TCAD simulation of RD53A compatible pixel cells and sensor productions by MPP

J. Beyer, M. Chatterjee, A. Macchiolo, R. Nisius, N. Perez, N. Savic, R. Taibah

Max Planck Institut für Physik

19.-21.02.2018

Trento Workshop on Advanced Silicon Radiation Detectors

MAX-PLANCK-GESELLSCHAFT

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Overview

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1. TCAD simulation of RD53A compatible pixel cells

- optimization of pixel implant size
- looking at AC simulations to simulate pixel capacities
- CCE before and after irradiation

2. Sensor productions by MPP

- SOI4 production at MPG-HLL
- development of temporary metal for quality assurance

Introduction

ATLAS ITk upgrade

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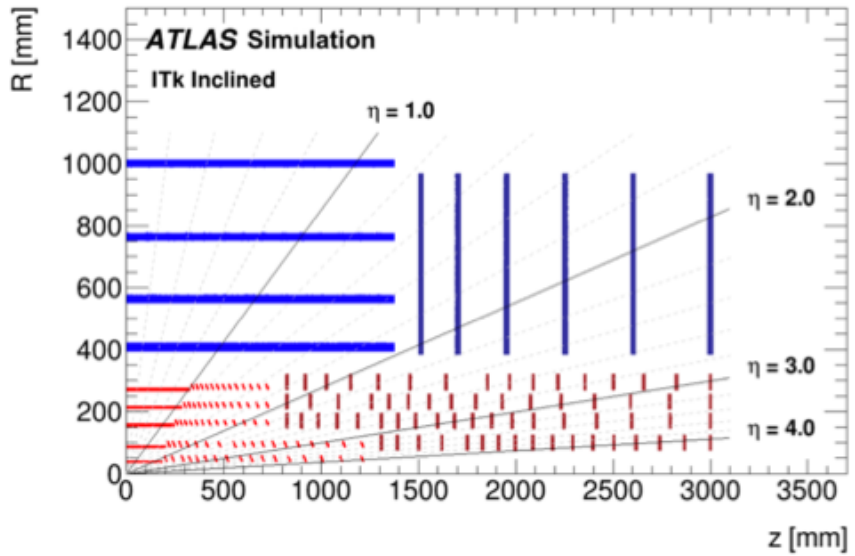
Inner Tracker (ITk) upgrade in preparation for the ATLAS experiment facing the High Luminosity phase of the Large Hadron Collider (HL-LHC)

- harsher conditions leading to
  - **higher track density**: smaller pixel cells to keep a low occupancy
  - **higher fluence**: thin sensors improve radiation hardness

  → Simulate thin sensors with small pixels for design optimisation

- punch-through (PT) structures to test sensors before interconnection induce significant performance degradation after irradiation

  →to enable testing for final productions replace PT by a temporary metal technology



TCAD Simulation

of RD53A compatible pixel cells

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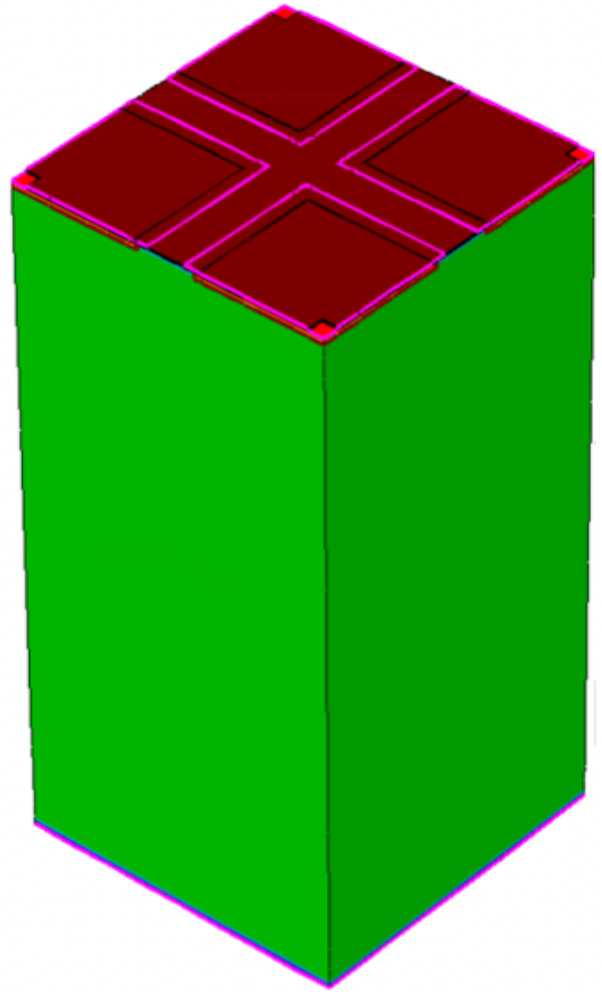
- use a 3D TCAD model for the investigation of properties of small pixel cells with different implant sizes
- because of symmetry, simulation of ¼ pixel is sufficient
  - four quarter pixels used in this study allowing for correct description of Ramo potential and inter-pixel capacitance
- investigate IV / CV / CCE of different implant sizes
  - radiation damage simulated with Perugia 2017 model [1] ($1x10^{15}$ n_{eq}/cm^2)
    - bulk damage: 2 acceptor, 1 donor trap, different e/h cross sections and introduction rates
    - surface damage: fixed oxide charge of $5\times10^{10}cm^{-2}$ for not-irradiated and $1\times10^{12}cm^{-2}$ for irradiated sensors
    - interface traps according to Perugia 2017 model



[2] F. Moscatelli et al., Combined Bulk and Surface Radiation Damage Effects at Very High Fluences in Silicon Detectors: Measurements and TCAD Simulations

TCAD Simulation

structure of interest

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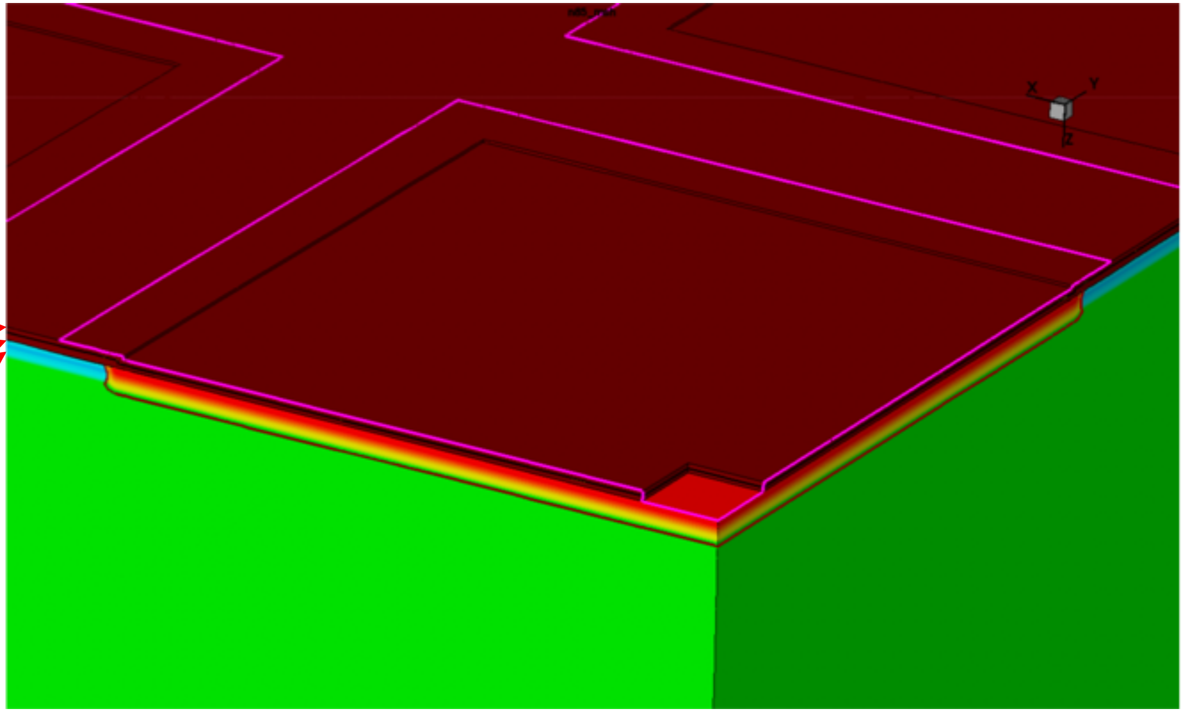
insulation layers:

- LTO
- Nitride
- SiO_2



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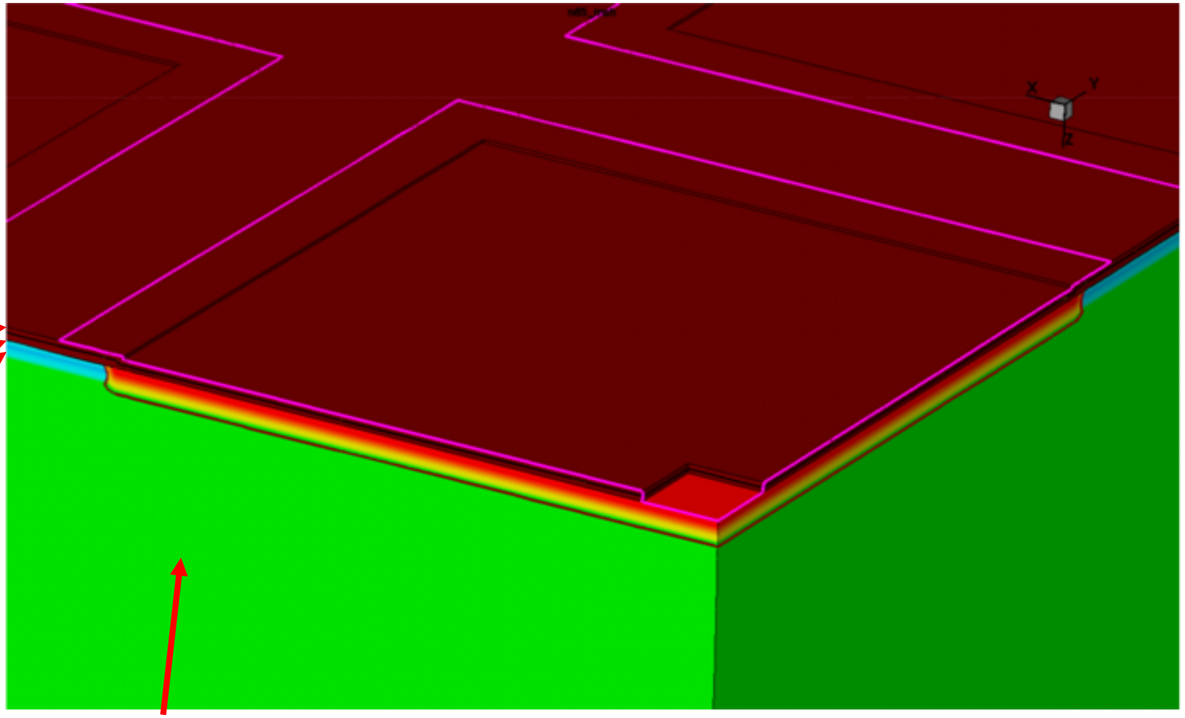

high resistivity p-type bulk material (5×10^{12} cm^{-3})

TCAD Simulation

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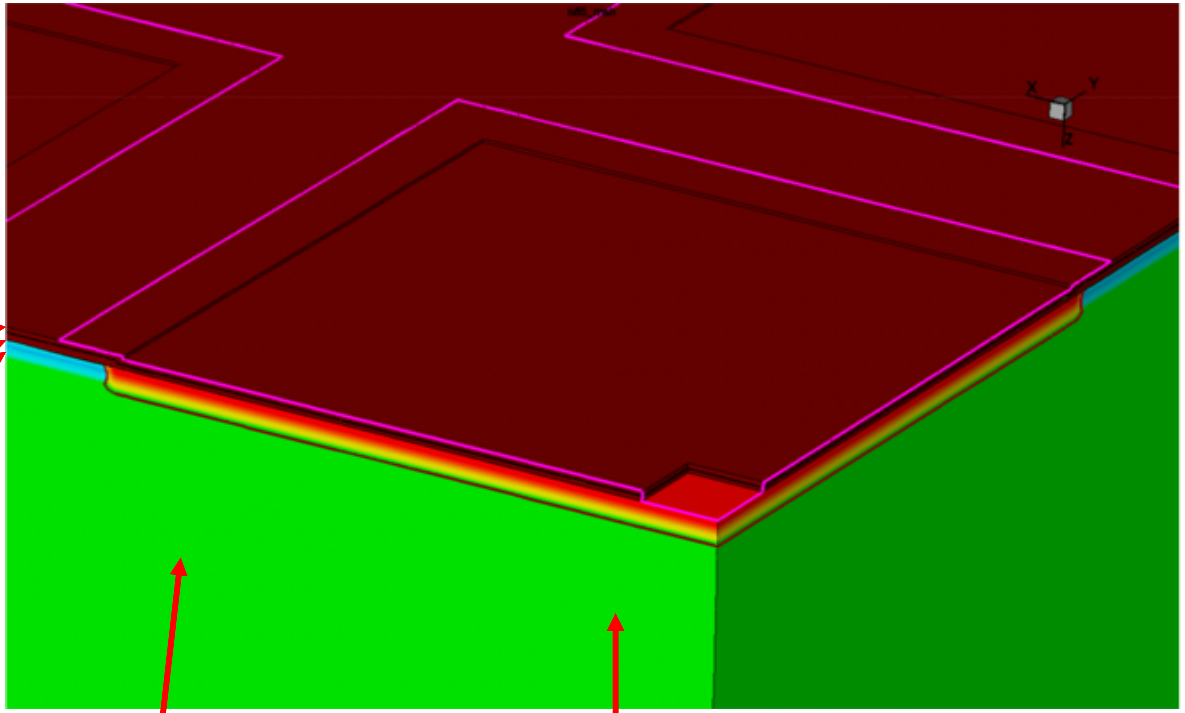

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high resistivity p-type bulk material (5×10^{12} cm^{-3})

thickness: 100 μm

TCAD Simulation

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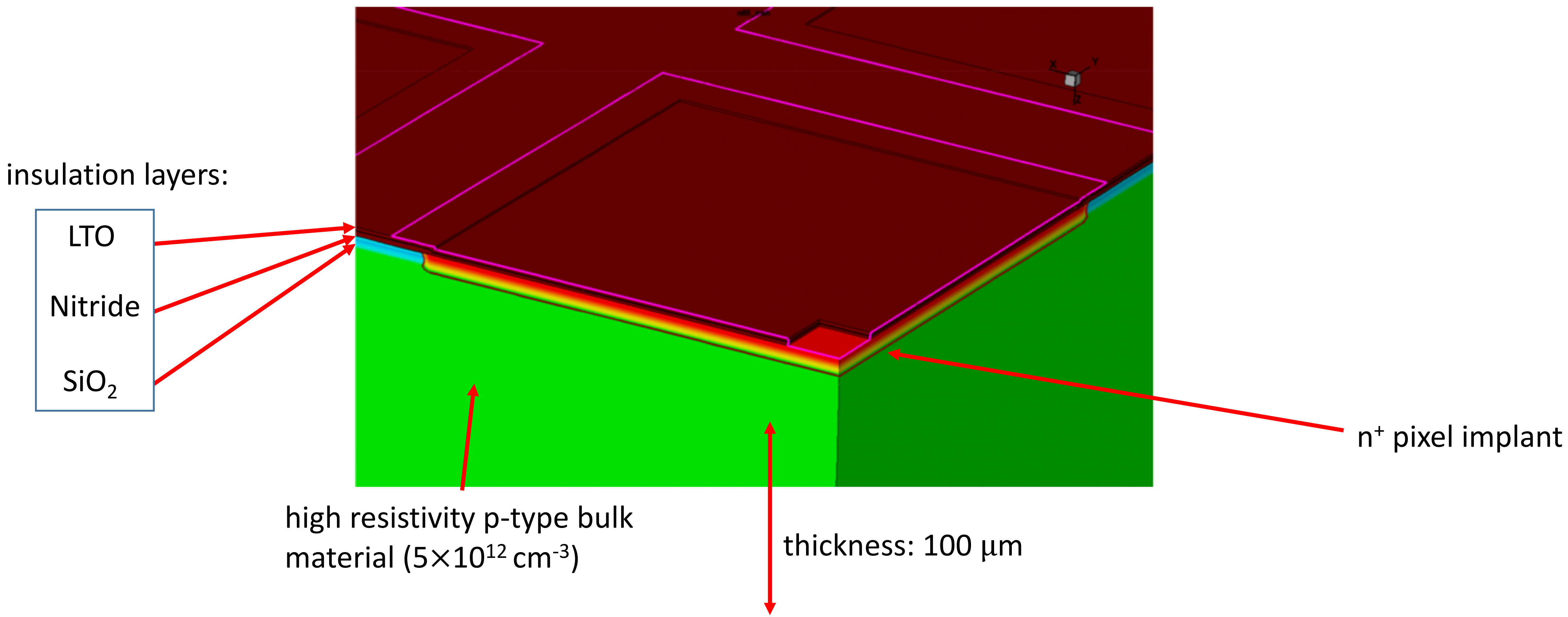

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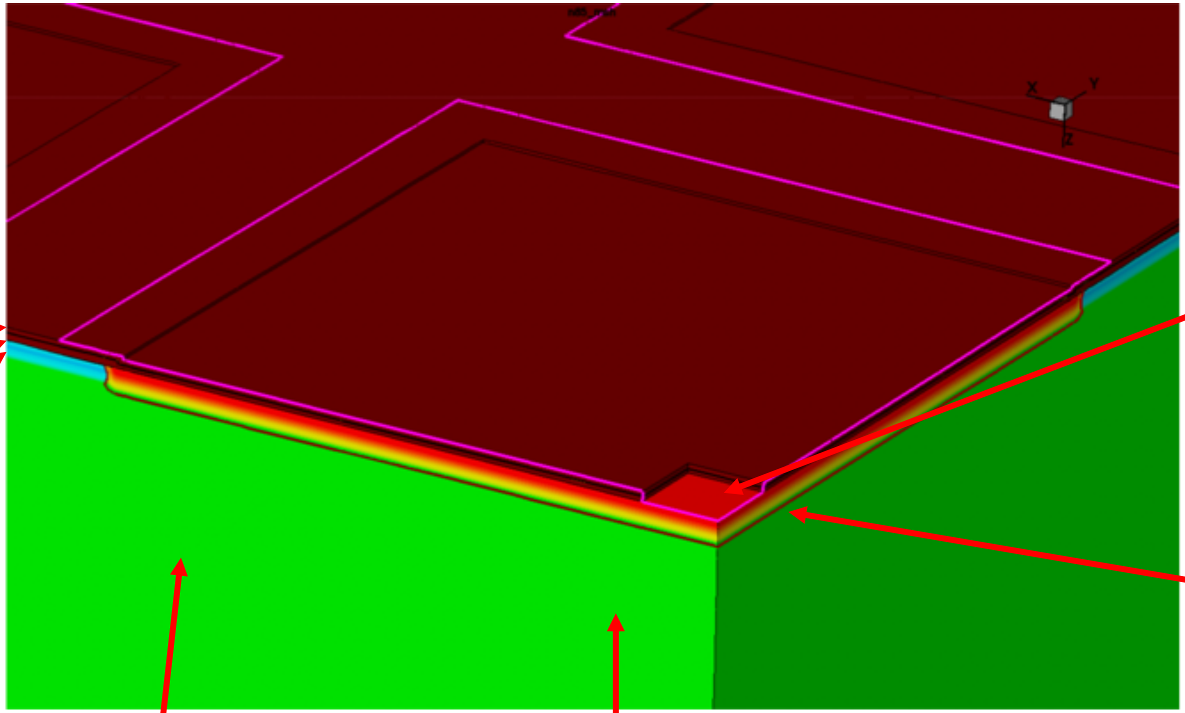

via to connect electrical contact with implant

n^+ pixel implant

high resistivity p-type bulk material (5×10^{12} cm^{-3})

thickness: 100 µm

TCAD Simulation

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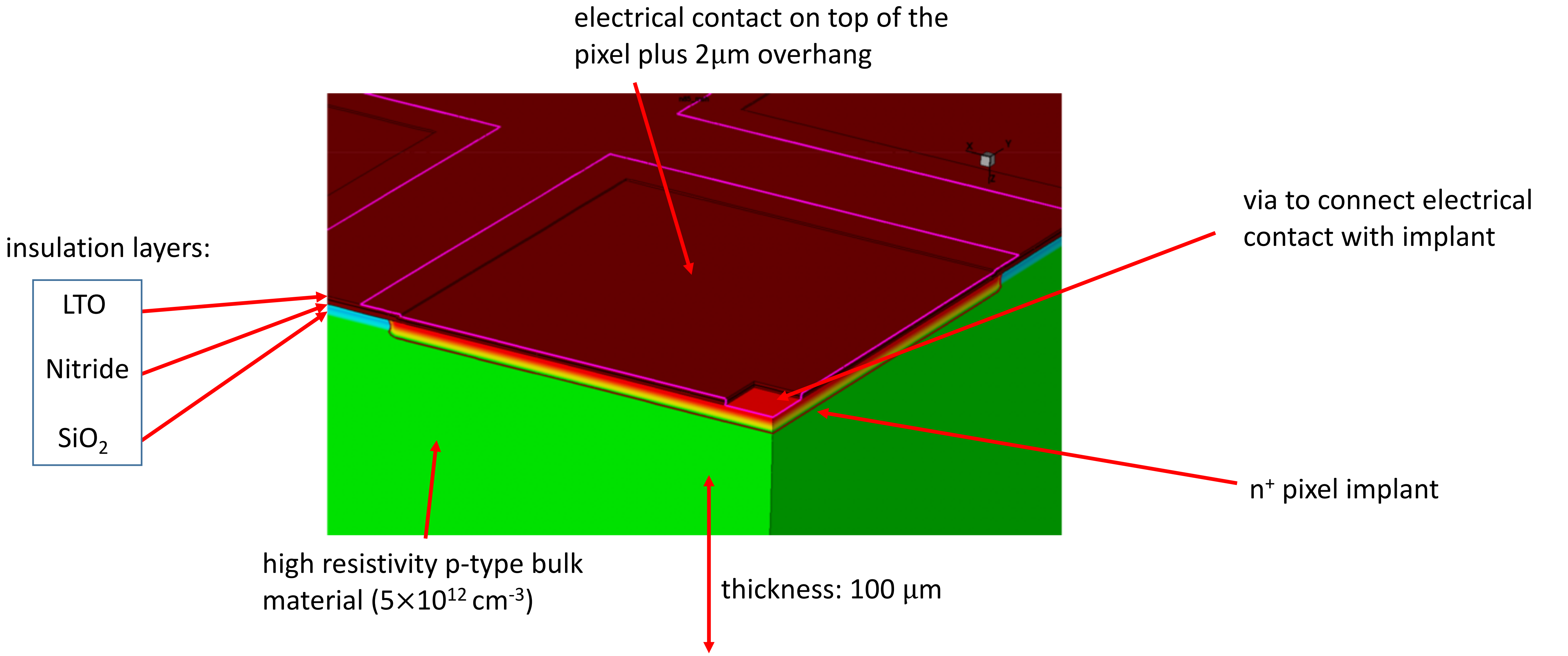

TCAD Simulation

structure of interest

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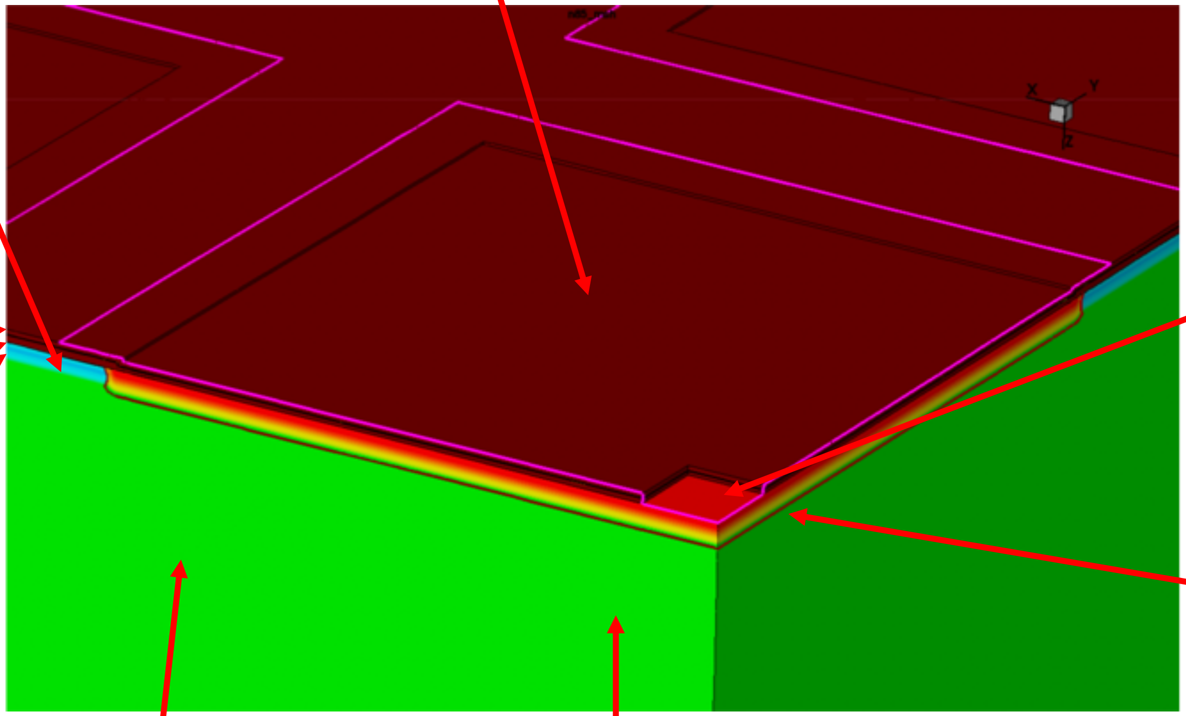
electrical contact on top of the pixel plus 2μm overhang

p-spray inter-pixel isolation

via to connect electrical contact with implant

insulation layers:

- LTO
- Nitride
- SiO_2



n^+ pixel implant

high resistivity p-type bulk material (5×10^{12} cm^{-3})

thickness: 100 μm

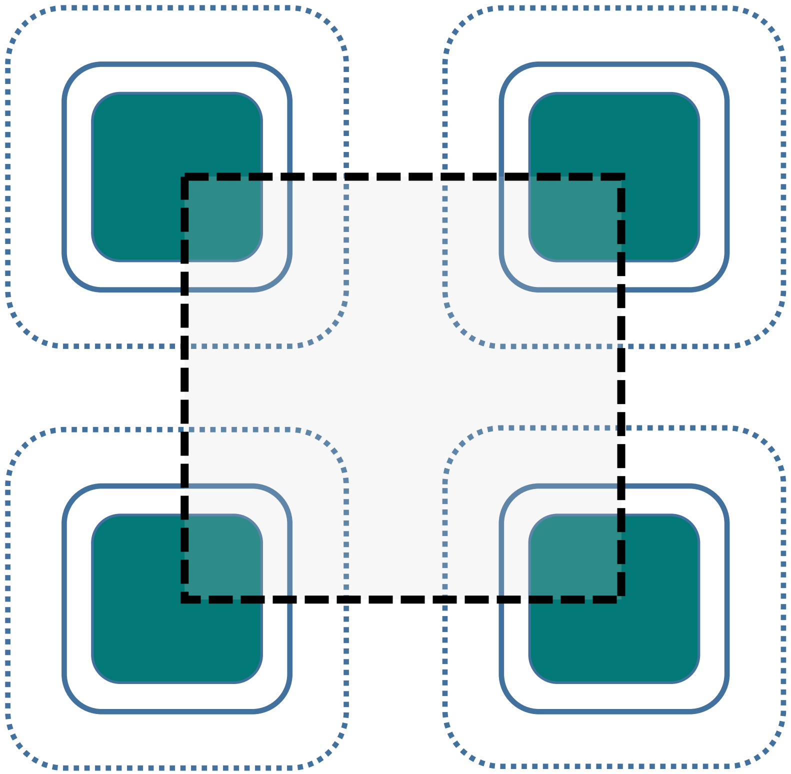
TCAD Simulation

influence of implant size: general

- the new RD53 read-out chip will have a 50x50μm^2 grid
  - pixel implant size and shape can be modified within this boundary condition

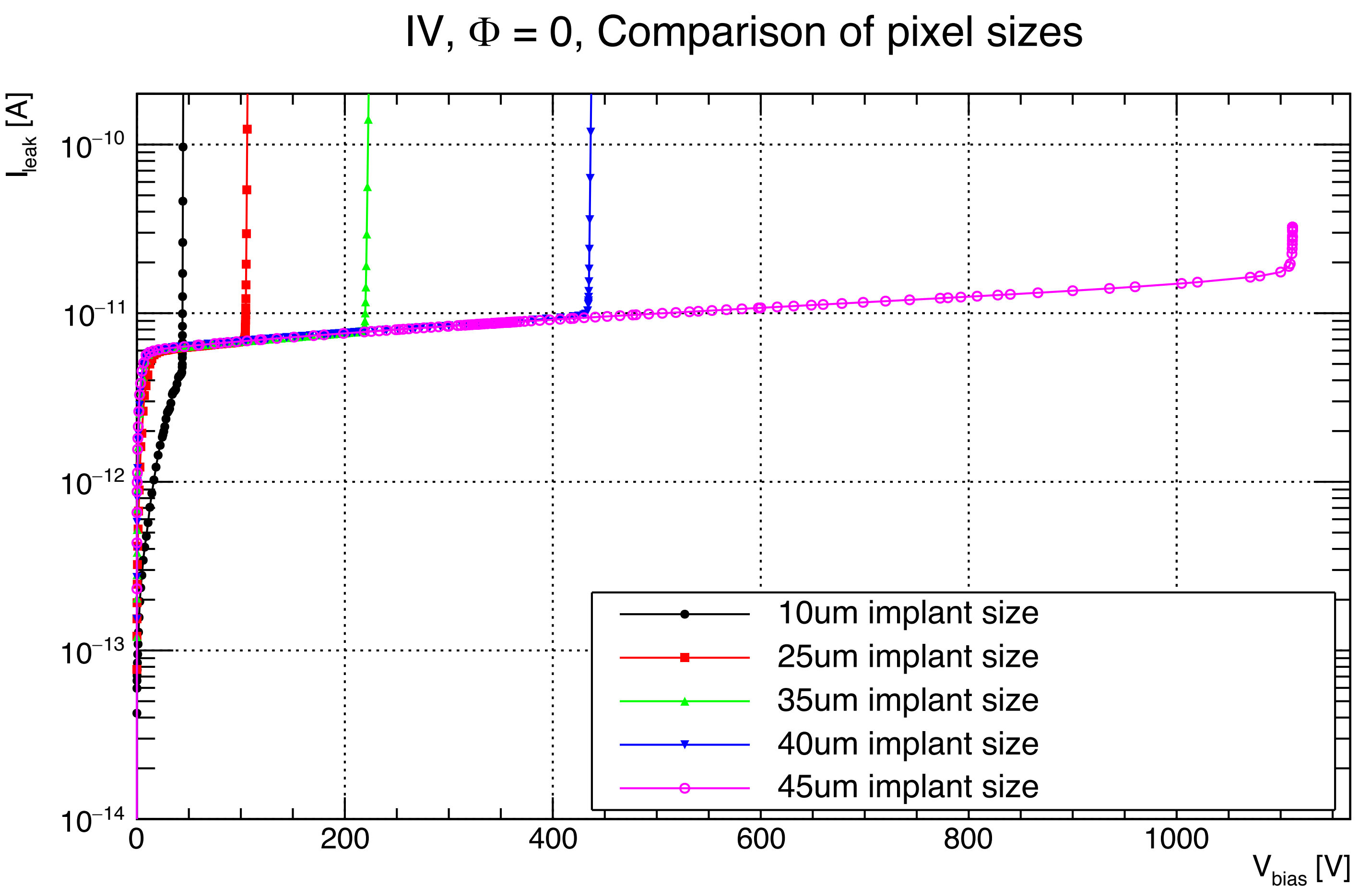
- larger implants theoretically:
  - \+ have higher breakdown voltages
  - \+ have better charge collection efficiency
  - \- have higher inter-pixel capacity (-> higher noise)

top-view, pixel sizes

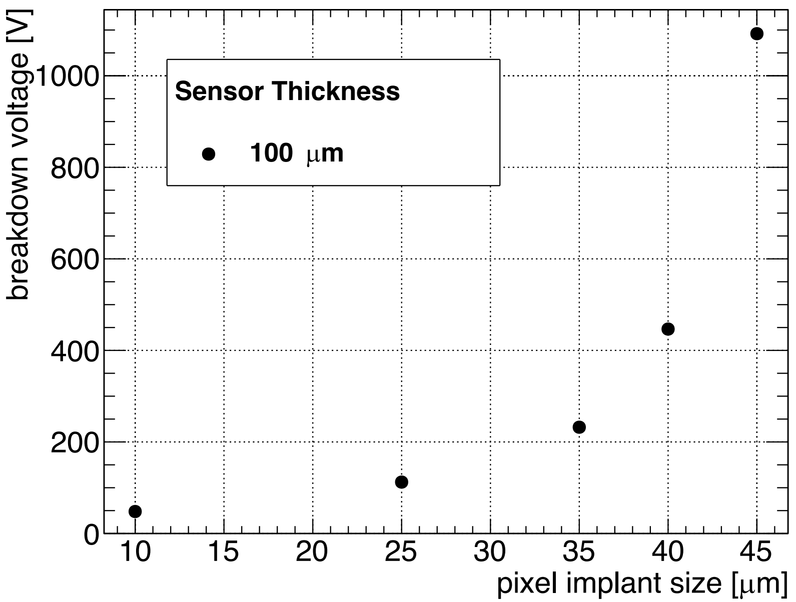


TCAD Simulation

influence of implant size: breakdown behaviour



- larger pixel implants shield the p-spray from the backside potential
  - smaller potential difference between p-spray and pixel implant
  - higher breakdown voltage



TCAD Simulation

influence of implant size: pixel capacity

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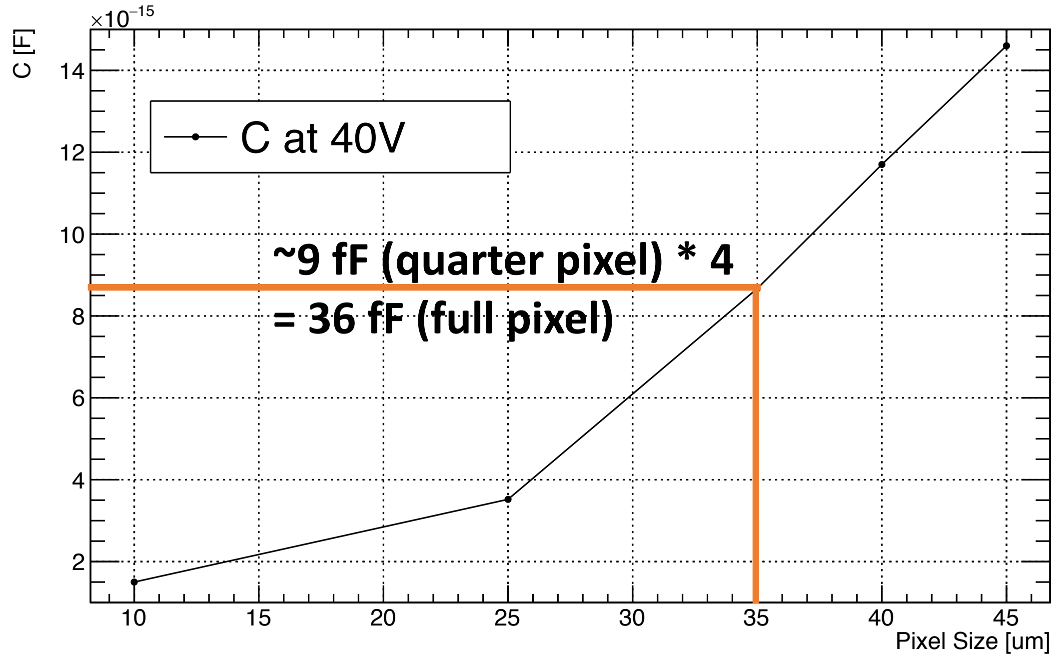
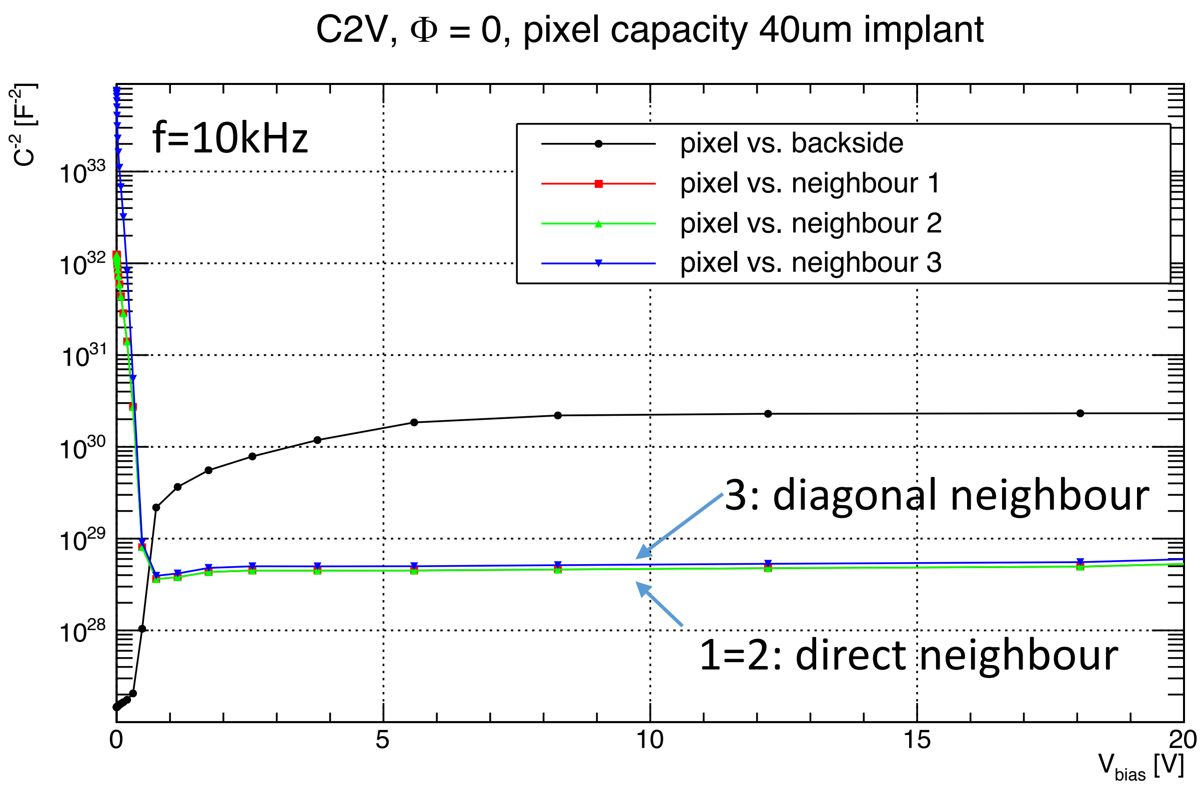
- RD53A is specified up to a 100 fF input capacity
- minimal threshold (600e) is guaranteed up to 50 fF
- inter-pixel capacity outweighs pixel-bulk capacity by far
    - inter-pixel capacity determined by implant size and p-spray doping concentration



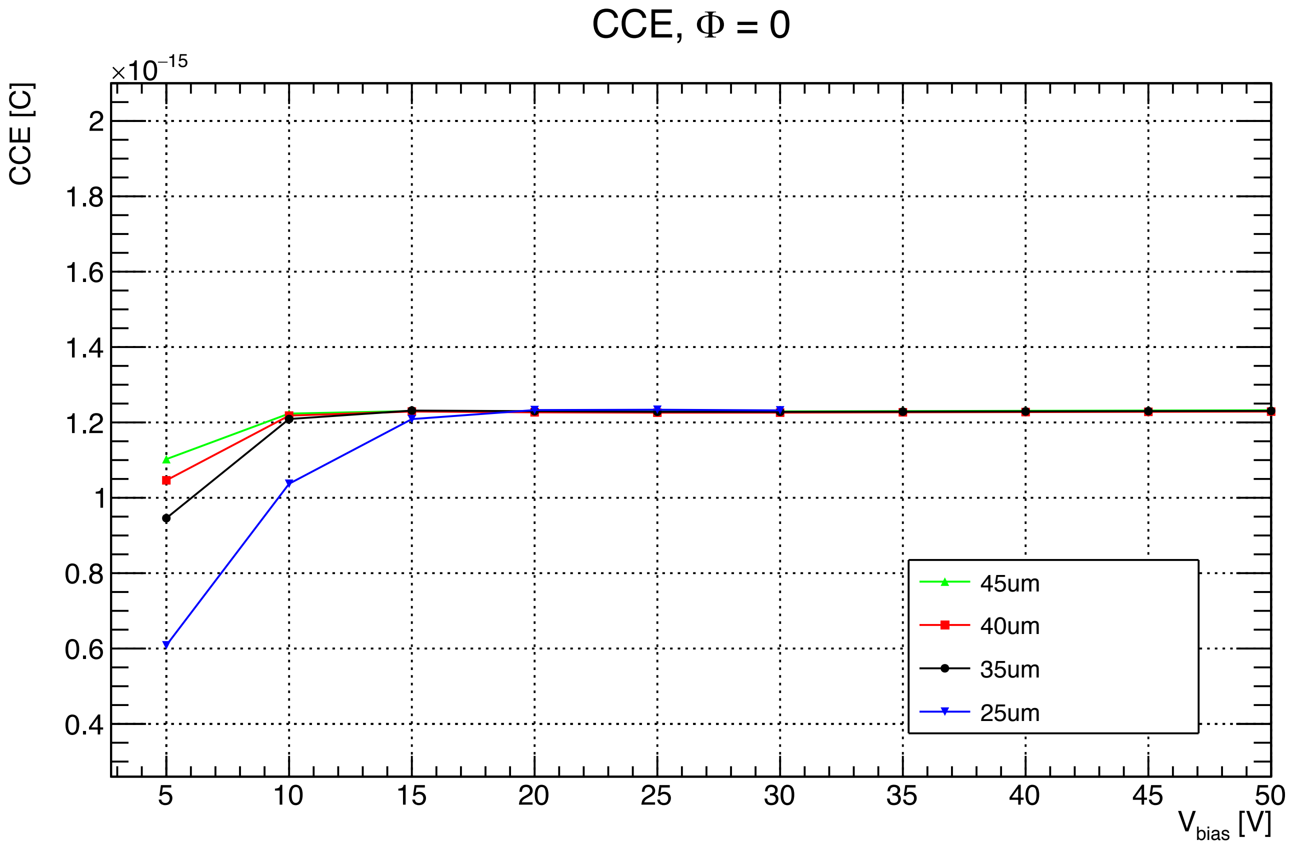


-> measurements indicate capacity between 20-40 fF

TCAD Simulation

influence of implant size: charge collection efficiency

- charge collection before irradiation is equal for all implant sizes from 25-45µm after depletion
- at low voltages, significantly more charge collected by larger pixel implants
- larger pixel implants have earlier depletion voltages



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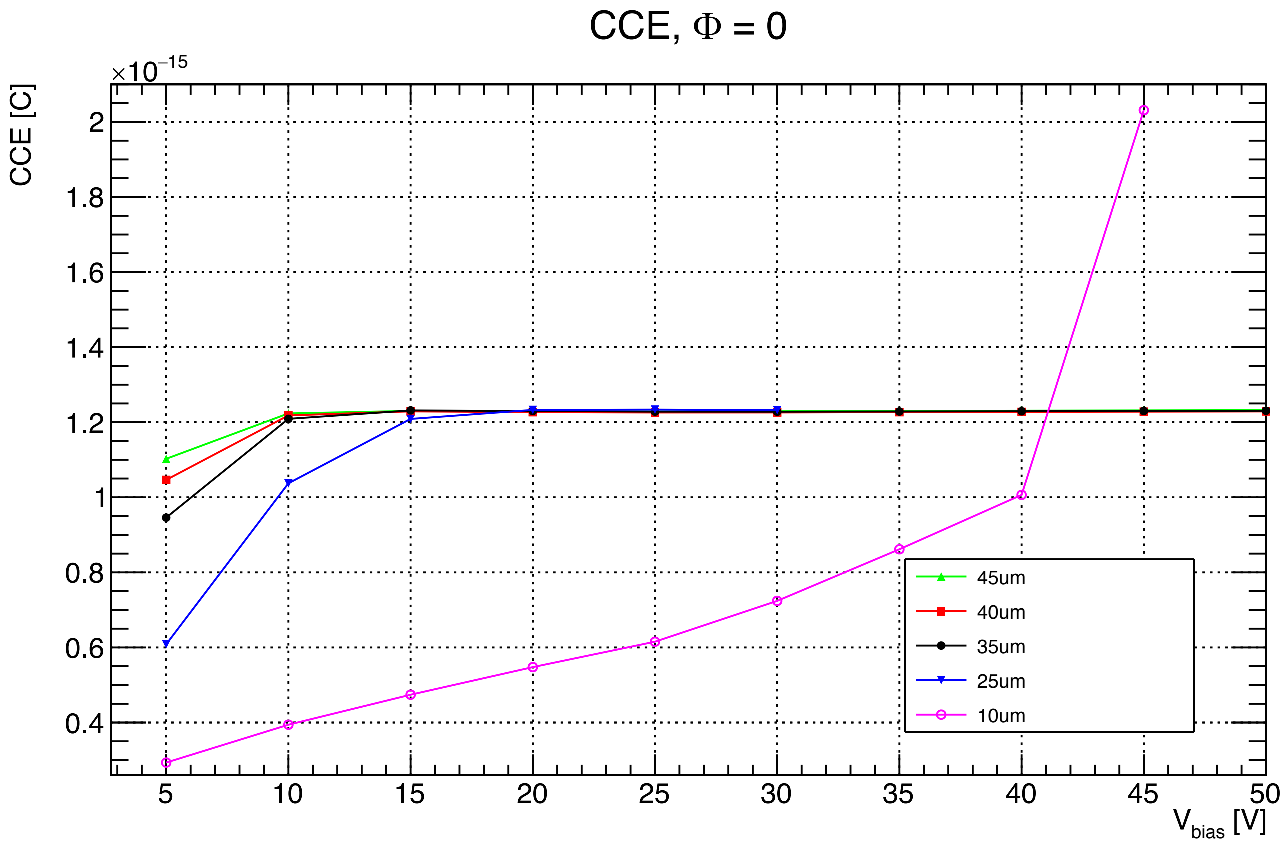
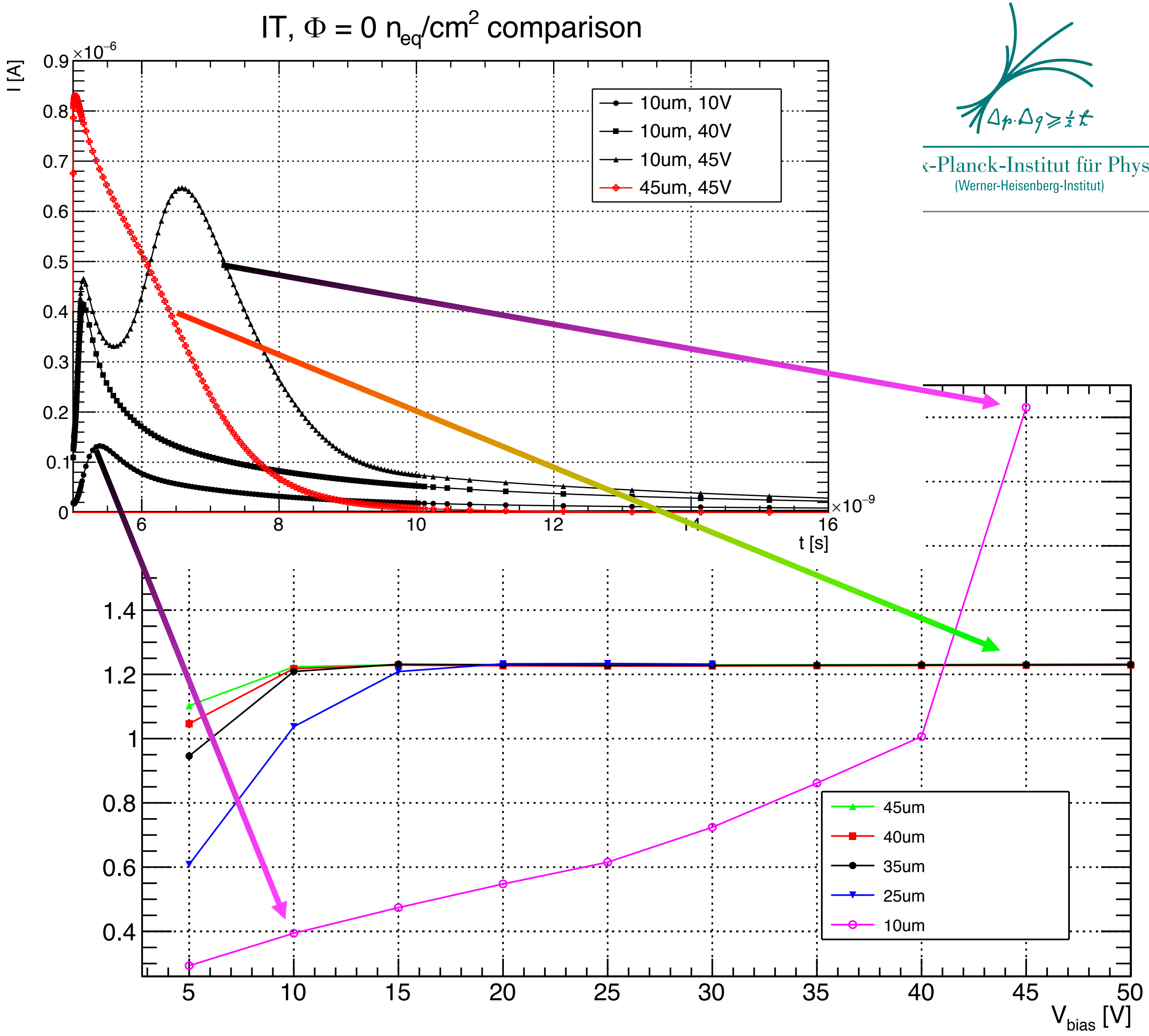
- 10µm shows that very small pixel cells can not be used due to much later depletion



TCAD Simulation

influence of implant size: charge collect



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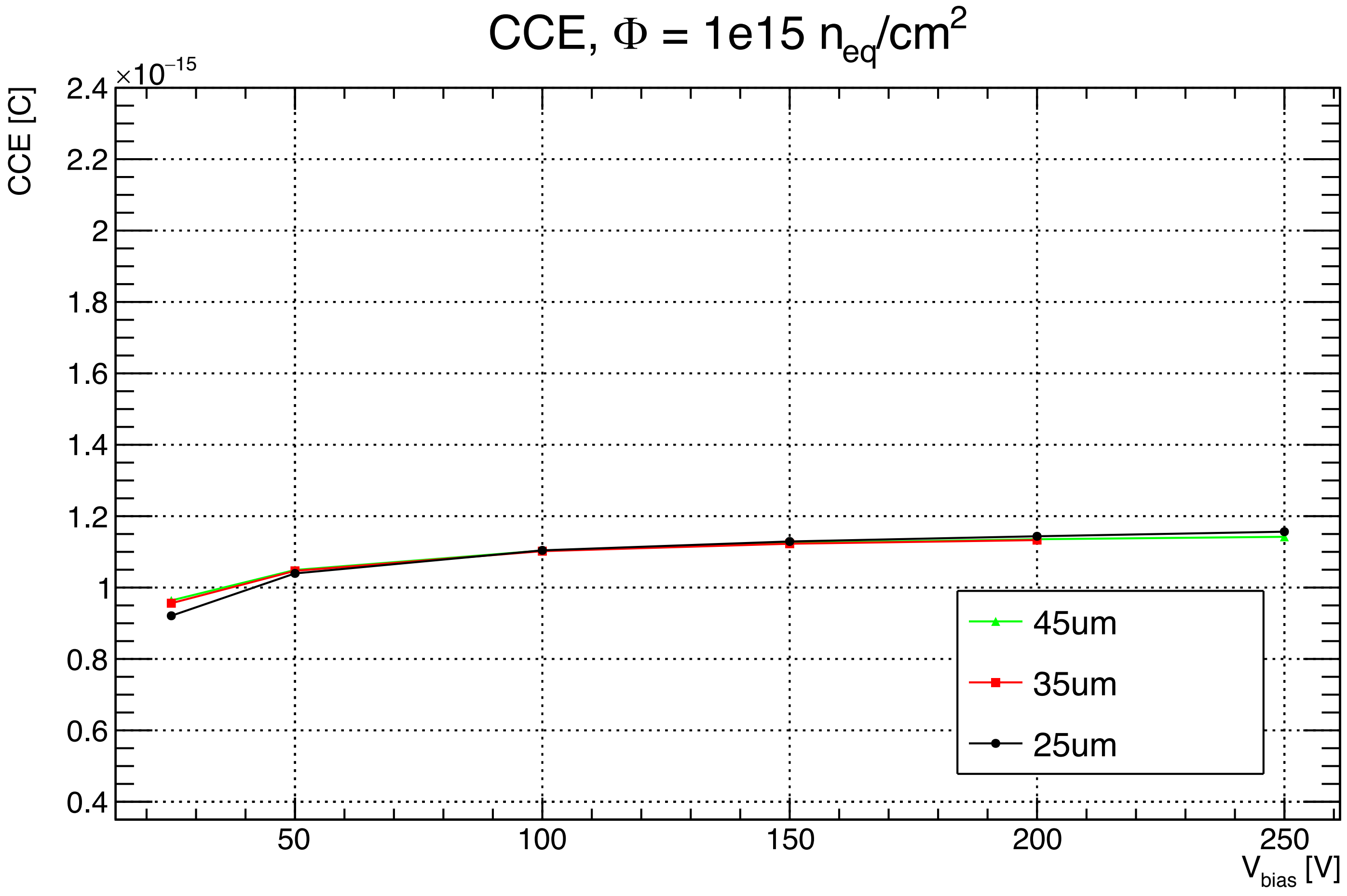
- charge amplification at 45V for 10µm implant size

TCAD Simulation

charge collection efficiency after irradiation

25-45μm

- no difference between 50 and 200V
- small differences at 25V
  - larger implants beneficial
- very small differences at 250V
  - smaller implants beneficial (charge multiplication)



TCAD Simulation

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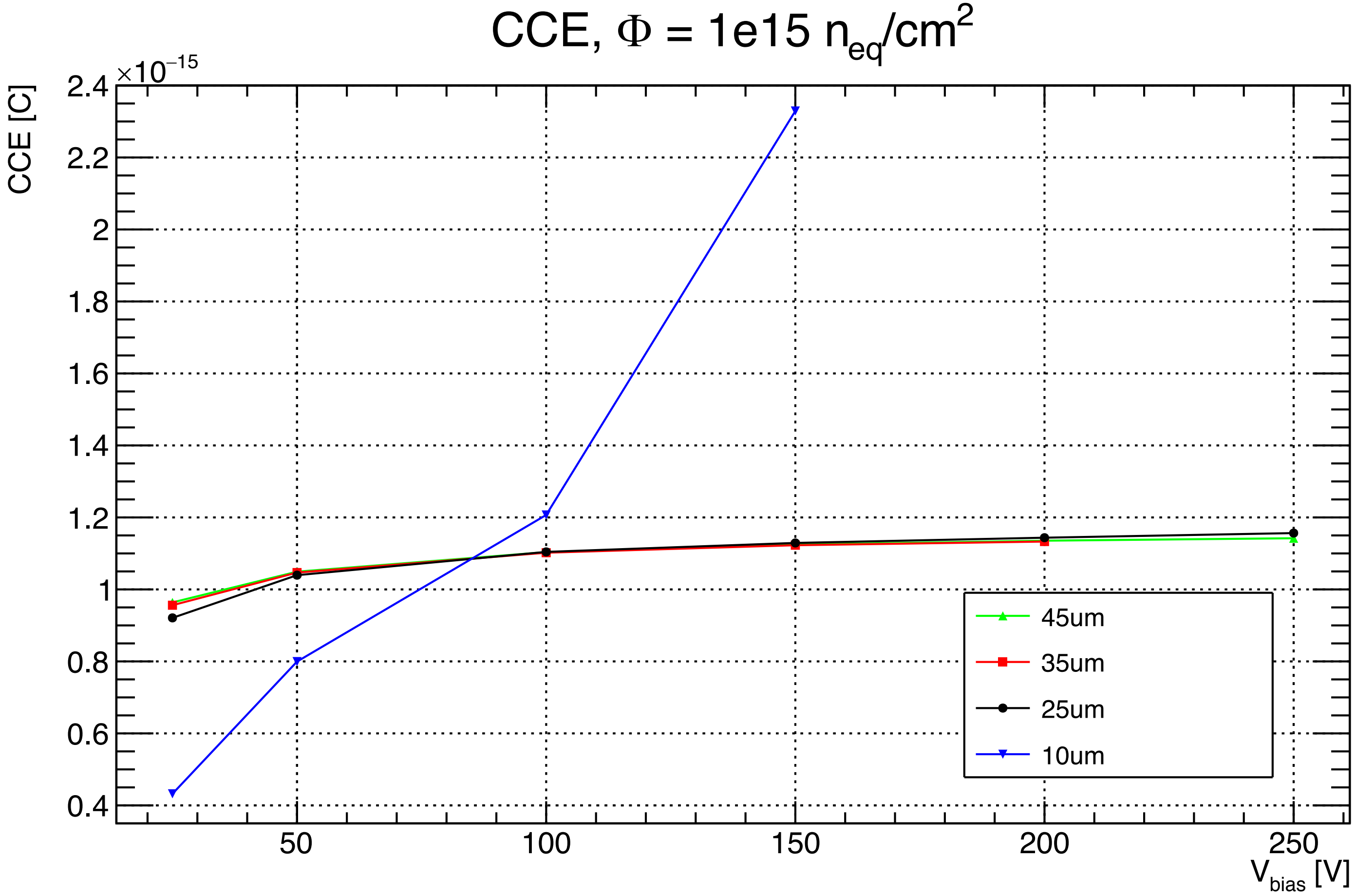
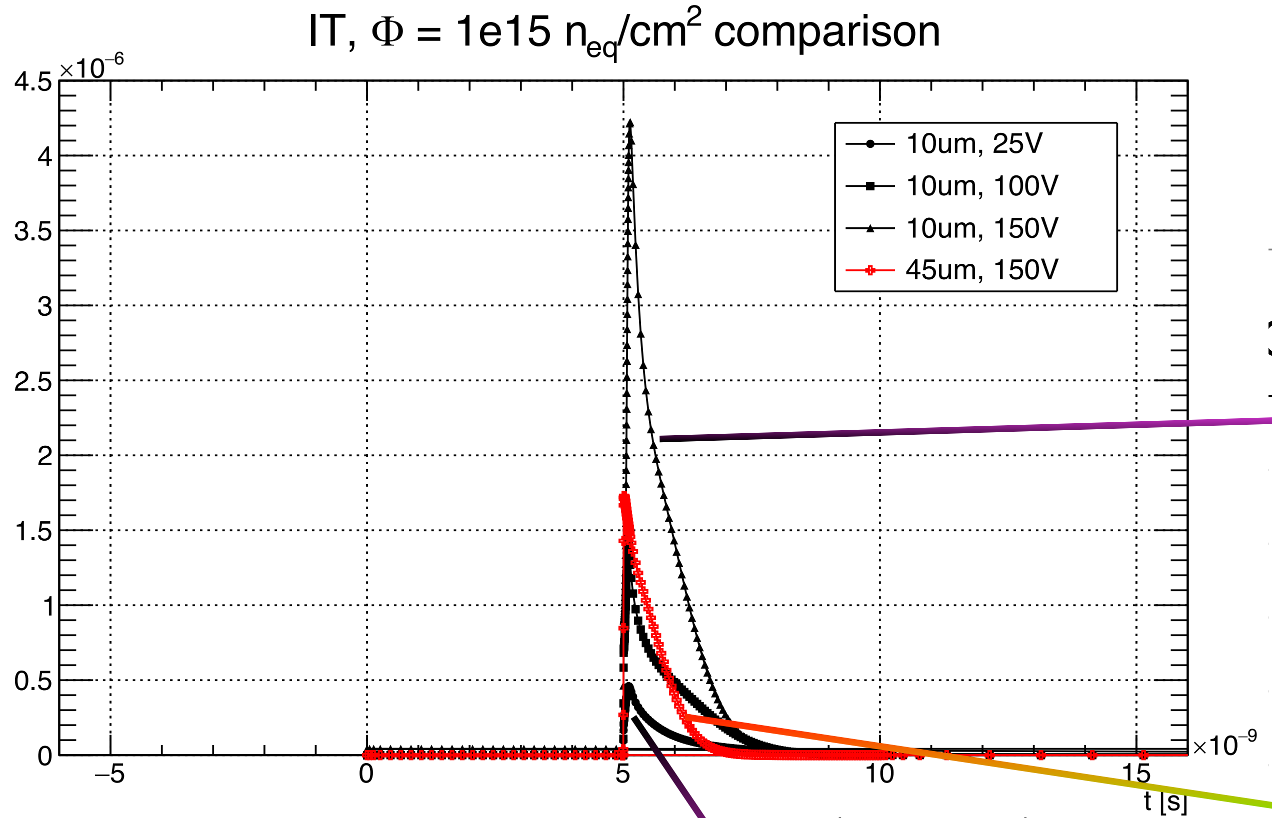
10μm

- much lower collected charge below 100V
- charge multiplication above 100V



TCAD

charge cc



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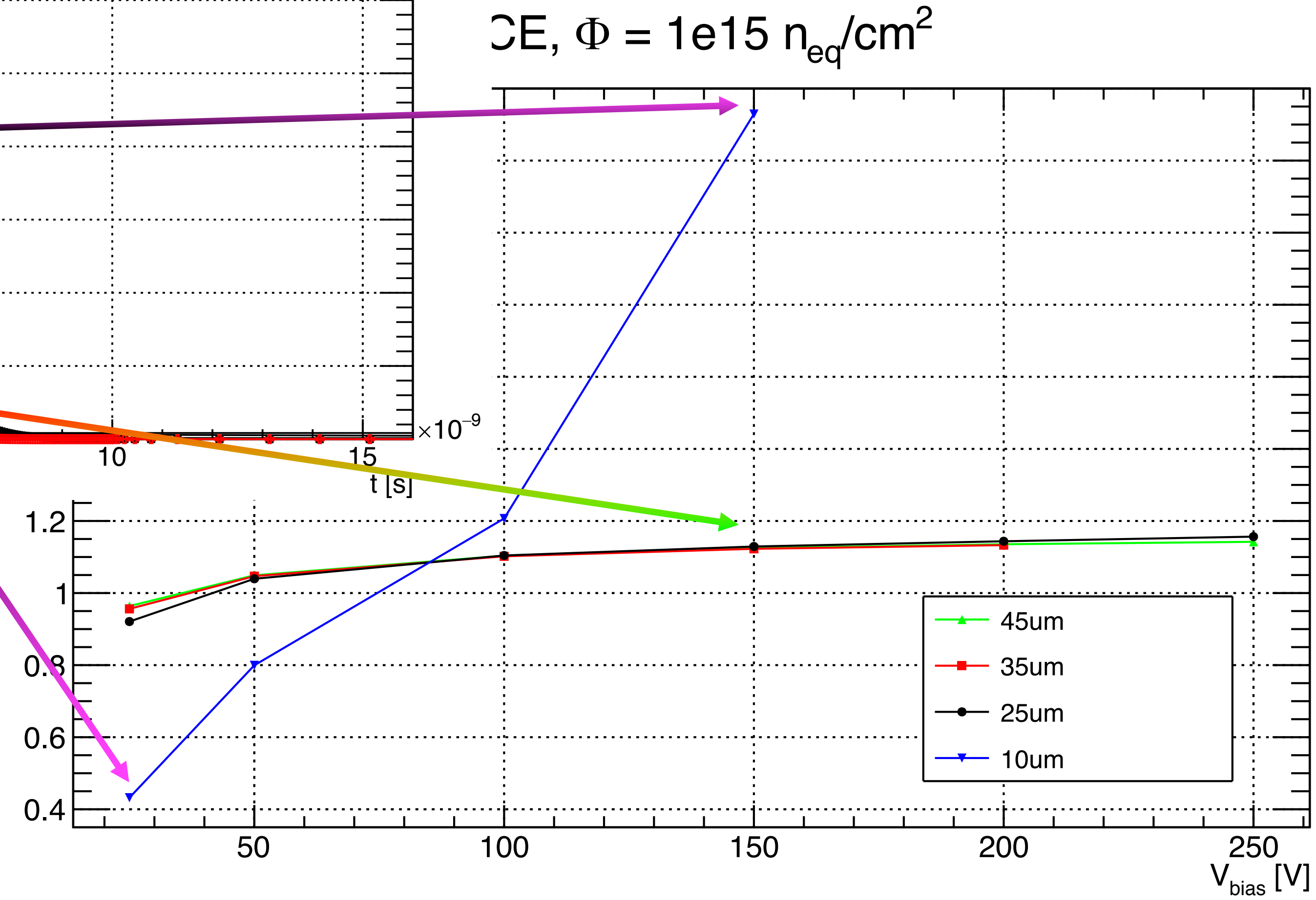

10μm

- much lower collected charge below 100V
- charge multiplication above 100V

Sensor productions by MPP

SOI4 production at MPG-HLL

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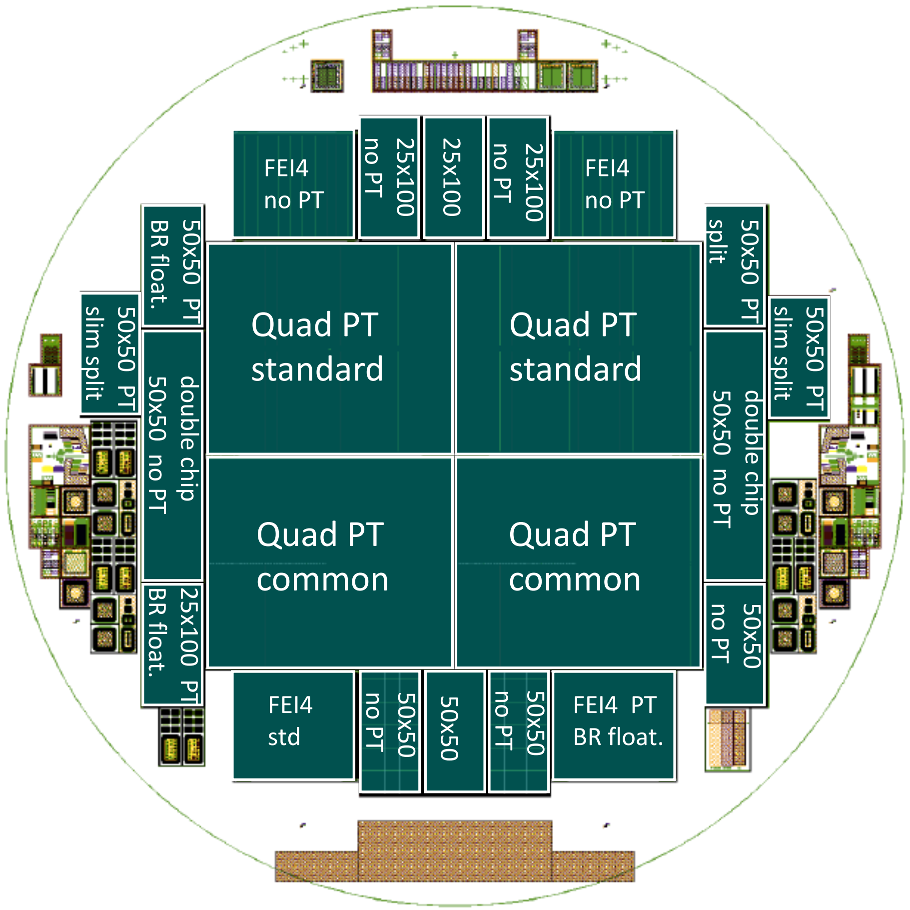
- latest production at MPG-HLL: SOI4
- 4 wafers (100µm) and 5 wafers (150µm) in SOI technology

- production to investigate:
  - different bias rail potential
  - RD53 compatible geometries
    - 25x100 µm² / 50x50 µm²
    - PT and PT with Al overhang and no PT
    - 250 µm / 450 µm edge
  - FE-I4 compatible quad sensors
  - process optimization: p-spray concentration
  - temporary metal technology



Sensor productions by MPP

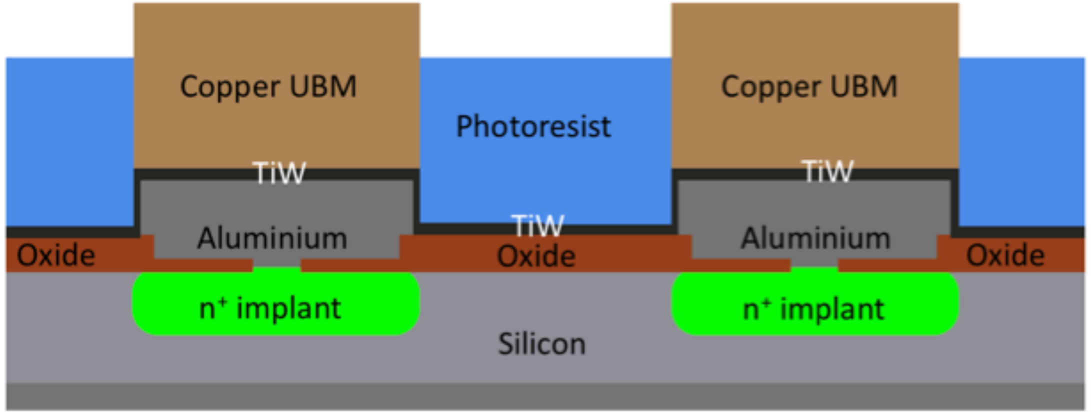
temporary metal technology

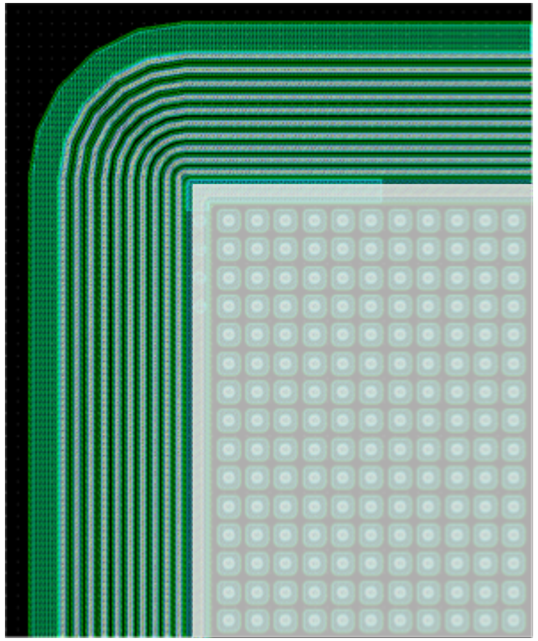
Standard:

- copper is used as UBM as it is very reliable and well known
- copper is electroplated on a seed-layer of TiW in openings of a photoresist layer
- photoresist and TiW are removed after finishing the process

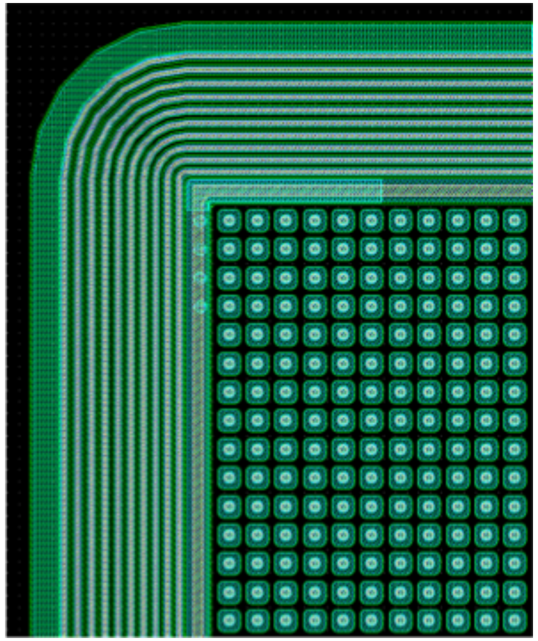
New:

- TiW is patterned after copper deposition to cover only the active area of the sensor
- a needle in the TiW layer connects to all pixels
- a standard etching after testing removes the TiW layer





- TiW in the pixel matrix, no TiW elsewhere

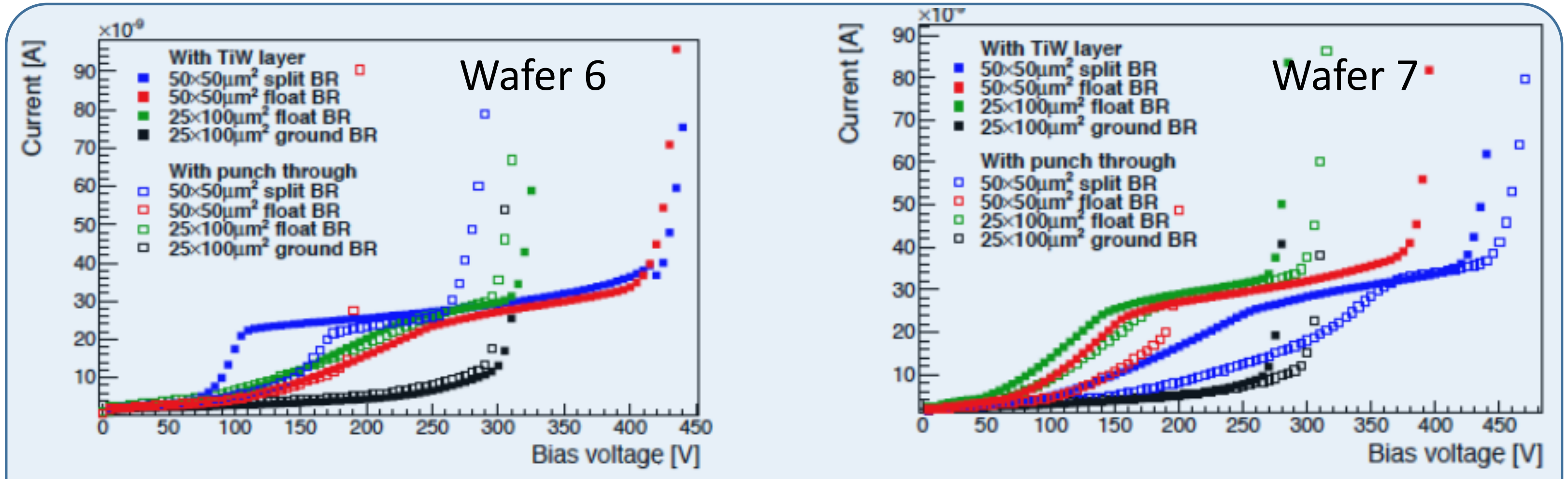


- etching the TiW layer away leaves isolated pixels behind

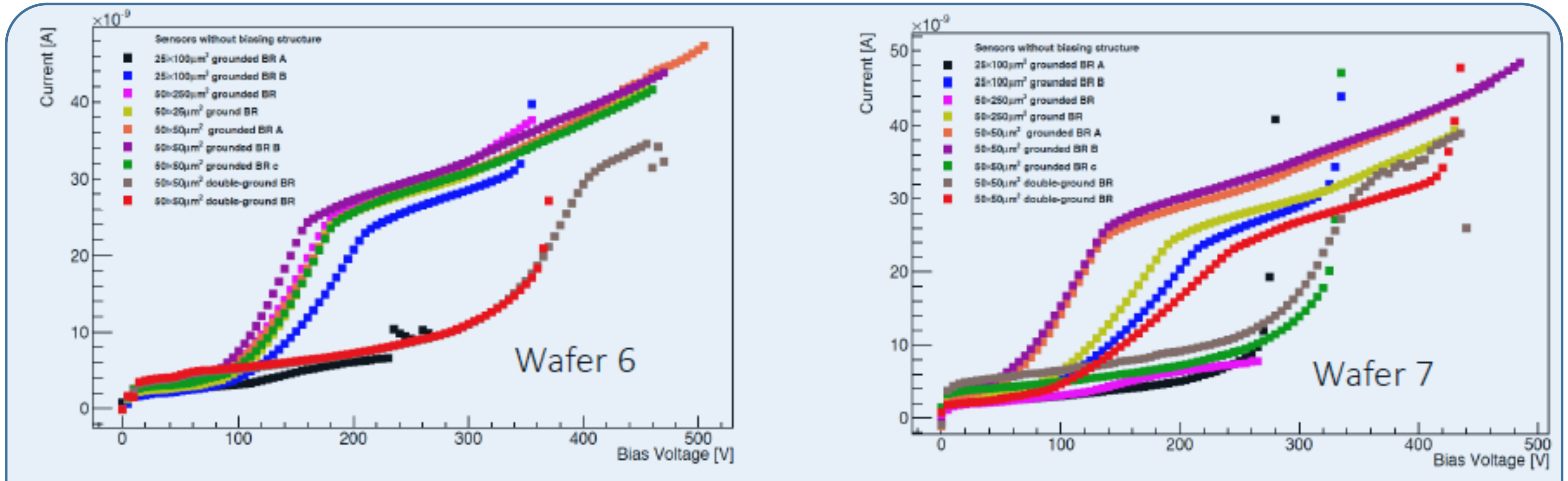
Sensor productions by MPP

temporary metal technology

- so far only structures with PT could be tested after removal of TiW since the wafers are still to be diced and flip-chipped
- no significant failure detected before or after removal of TiW
- interplay of PT and TiW is difficult to disentangle
  - will have to wait for structures without PT flip-chipped to read-out chips for final conclusions
- for most of the structures: before/after variations compatible with typical spread between repeated measurements



Measurement using PT vs. temp. metal



Measurement using temp. metal only

Sensor productions by MPP

Outlook: SOI5 production

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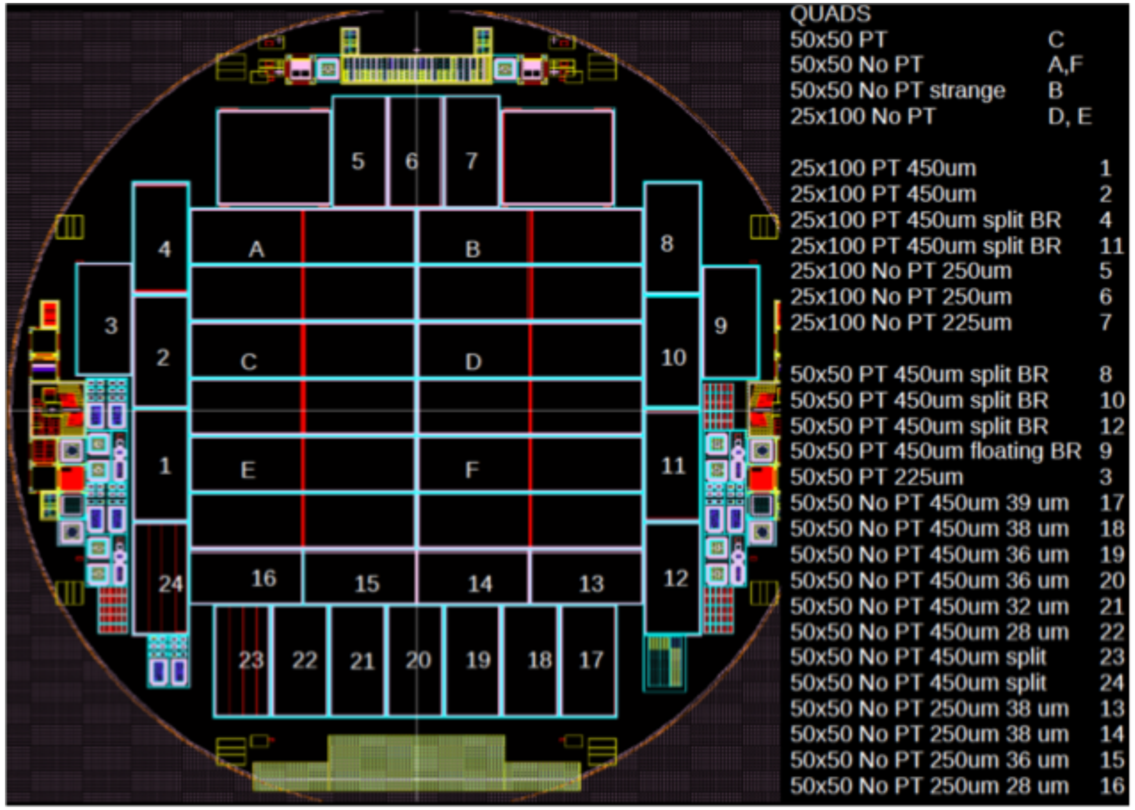
- SOI5 production at HLL with ~20 wafers
- processing identical to SOI4:
  - Cu UBM and BCB deposition at HLL
  - thinning and dicing at IZM
  - low-dose p-spray for whole production

- focus on RD53A compatible sensors:
  - 6 pseudo-quad sensors
  - 25x100µm² and 50x50µm² pixel cells
  - mostly without PT -> use TiW testing method
  - PT sensors have floating/split/grounded bias rail
  - different implant sizes to validate the simulations



Summary & Outlook

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- TCAD simulation of RD53A compatible pixel cells
  - larger pixel implants lead to lower depletion voltages, thus collecting more charge after irradiation at the same voltage
    - effect at $1x10^{15}$ n_{eq}/cm^2 smaller than expected, what will happen at higher fluences?
    - measurements on RD53A modules and test-structures planned
  - capacity drastically increasing for increasing implant size
  - dependence of noise on input capacity of RD53A will determine the signal-to-noise ratio

- sensor productions at MPP
  - several design possibilities will be evaluated with the latest productions SOI4/5
  - new testing technique for sensors without biasing structure is being developed to avoid charge losses after irradiation

This project has received funding from the European Union's Horizon 2020 research and innovation programme

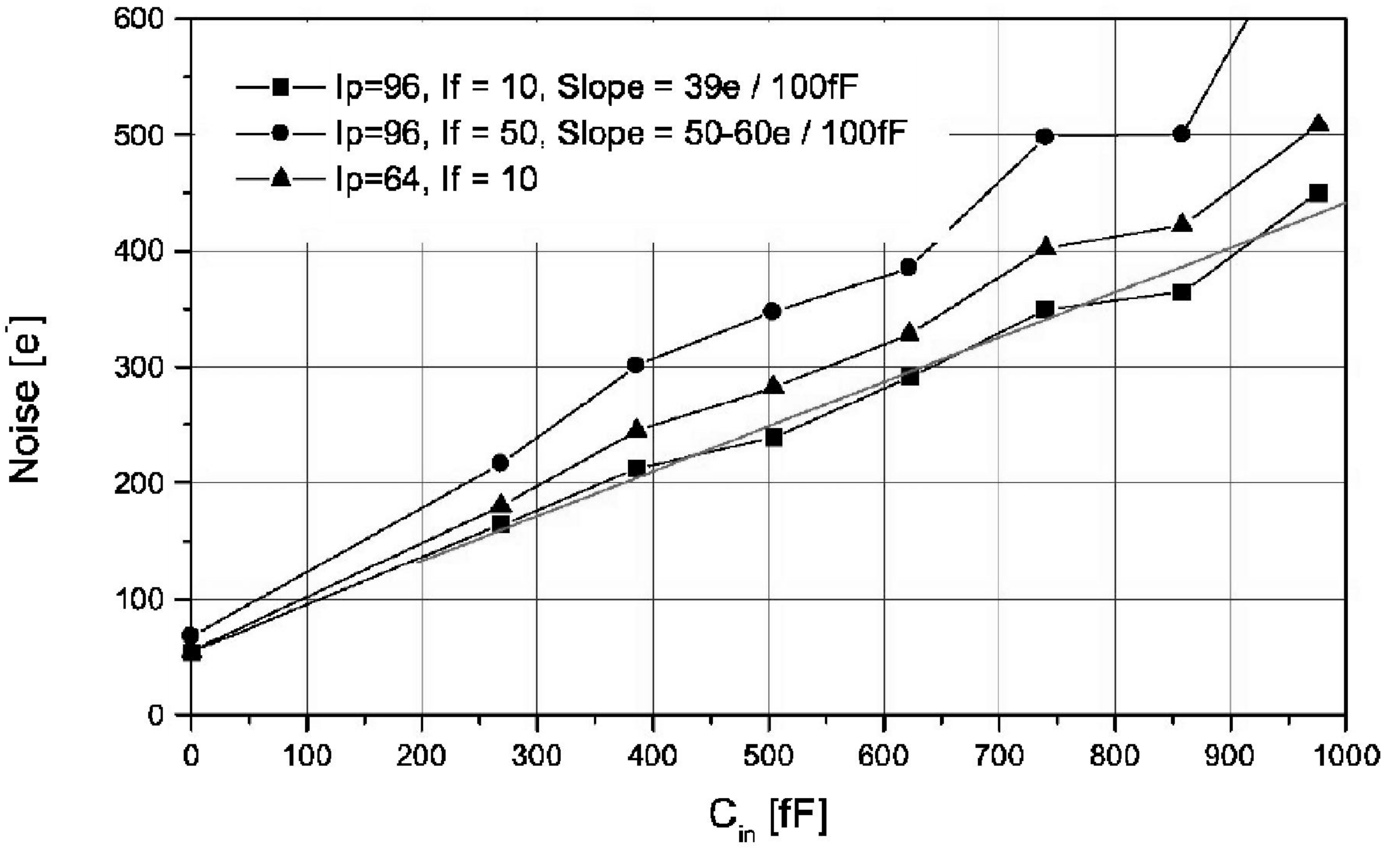
AIDA 2020

Backup

Noise vs input capacity

FE-I3

A. Andreazza,
Progresses on the ATLAS pixel detector,
Nuclear Instruments and Methods in
Physics Research Section A,
Volume 461, Issues 1–3,
2001,
Pages 168-171,



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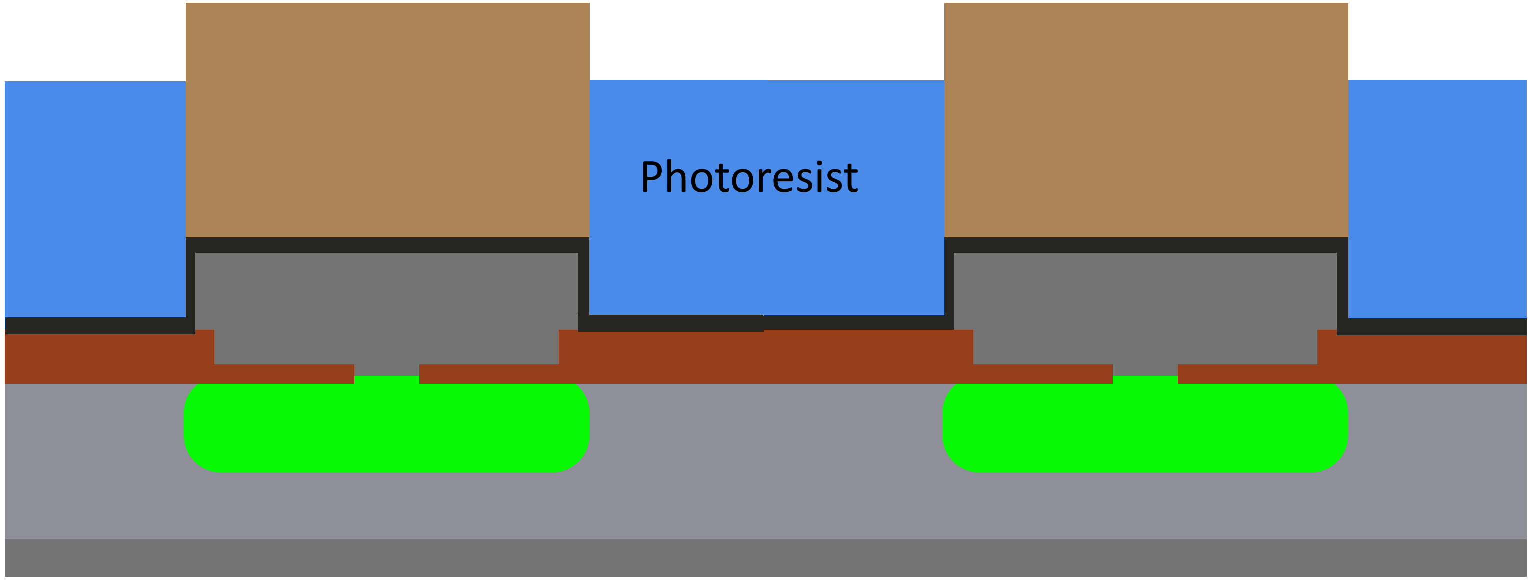

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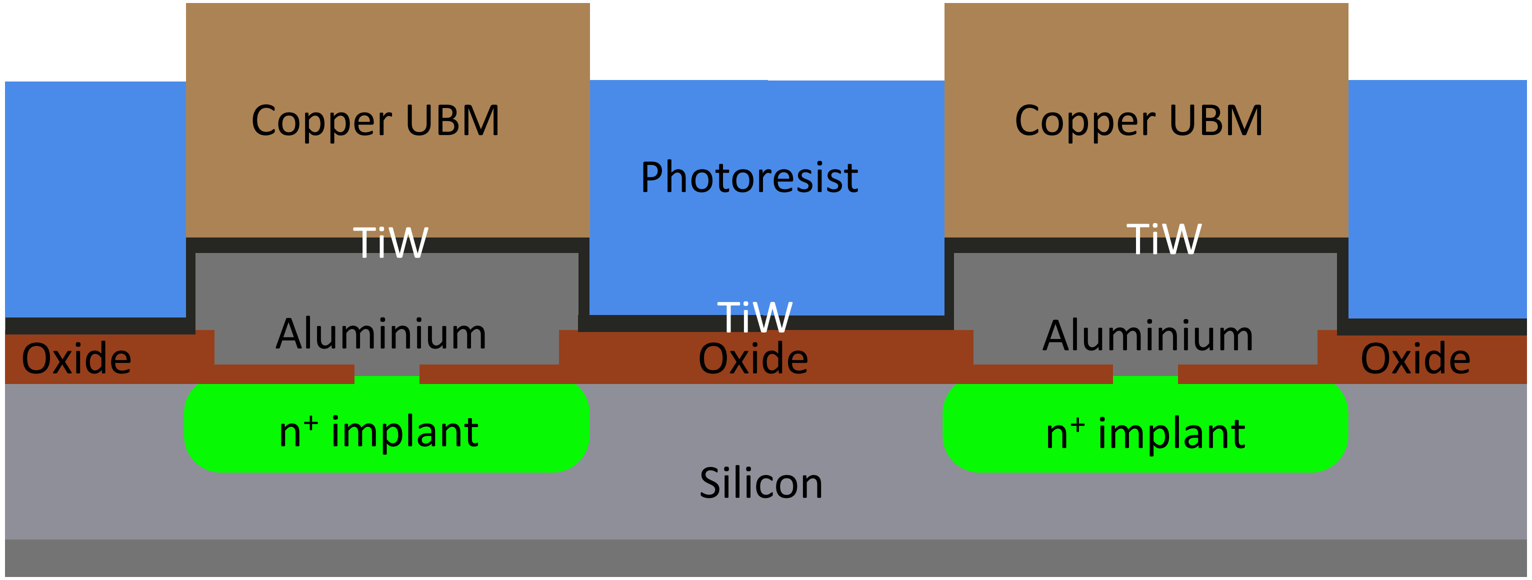
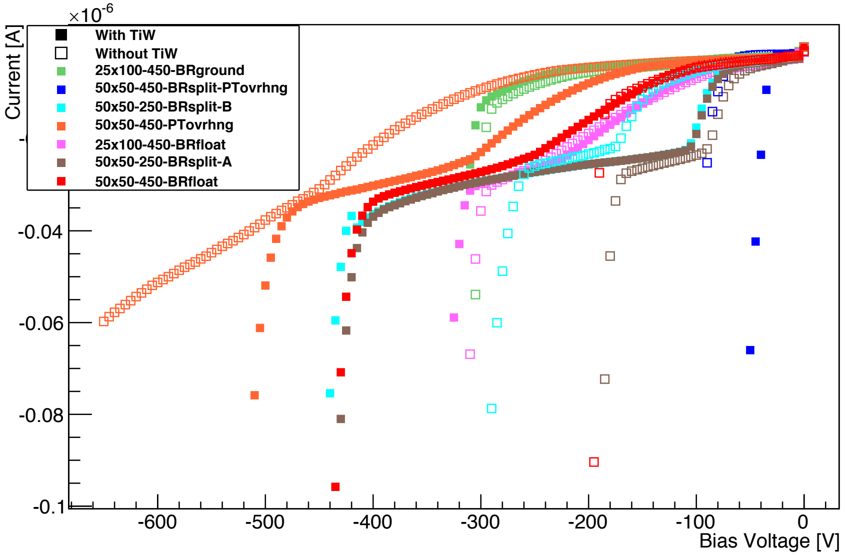
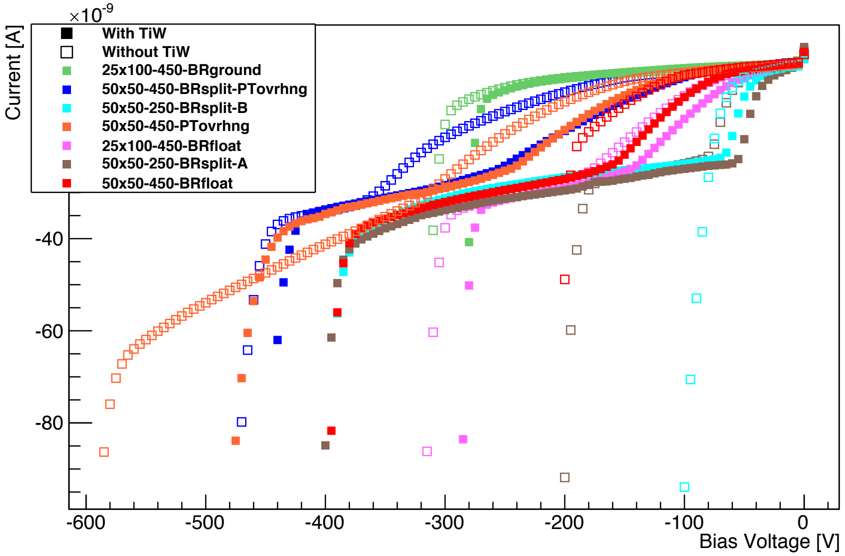


Wafer 6



Wafer 7



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