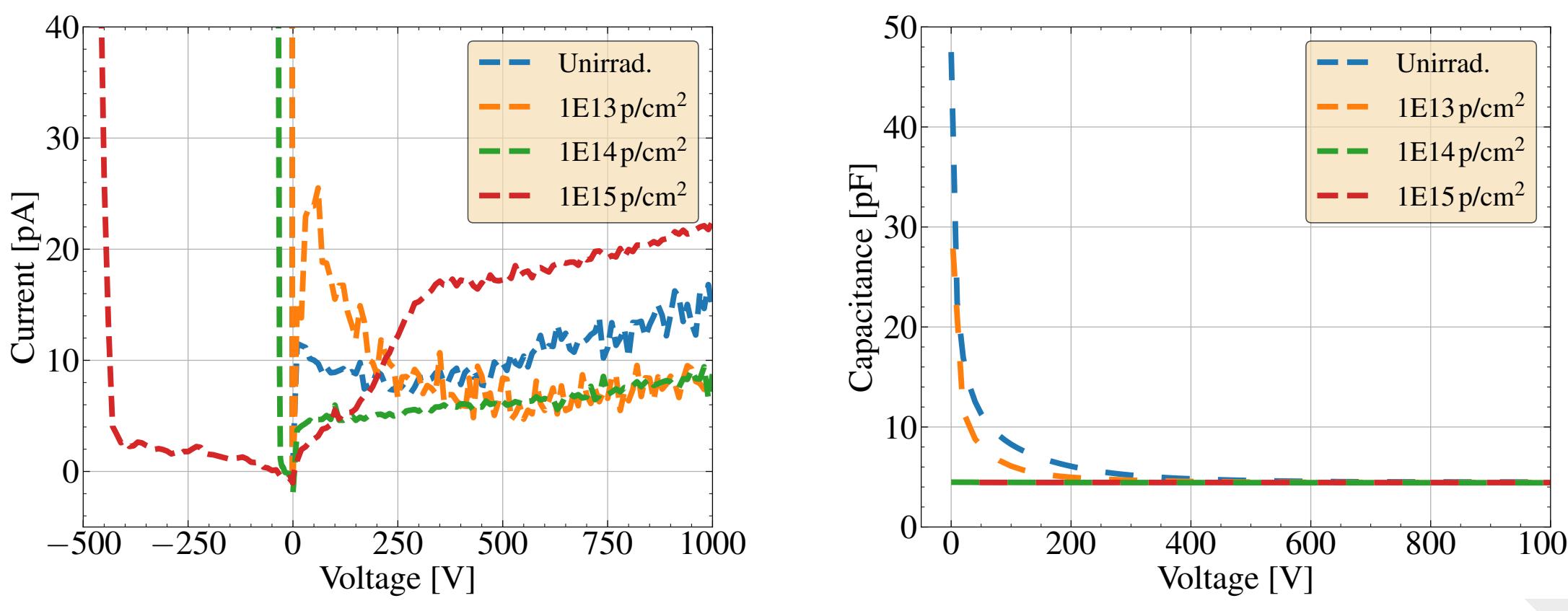
Results

Studied Devices



- Produced by IMB-CNM, Run 14171, Wafer 1
- n-type, epitaxial 4H-SiC pad diodes
- 2E14 cm^{-3}, nitrogen doping
- 50 µm active thickness, 0.09 cm^2 area
- 23 GeV proton irradiation at PS-IRRAD

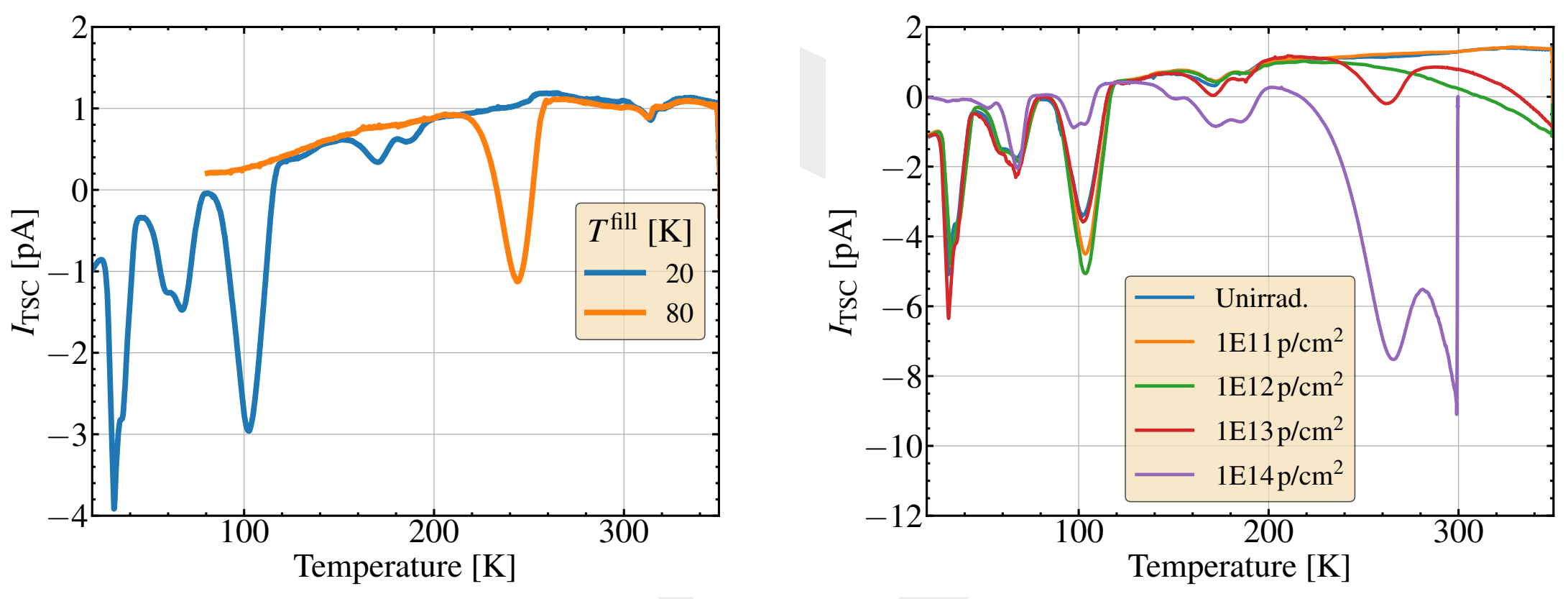
IV & CV



- No breakdown up to 1000 V reverse bias
- Leakage current in low pA range, even after 1E15 p/cm^2
- Forward junction potential increase from −1.8 V to −400 V after irradiation
- Flat capacitance curve after 1E14 p/cm^2

⇒ Diode loses rectifying properties

Thermally Stimulated Currents

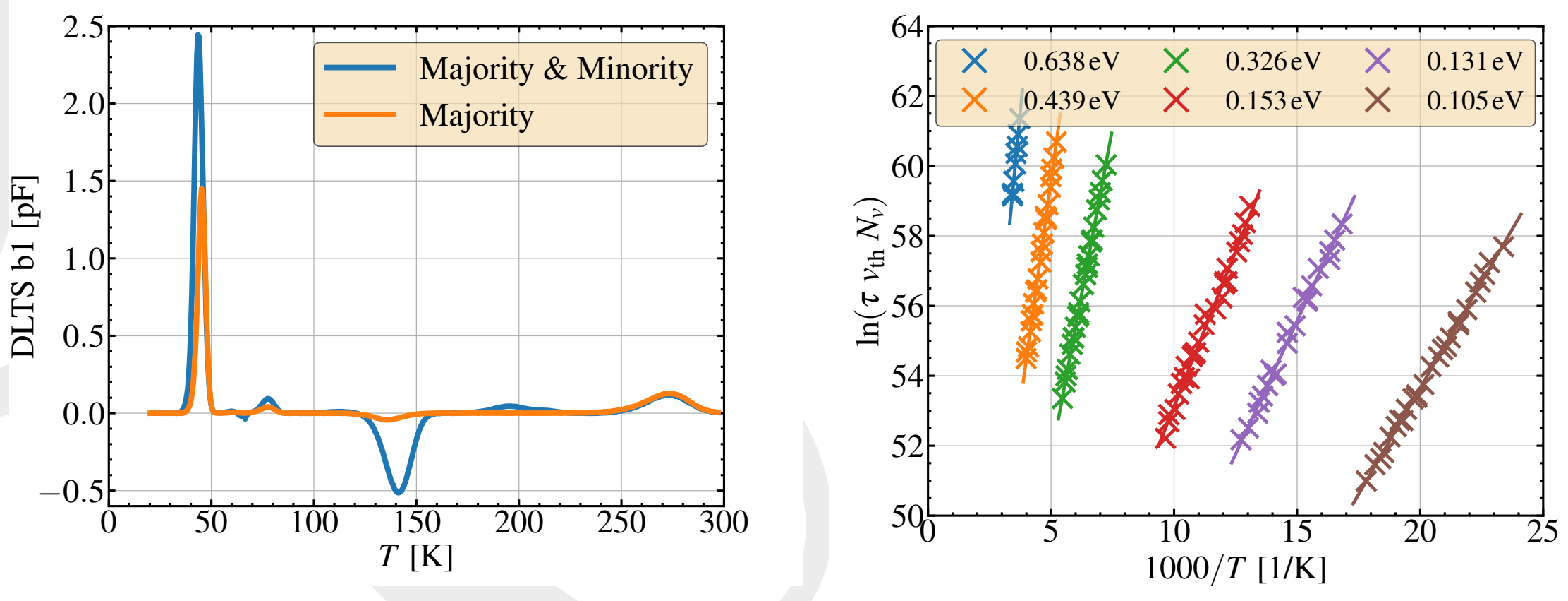


- Non-irradiated material has multiple defects

⇒ Intrinsic (vacancy, interstitial, anti-site) or impurity related

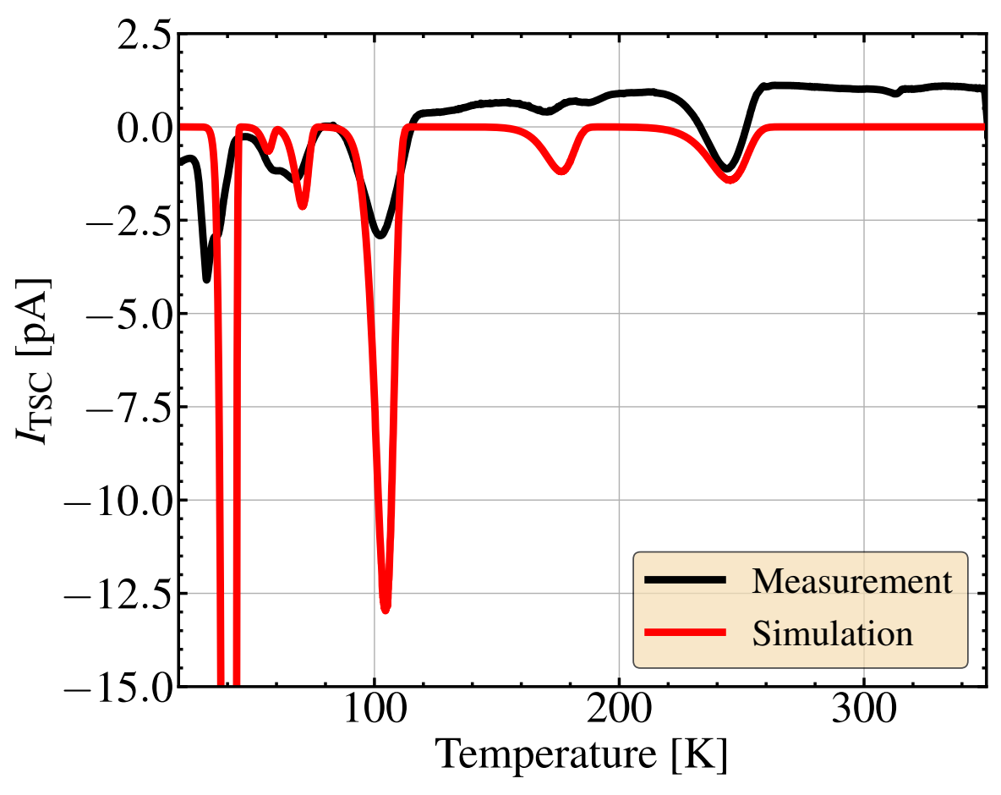
- Strong dependence on filling temperature observed for most defects
- $Z_{1/2}$ defect identified at 240 K
- Radiation increases defect concentration

Deep-Level Transient Spectroscopy



- Multiple defects present in non-irradiated material
- Extract defect parameters through correlator function analysis and Arrhenius plot

Simulation of TSC Spectra



- DLTS and TSC spectra are difficult to compare

⇒ Simulate TSC spectra using defect parameters obtained from DLTS measurements

- Good match of peak positions
- DLTS and TSC each reveal defects not observed by the other

Conclusion & Outlook

- Multiple defects present in non-irradiated material
- Defect parameters (energy, capture-cross section, concentration) were measured
- Simulation used to match TSC and DLTS measurements
- Radiation increased concentration of present defects, but no formation of new defects observed

- Newly acquired cryostat will be used to measure up to 800 K, scanning the full bandgap of 4H-SiC

⇒ Observation of radiation induced defects?

- Irradiation campaign with Protons, Neutrons and Gammas to compare damage

Niels G. Sorgenfrei
niels.sorgenfrei@cern.ch

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