TCAD Simulation of the Electrical Performance of the ATLAS18 Strip Sensor for the HL-LHC

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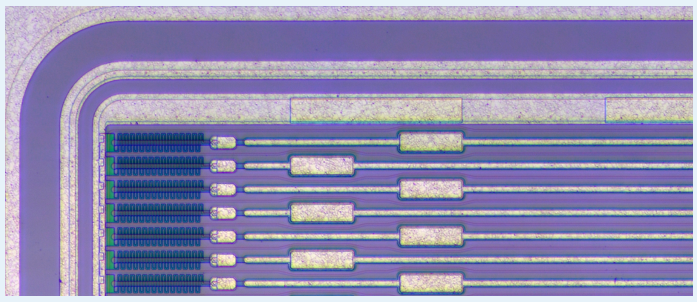
The ITk Strip Detector

- High-Luminosity LHC: upgraded collision rate for higher stats to probe rare processes
  - beam-on planned for 2029
- ITk: in-production Inner Tracker upgrade for ATLAS experiment in HL-LHC
  - needs to deal with 5x higher luminosity and 10x higher lifetime radiation fluence
- Inner layers use square pixel sensors to maximize tracking performance
- Outer layers use crossed pairs of strip sensors [1] to provide full tracking with fewer channels than pixel sensors
  - up to 10^{15} 1-MeV n_{eq}/cm^2 radiation fluence expected in strip detector

Strip Sensor Layout

- Strip sensors are fabricated on 6" wafers in 8 different layouts to cover cylindrical ITk
  - manufactured by Hamamatsu Photonics
  - sensors have 2 or 4 rows of ~1k strips each
  - n^+-in-p strips: roughly 75µm x 40mm
  - active thickness: 300µm

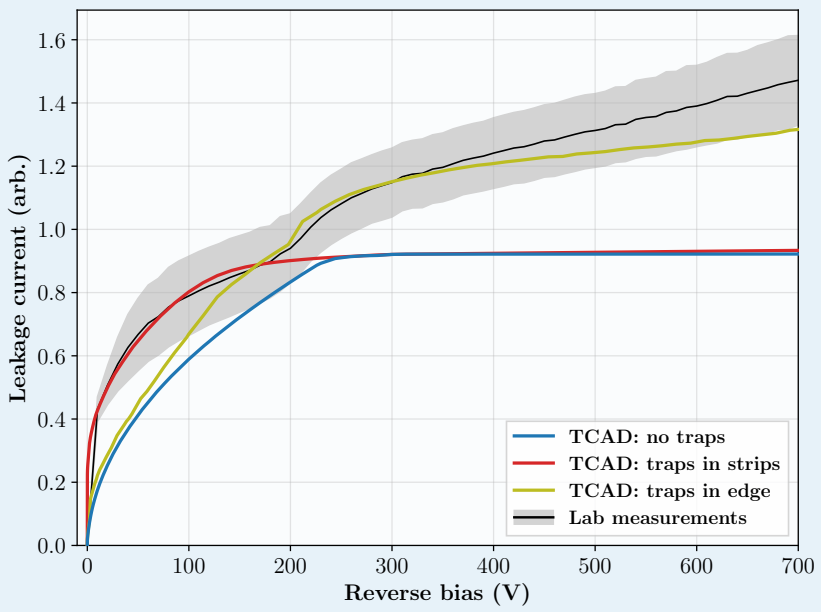


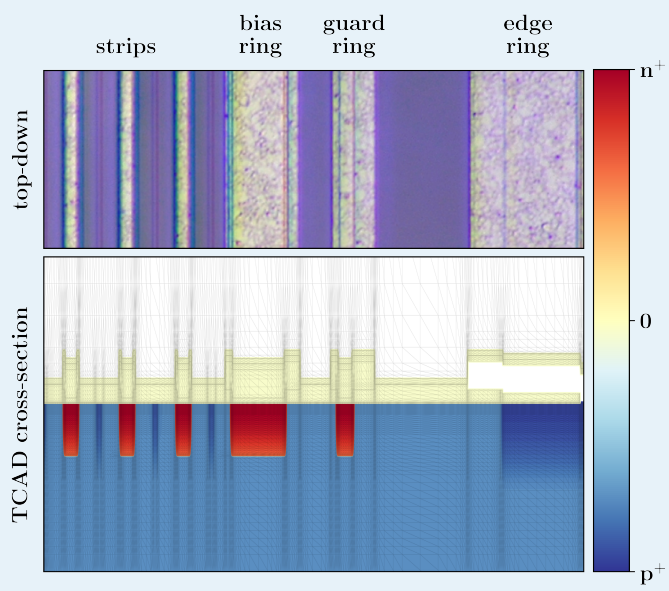
TCAD Simulation

- Sentaurus TCAD is used to simulate the electrical behaviour of a sensor
- Can simulate edge structures and/or multiple strips to model full device
  - 2D simulation takes advantage of sensor symmetries to simplify computation
- Simulation includes:
  - detailed geometrical model of field oxide, passivation, and top-side contacts
  - doping and fixed oxide charge measured via CV and implant resistance (see also [2])
  - traps measured by DLTS [3], inferred from TCAD results, or based on existing models
  - model of humidity effects on passivation surface based on diode simulation [4]

Sensor IV

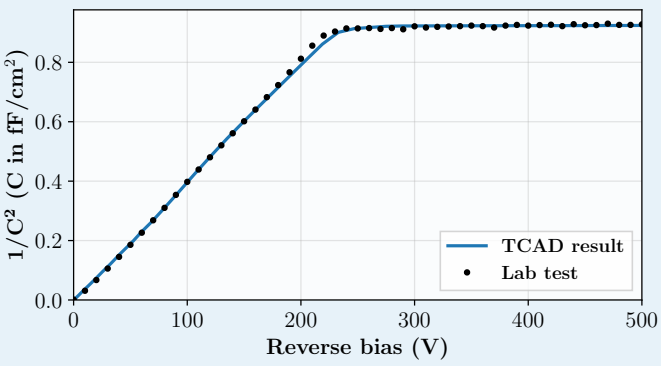
- Sensor IV depends on geometry, surface effects, charge trapping
- Tuning TCAD to match lab IVs reveals mechanisms of current generation
  - surface currents in sensor edge have large effect on sensor IV
  - using bulk traps from DLTS [3] and parametrizing surface traps as in [5]
  - traps in strip area increase generation current at low bias
  - surface leakage from traps near edge reproduces shape of IV past 200 V
- Next steps: combine simulations coherently, model radiation damage





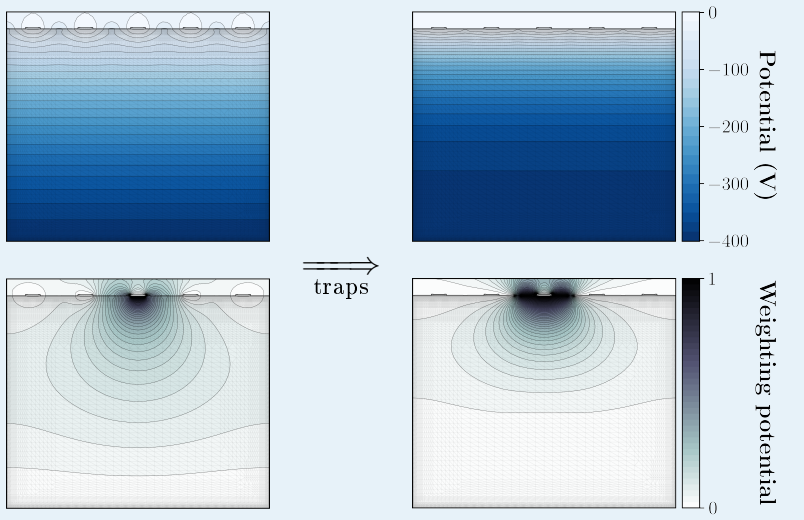
Sensor CV

- Sensor CV ($1/C^2$ shown) is a simple function of bulk thickness and doping
  - allows precise estimation of these parameters



Inputs for ATLAS Detector Simulation

- ATLAS physics analysis needs detailed simulation of collision, detection, reconstruction
- Simulation of detector response requires input from TCAD
  - electric field for charge drift
  - weighting field for induction
- TCAD results show effect of radiation-induced traps
  - Perugia trapping model [5] used to estimate end-of-life damage
  - traps raise depletion voltage, reduce interstrip isolation



Conclusions

- We have developed a detailed 2D TCAD model of the ITk strip sensor
  - model is based on measurements of sensors and test devices
  - simulation reproduces observed behaviour of unirradiated sensors
  - next step: extend simulation to include post-irradiation behaviour
- This work supports the development, future operation, and physics analysis of the ATLAS ITk

References

[1] Y. Unno *et al.* "Specifications and pre-production of n^+-in-p large-format strip sensors fabricated in 6-inch silicon wafers, ATLAS18, for the Inner Tracker of the ATLAS Detector for High-Luminosity Large Hadron Collider". JINST 18 (2023).

[2] Y. Unno. "Analysis of MOS capacitor with p layer with TCAD simulation". HSTD 13 (2023).

[3] C. T. Klein. "Defect level identification of ATLAS ITk Strip Sensors using DLTS". HSTD 13 (2023).

[4] I-S. Ninca. "Understanding the humidity sensitivity of sensors with TCAD simulations". HSTD 13 (2023).

[5] P. Asenov *et al.* "TCAD modeling of bulk radiation damage effects in silicon devices with the Perugia radiation damage model". NIM A 1040 (2022).

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