Investigation of the Current-Generation Mechanisms in the Edge Region of Planar Silicon Sensors using TCAD and TCT

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Motivation

Silicon sensors used in HEP experiments require a high electric field.

Problems:

- Large potential drop between the main detection region (Pad) and sensors edge (ER)
  → Susceptible to **electrical breakdown** in the **edge region.**
- Strong dependence of this breakdown on **surface conditions.**

To understand the breakdown, we need to understand the sensor better!

Questions:

i. Which parameters are relevant to this breakdown?
ii. How do different current-generation mechanisms contribute to the diode current?
iii. Can we probe the electric field near the surface?

Approaches: Field Maps: Electric Field + Doping Profile +Weighting Potential

Full FEM simulation

Synopsys TCAD

IV/CV:
→ Sensor geometry
→ Current generation mechanism

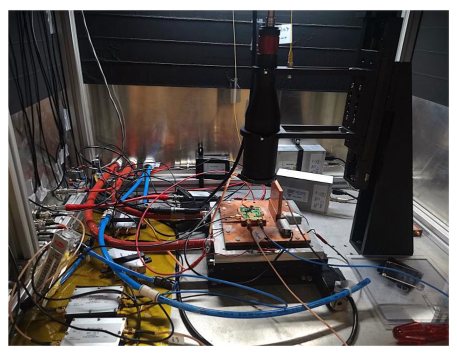
Monte Carlo Simulation

ap²

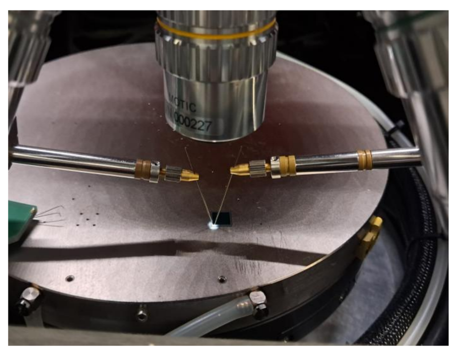
allpix-squared.docs.cern.ch

Fixed Fields
Fast transport simulation
Laser illumination (TCT):
→ Surface electric field

Measurement



TCT



IV/CV

Feedback to TCAD parameters

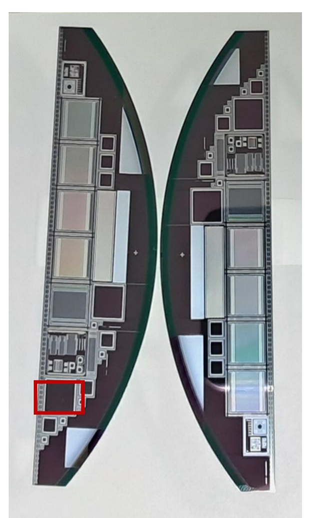
Test Diodes

ATLAS18 ITk Strip Upgrade test structure

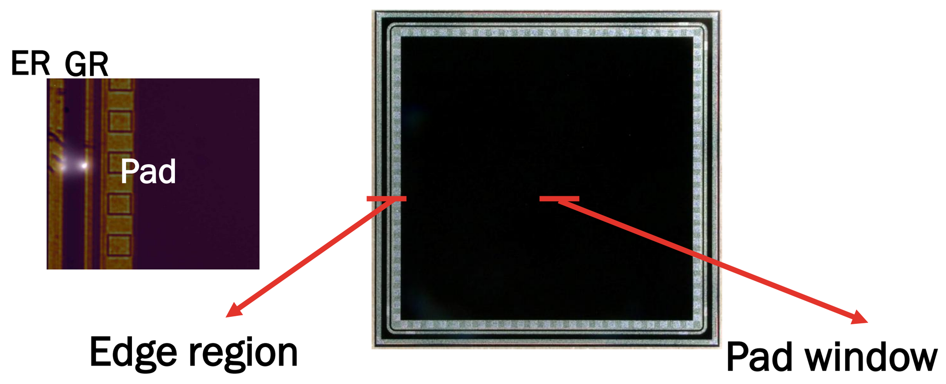
- 8 mm x 8 mm n^+pp^+ diodes (MD8)
- Guard ring and pad grounded
- Manufactured by Hamamatsu Photonics

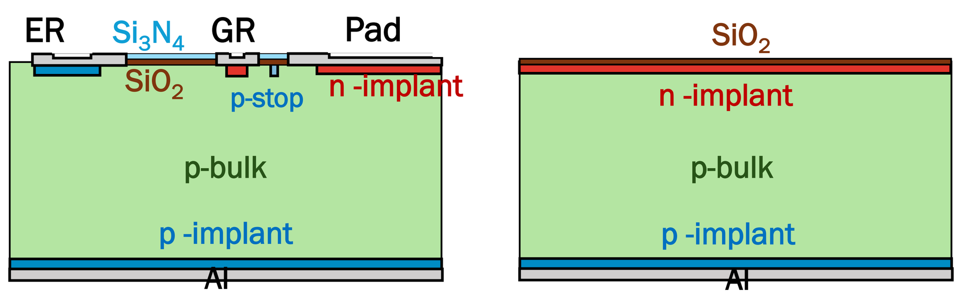
Diced MD8
Placed on a PCB

MD8 in
Halfmoon sensors



MD8 Geometry in TCAD





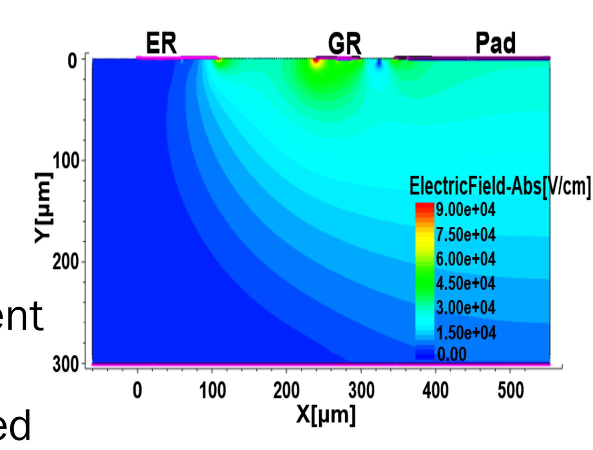
- 2D cross-section.
- Simulated currents are scaled according to diode area. $I_{sim} = I_{pad} \cdot A_{pad} + I_{edge} \cdot A_{edge}$

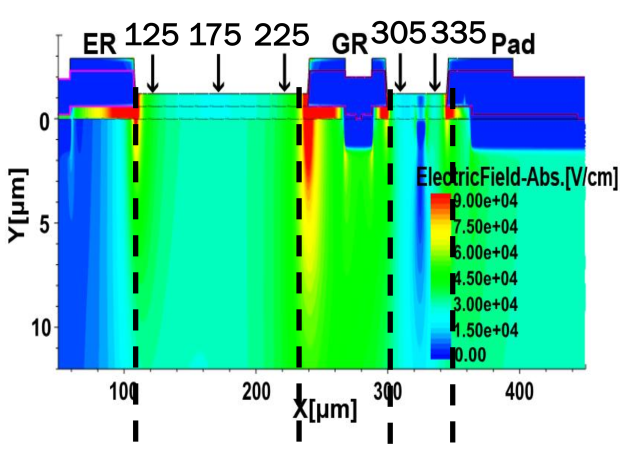
Investigation of Surface Electric Field

TCAD simulated electric field -500V

- Undepleted edge
- Low field region introduced by P-stop
- Strong field peaks at the edges of ER & GR metal (and implants)

★ Red laser illumination on the front side





Charge profile (charge collection):

- Obtained by integrating the full induced current
- Sensitive to local charge loss or gain

→ No charge loss between ER and GR observed

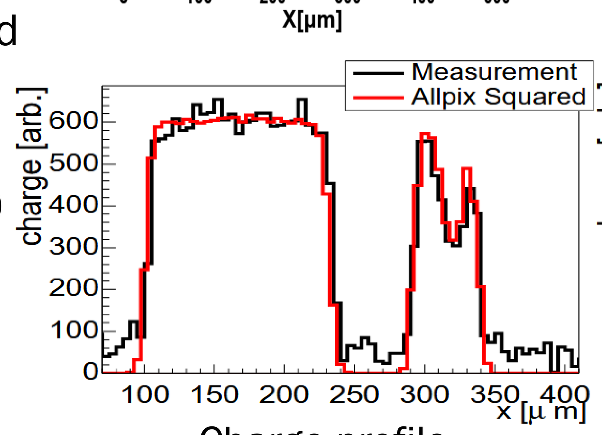
Prompt current profile

- Obtained by integrating the initial rise (0.2 ns) of the transient currents

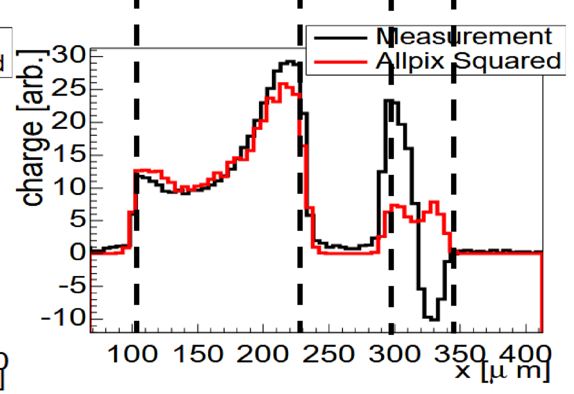
$$I_{e,h} = Q \cdot \vec{E}(\vec{x}) \cdot \mu_{e,h}(|\vec{E}(\vec{x})|) \cdot \vec{E}_w(\vec{x})$$

- $\Delta t \to 0$: **Reflects the local electric field**

$$I \propto E \cdot \mu(E) \cdot E_w$$

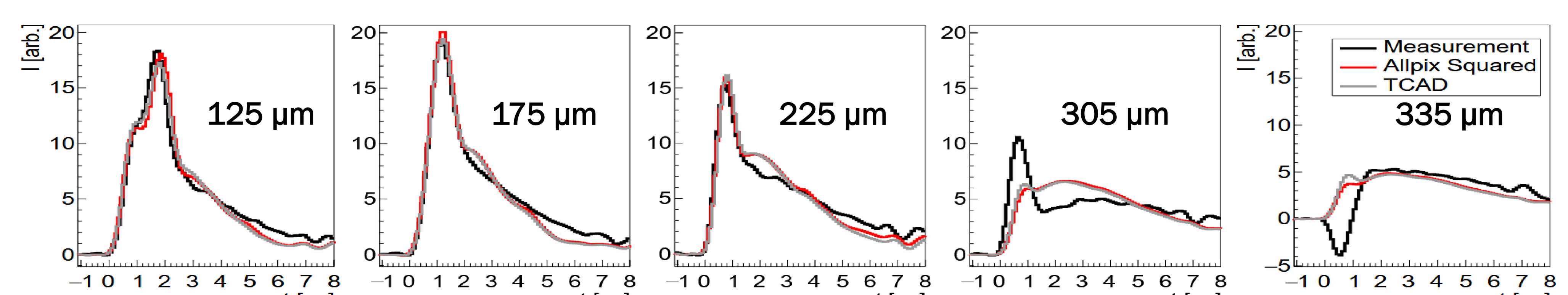


Charge profile



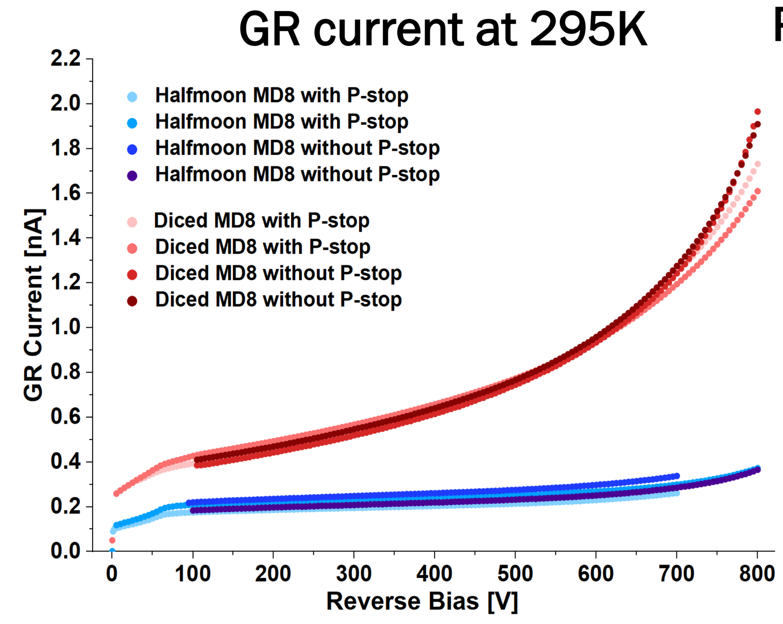
Prompt current profile

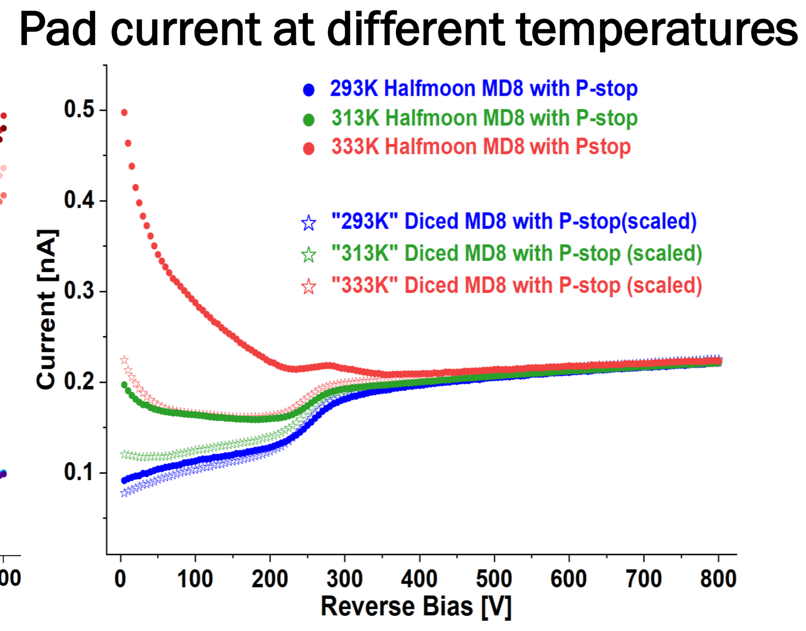
Allpix² and TCAD simulated transient currents from red laser generation ★



Good agreement of measurement and simulation!   Discrepancy in the P-stop region

IV Measurements





Guarg Ring (GR) Current:

- Higher GR current observed for diodes with shorter edges (diced diodes).

Pad Current:

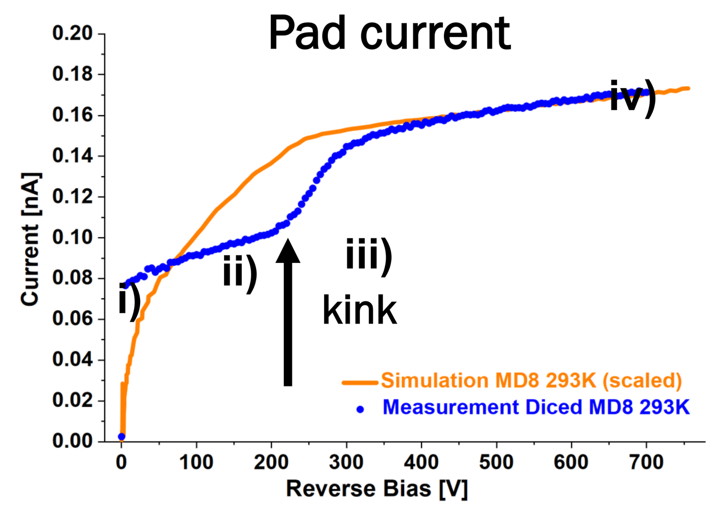
- Strong temperature dependence of the current shape at low bias voltages.
- Current decreases until a certain bias at high temperatures.
- Currents scale with bulk generation at high bias voltages ~ n_i (T)
- Kink at ~250V, near the full depletion voltage
- **Stronger decrease observed for diced MD8**

→ Are defects at the dicing edge causing the current at low bias voltages?

Simulated IV without Defects Implementation

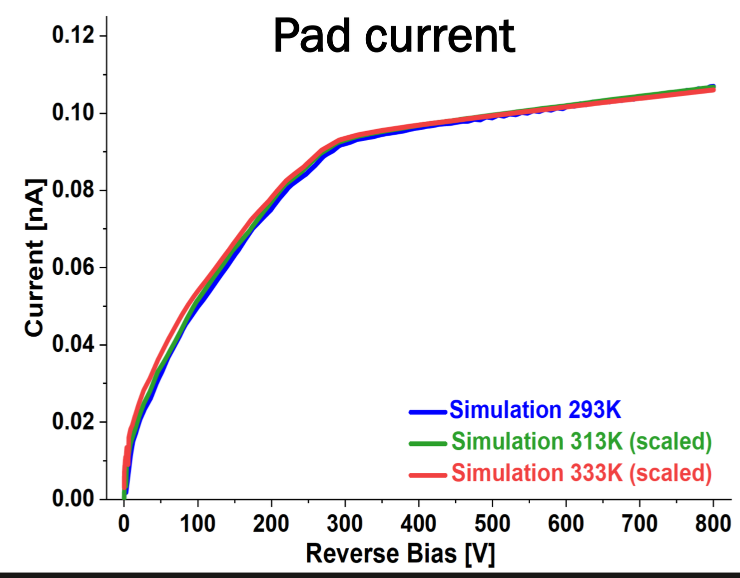
Measured behaviors:

i. Sharp increase within the first 0.5V, like an “offset” current.
ii. Slow increase at low bias voltages.
iii. **Kink near the $V_{full\text{-}depletion}$**
→ **Defects at the backside implant?**
iv. Slow increase after full-depletion.



Initial simulations (without any defects):

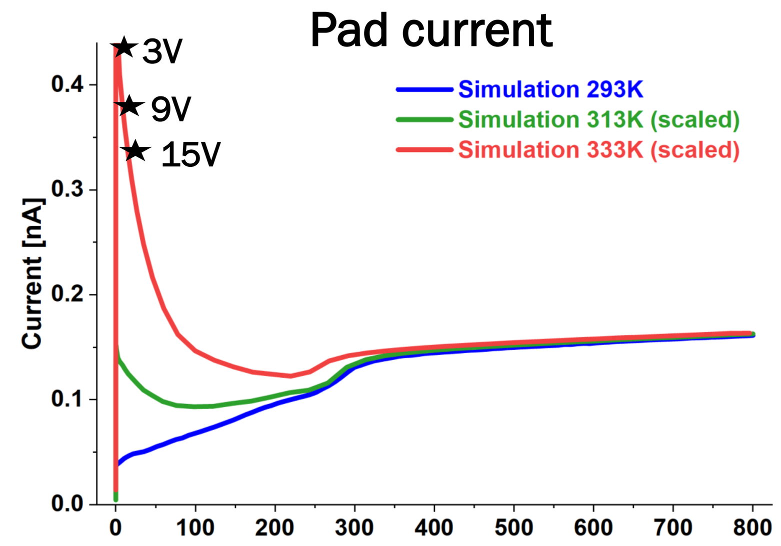
- No noticeable temperature dependence observed.
- No “offset current” observed.
- ✓ Currents at high bias voltages reproduced.



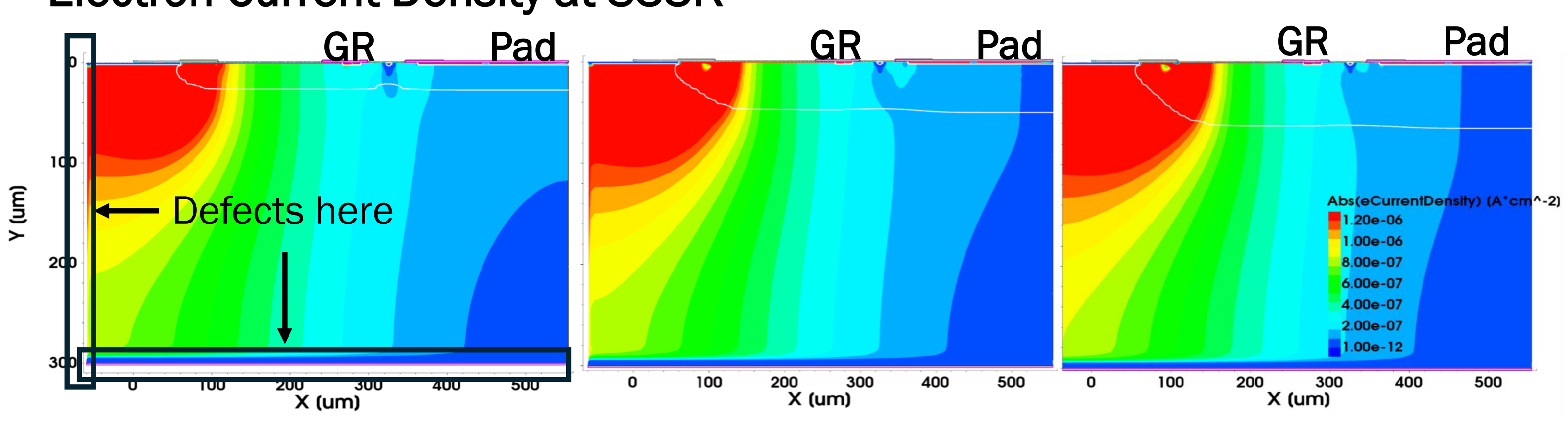
Simulated IV with Defects Implementation

Defects at the dicing edge + the backside implant

✓ Currents decrease at low bias and high temperature reproduced.
✓ Currents at high bias voltages still reproduced.
✓ Kink around $V_{full\text{-}depletion}$



★ **Electron Current Density at 333K**



- Charge carriers generated by defects at the dicing edge.
- As the bias increases, fewer electrons are collected by the pad electrode. more are collected by the GR instead.

Summary

✓ Shape of IV roughly reproduced for different temperatures after implementing defects at the dicing edge and backside implant.
✓ 660 nm top TCT was used to study the electric field in the periphery of silicon sensors, the goal to probe the surface electric field was achieved.
✓ TCT pulses, prompt current and charge collection well reproduced by simulations between the GR and ER.
? Deviations near the p-stop not yet understood