Simulation of the Electrical Performance of the ITk ATLAS18 Test Diode and Main Sensors Before and After Irradiation

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The ATLAS Inner Tracker (ITk) Strip Detector

The ATLAS Inner Detector upgrade with **Inner Tracker (ITk)** to accommodate **higher occupancy and radiation level** anticipated at the **High-Luminosity LHC (HL-LHC)**.

- The ITk consist of **silicon-based pixel and strip sub-detectors**.
- The strip sub-detector is designed to operate up to fluence of 1.6×10^{15} 1-MeV neq/cm^2.

The ITk Strip Detectors:

- **n$^+$-in-p** silicon strip sensors.
- **~75 µm strip pitch** and approximately **~300 µm active thickness**.
- Each sensor contains **2 or 4 rows**, with approximately **1k strips per row**.
- **Fabricated by Hamamatsu Photonics (HPK)**.

Sensors Data Used in Tuning TCAD Simulation

Test Diodes:

- Fabricated on the **same wafer** as main strip sensors.
- Include **optical and electrical characterization data**.
- **Extensive QC** data collected during reception acceptance measurements.
- **Additional in-lab measurements at Carleton** for TCAD model studies.

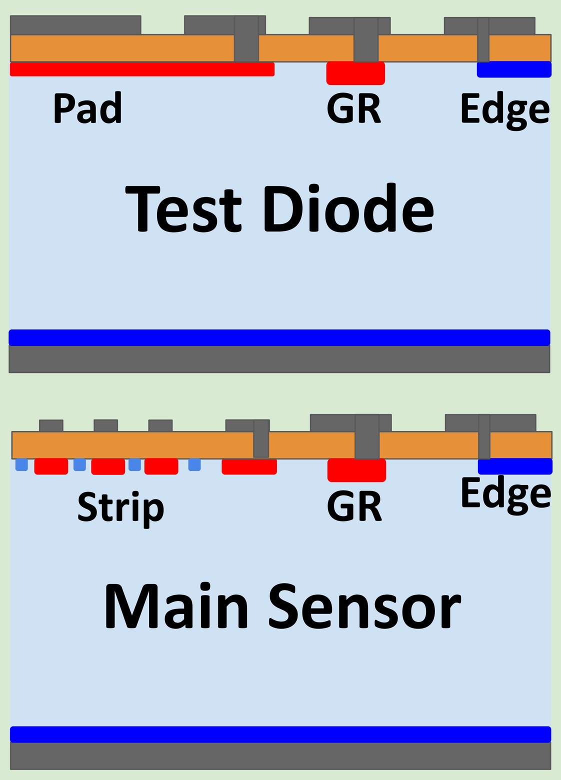
Main Strip Sensors:

- Measurements of main sensors (R0/2/3) at Carleton to **validate and compare TCAD simulation results** based on models tuned with the test diode data.

TCAD Simulation of ITk Strip Sensors

Simulation Setup

- **Models and Parameters:**
  - **Doping** and **passivation fixed charges** estimated from **C-V measurement** and **implant resistance**.
  - The **bulk defect model** is based on **DLTS measurement** of **non-irradiation sensors**.
- **Test Diodes:**
  - Simulated as **half-size 2D structure** to exploit symmetry and reduce computation time.
  - **Electrical simulations** use **cylindrical boundary condition** to reproduce the effective sensor area.
- **Main Sensors:**
  - Simulation include the **edge structure** and **a few strips**, then results are rescaled to full sensor size.



Initial Attempts

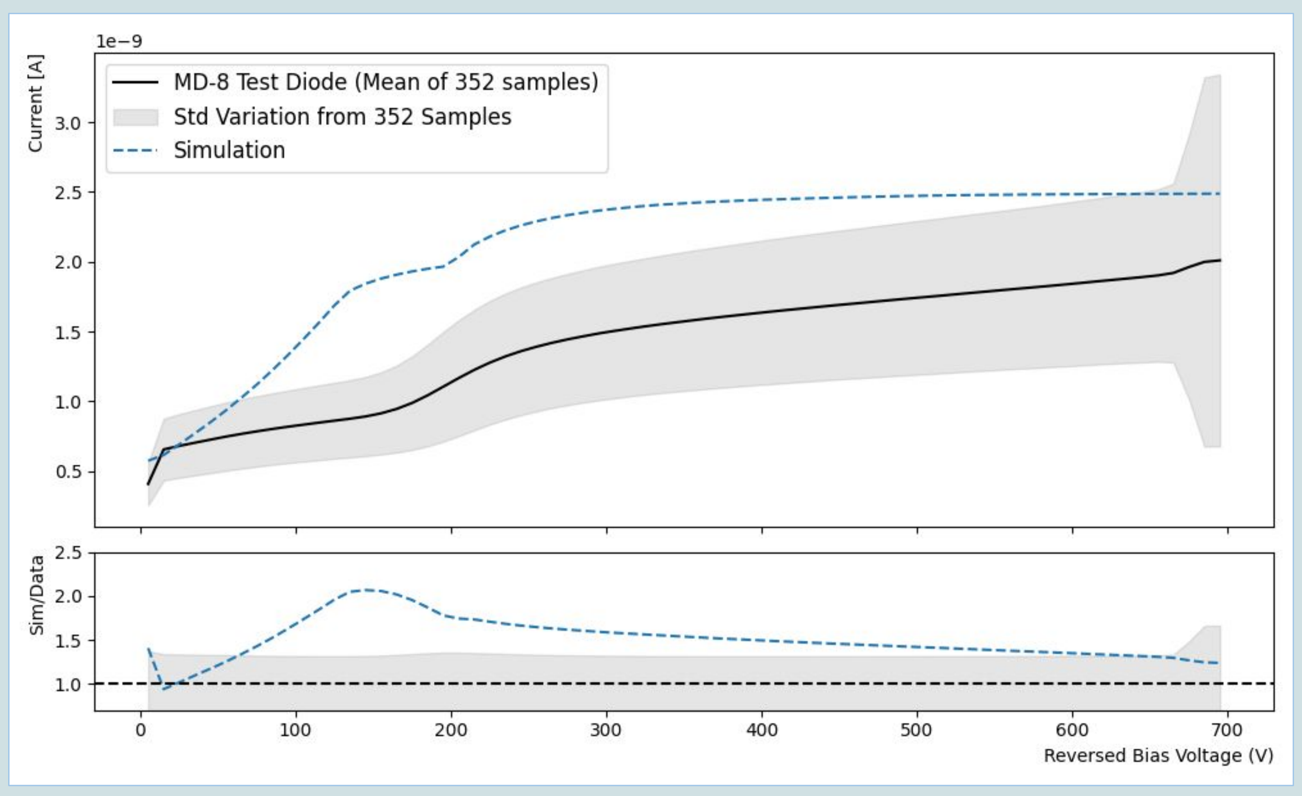
- An additional **area scaling 0.06** is applied to match the simulated leakage current to the measurement value.
  - The excess current still under investigation and may be due to inaccurate effective area.
- The **simulated leakage current** increase **faster than measured** before full depletion.

Important Models:

- **Uniform passivation oxide charge density: 10^{11} /cm^2** at the SiO_2-Si interface. [1]
- Bulk defect model: Based on **DLTS measurements.** [2].
- **SRH recombination lifetime** (e/h): 200ms.

Large discrepancy observed between TCAD and measurement

⇒ Current models may be incomplete and require further tuning.



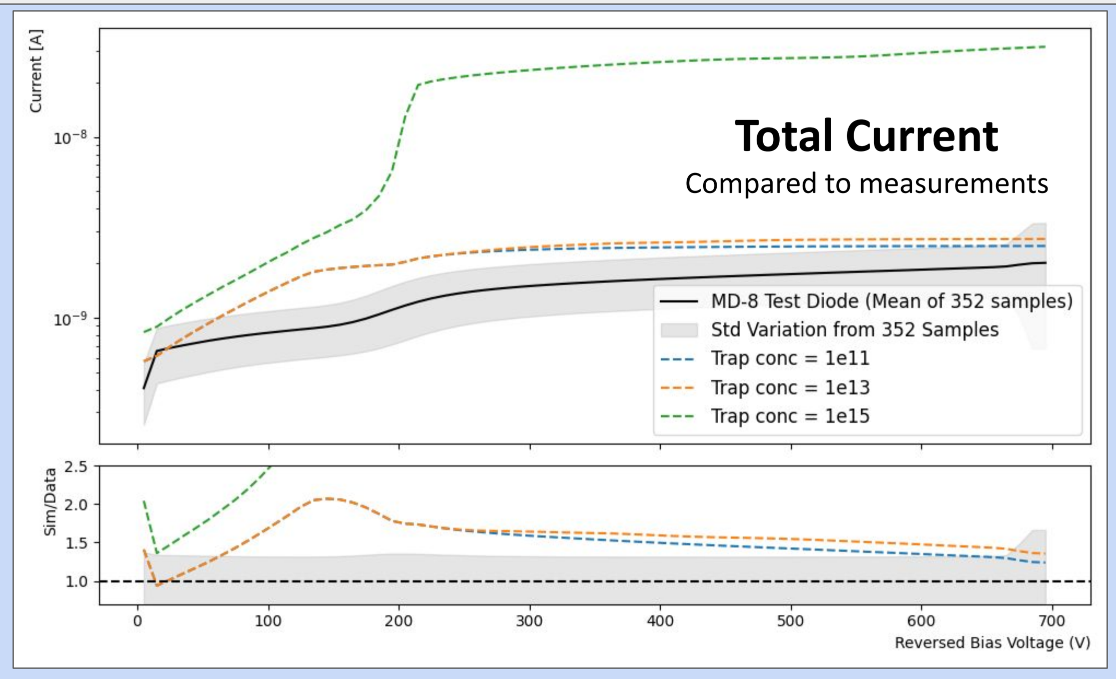
Separating Bulk and Edge Leakage Contributions:

- The **total leakage current** can be decomposed into **bulk (pad)** and **surface (edge)**
  - with edge contribution dominates the total current
- Help evaluate the impact of different models on each contribution.
- In the TCAD simulation, the **guard ring is grounded** to allow **extraction of bulk and edge currents independently**.
  - Note this is different from nominal operation of the device, where GR is floating.

TCAD Model Tuning to Test Diodes

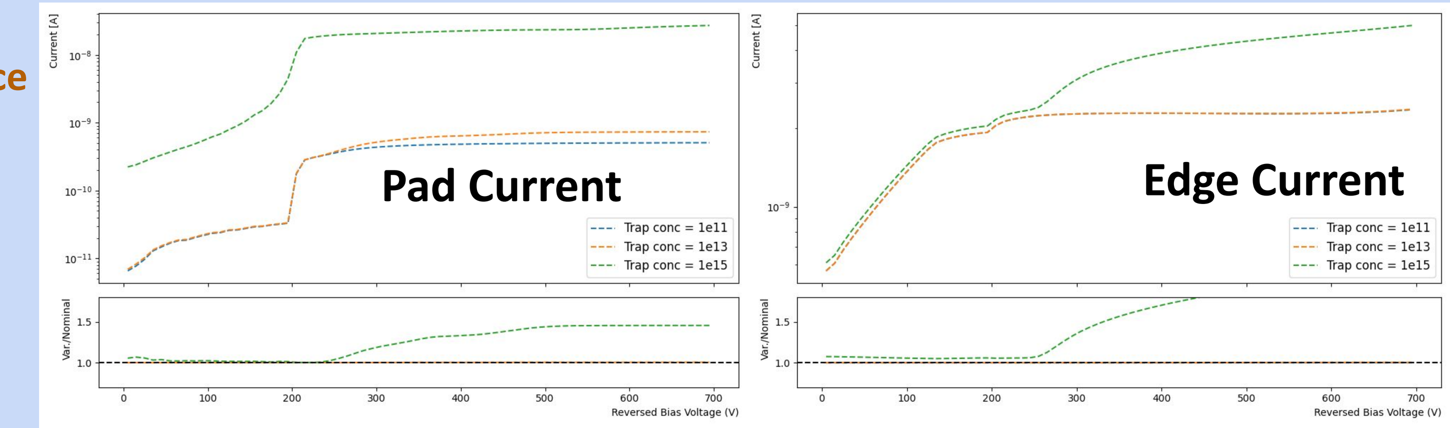
Backside Trap Effects

- A **kink** observed in the measured I-V curve corresponds to the **onset of full depletion in the sensor**.
- This behavior is linked to how the **depletion region extend toward the backside** as the bias voltage increase.
- To reproduce the kink simulation, **traps with Gaussian spatial distribution near the backside** were attempted.
  - Trap parameters are inferred from the **Perugia surface model** [3].



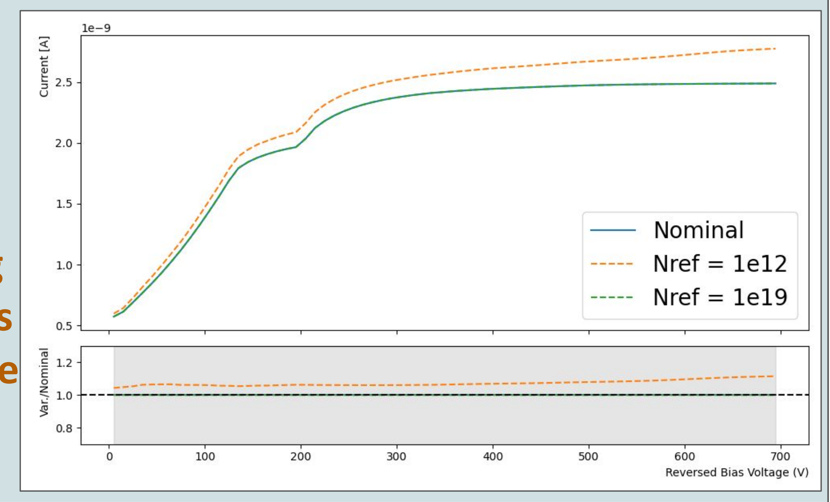
However, the traps introduce higher leakage after depletion, with the kink before depletion remains unaffected by the traps.

⇒ Further optimization under study.



SRH Recombination Lifetime

- The **doping dependence** of the **SRH lifetime** is modeled as: $\tau_{\mathrm{dop}}(N_{A,0}+N_{D,0}) = \tau_{\min} + \dfrac{\tau_{\max}-\tau_{\min}}{1+\left(\dfrac{N_{A,0}+N_{D,0}}{N_{\mathrm{ref}}}\right)^{\gamma}}$
- The τ_{max} = 200 ms (typically for high-purity silicon).
- The τ_{min} = 0 ms (nominal model value).
- The γ parameter is set to 1.0 (nominal model value).
- The reference doping concentration N_{ref} is varied:
  - 1e12 N/cm^3 (bulk doping level)
  - 1e19 N/cm^3 (surface implant doping level)



Increasing the reference doping concentration to the implant level yields results similar to the nominal case, while reducing to the bulk level slightly increase the current. ⇒ This indicates the SRH lifetime doping dependence has minimal effect on the edge current contribution.

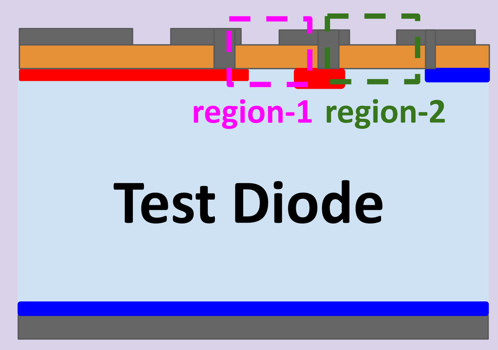
Surface SRH effects will be investigated in the future studies.

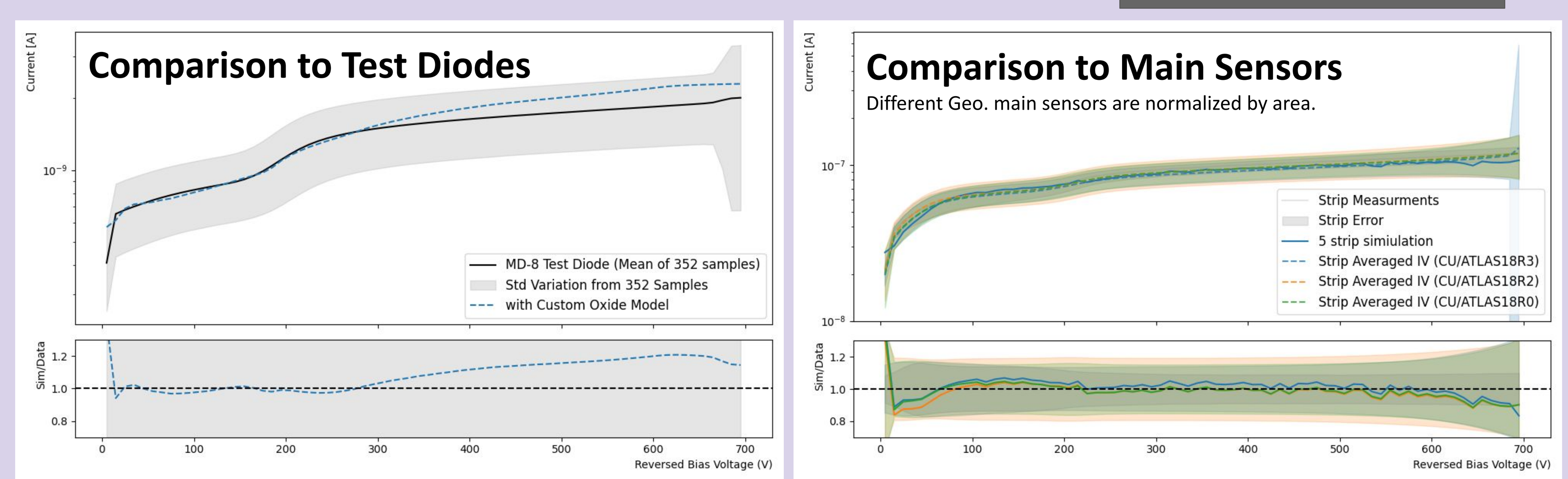
Custom Oxide Fixed Charge Modeling

- Analysis of the **bulk and edge current contributions** shows that the **edge current dominates** the total leakage.
- To account for this, an additional fixed oxide charge with **spatial distribution** is introduced in the **peripheral regions**.
- Such **non-uniform oxide charge distributions** are plausible due to **fabrication process variations**.
- **Hysteresis observed in the inter-strip capacitance measurement** suggests the presence of these oxide charge variation [4].

A Gaussian-distributed fixed charge is introduced throughout the oxide layer, defined such that the integrated charge density across its depth corresponds to an **equivalent surface charge of 1×10^{11} N/cm^{-2}.**

An **additional localized uniform charge distribution** is applied to regions 1 and 2, where the total equivalent surface charge within these regions are **2.42×10^{11} N/cm^{-2}**





Conclusions

Summary:

- **Dedicated TCAD model tuning** is essential to ITk strips to reproduce the **electrical measurements**.
- The custom oxide fixed-charge modeling shows good agreement with both test diodes and main sensors measurement up to full depletion, with slightly higher leakage current beyond full depletion. An overall current normalization factor remains under investigation.

Future Development:

- Investigate the **origin of the overall excess current** observed in TCAD simulation.
- Study the **impact of additional physical models on the pad and edge current contributions**, including tuning **surface SRH model**.
- **Implement irradiation-induced defect models** based on recent **DLTS measurement from the latest irradiation campaign.**

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