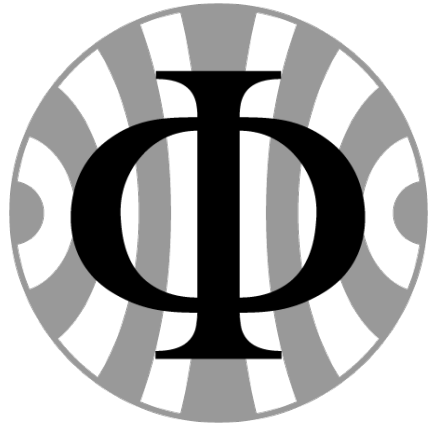
TCAD Simulation of High Voltage Monlithic Active Pixel Sensors



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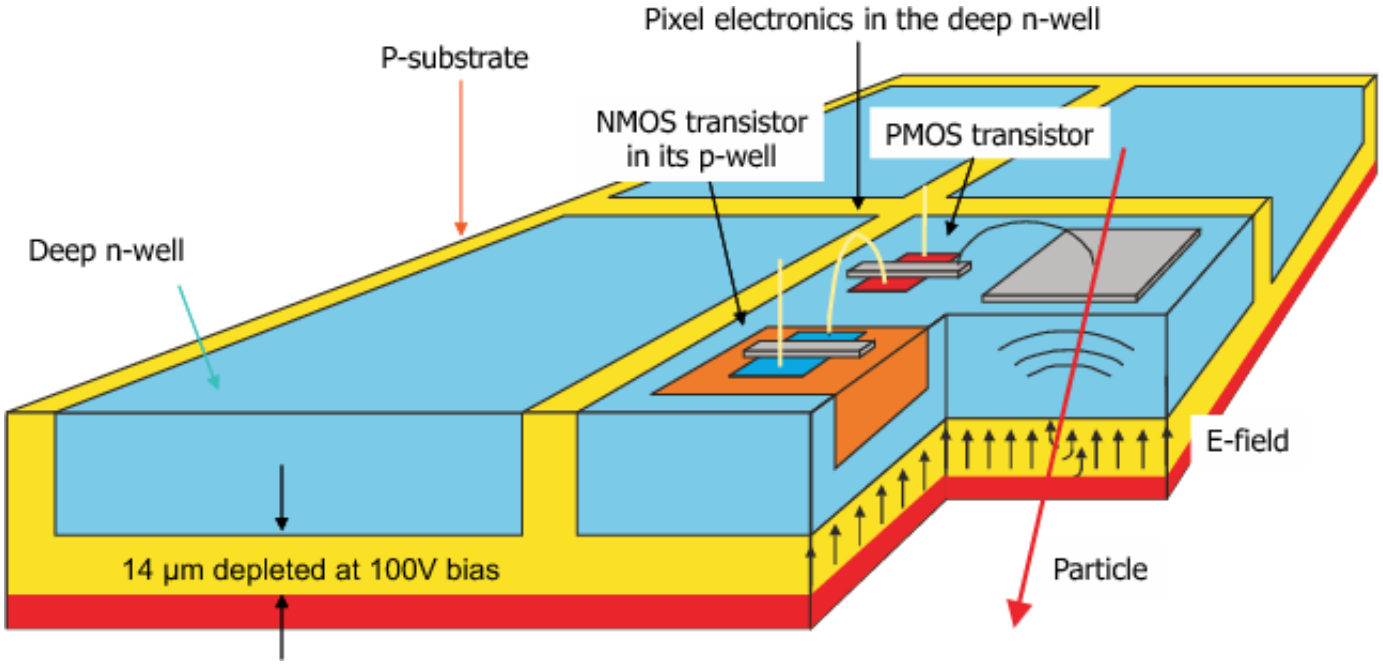
Bundesministerium
für Bildung
und Forschung

HighRR

High Voltage Monolithic Active Pixel Sensor

- Integrated readout electronic and sensor.
- Implemented in a commercial CMOS process.
- Depletion area $\sim 15\ \mu m$ at -60V for 20 Ωcm.
- Fast charge collection via drift.



*N. Wermes / Nuclear Instruments and Methods in Physics Research A 650 (2011) 245–252

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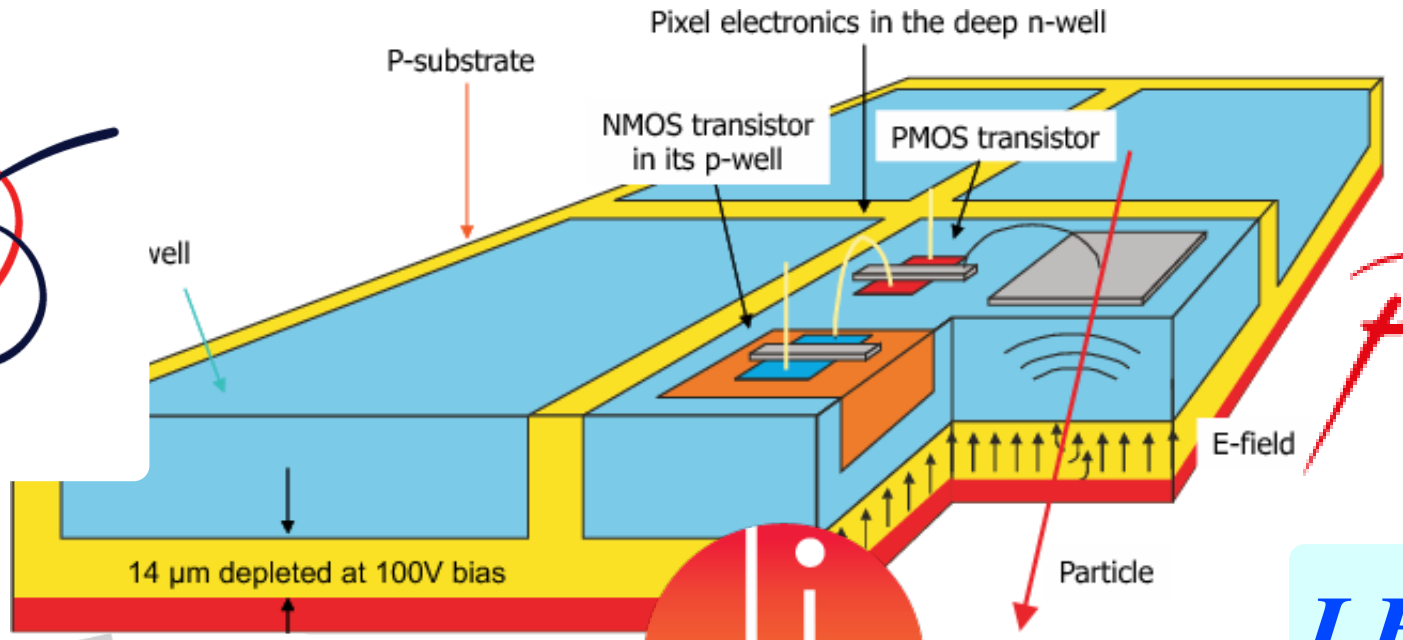


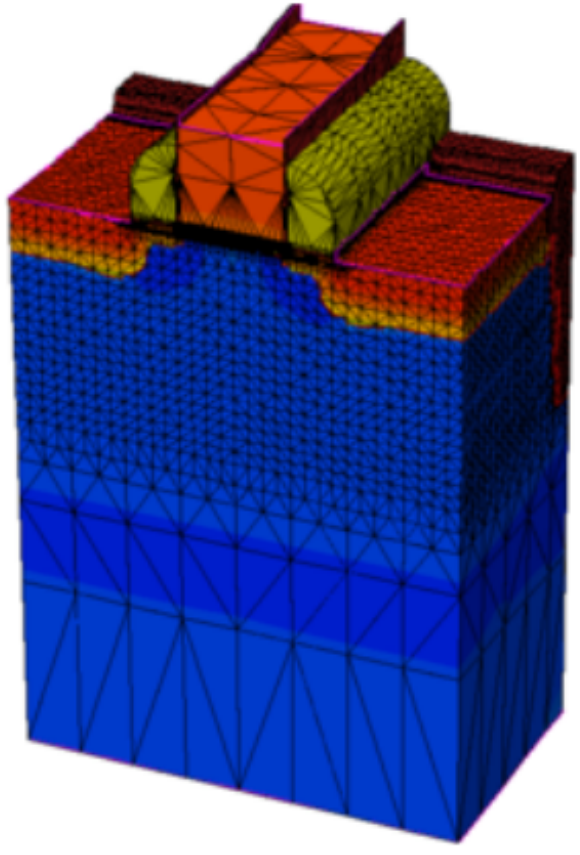
Technology Computer Aided Design

Use of computer simulations to develop and optimize semiconductor processing technologies and devices.

Why TCAD?

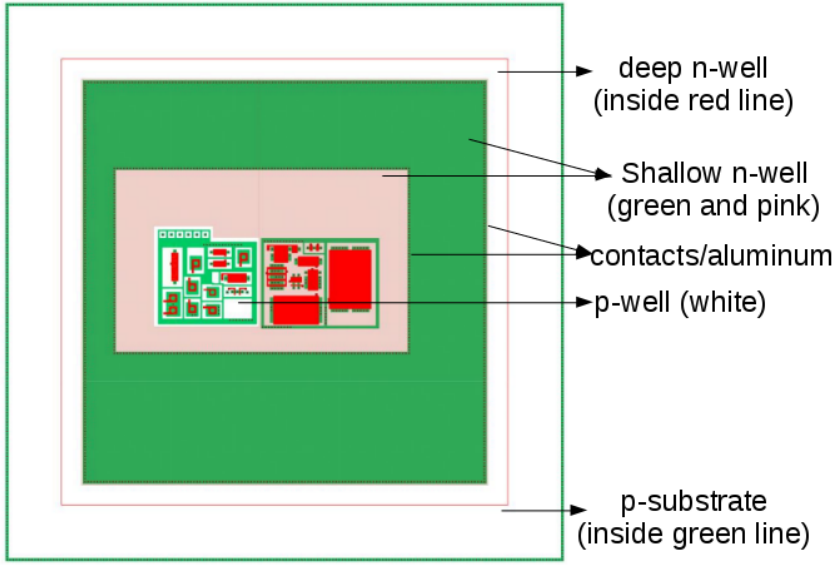
- Fabrication process and electrical behavior.
- Tiny and complex structures.
- 2D and 3D Simulations.
- Visualization tool.
- Save time and money.
- Complement to laboratory measurements.

SYNOPSYS®

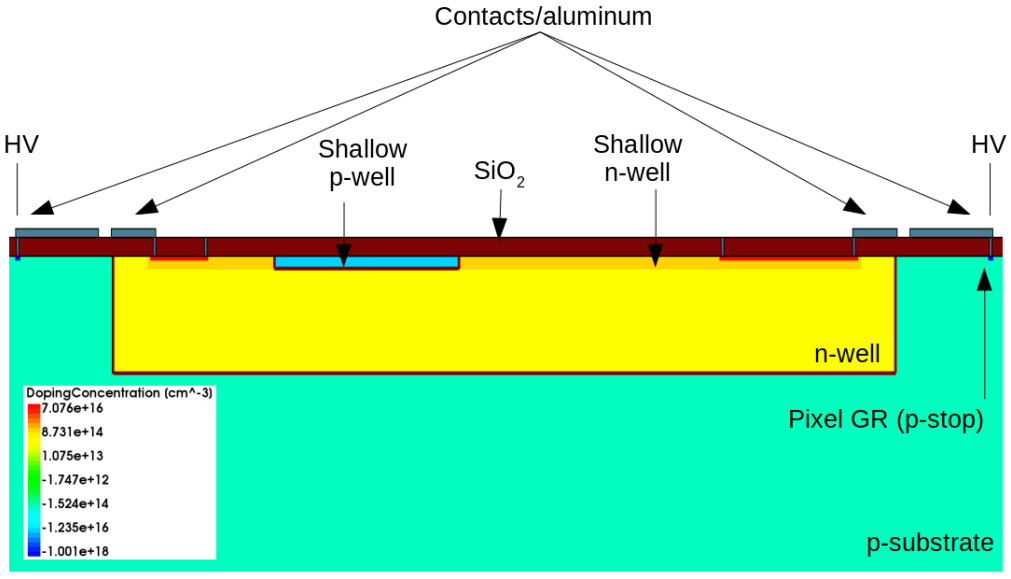


TCAD Process Flow

- Structure Simulation (Device structure and doping profiles)



*Layout of MuPix8

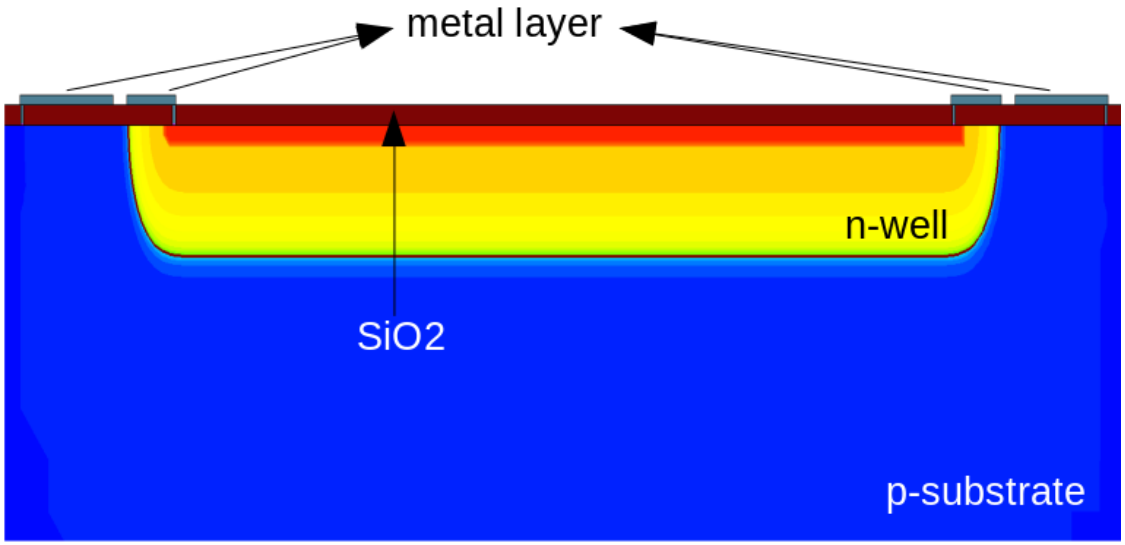


- Device Simulation (Physical models: temperature, mobility, recombination, avalanche, radiation damage)

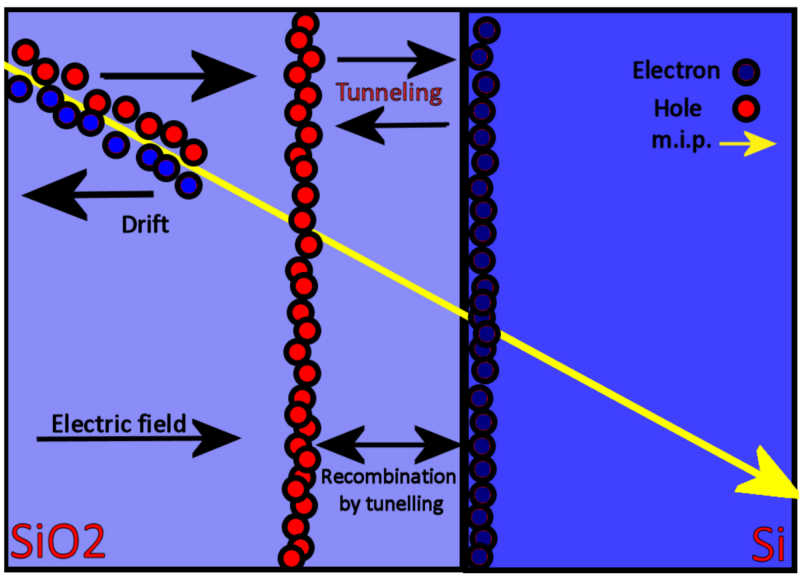
1. Quasistationary (Breakdown Voltage, Capacitance, Electric Field ...)
2. Transient simulation of Minimum Ionizing Particle (MIP) (Charge collection process)

TCAD Simulation

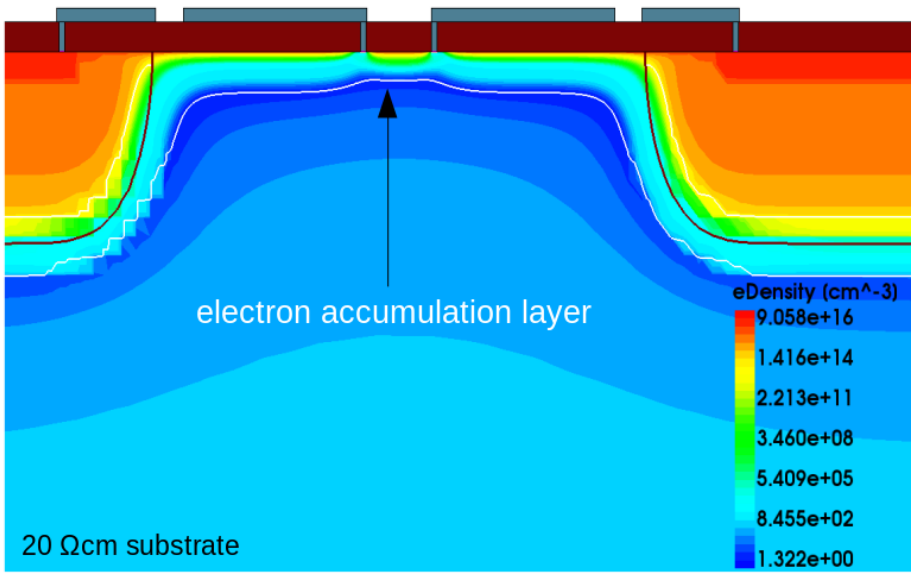
- Simple Pixel Structure



Ionizing radiation damage in the Si-SiO2 interface*



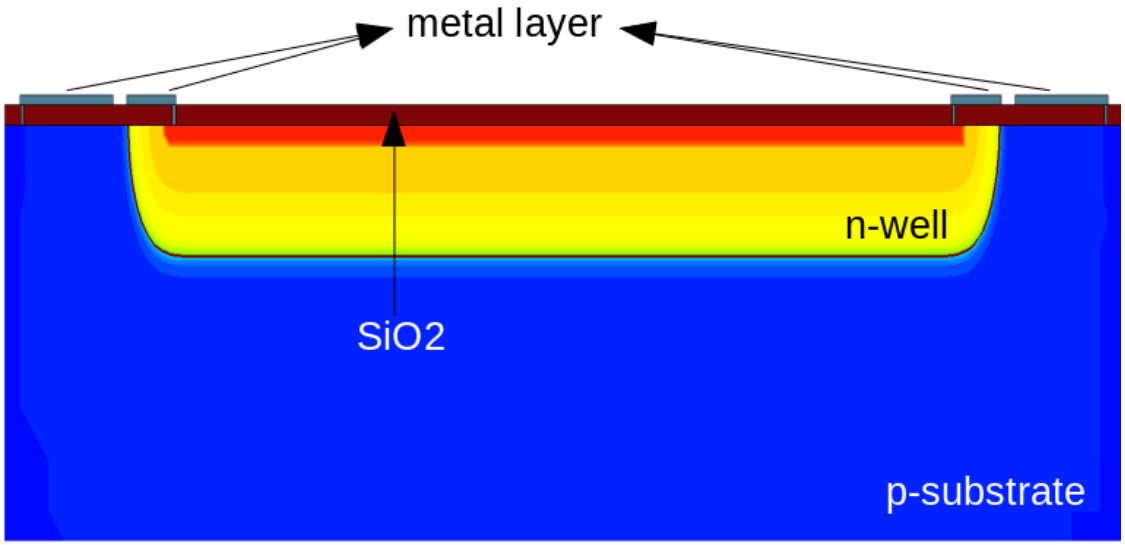
eDensity



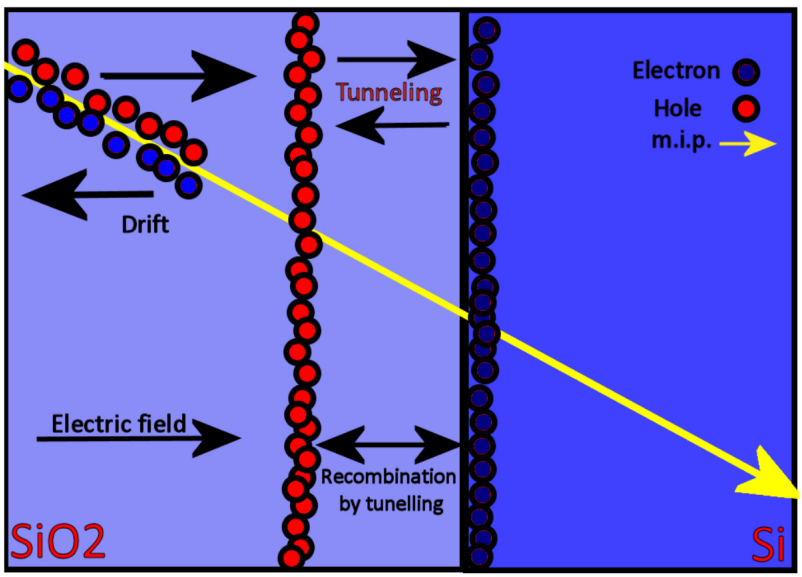
*Charge density in Si-SiO2 interface from 10^{11} cm^{-2} to 10^{12} cm^{-2} between 0 and 10^{8} Rad

TCAD Simulation

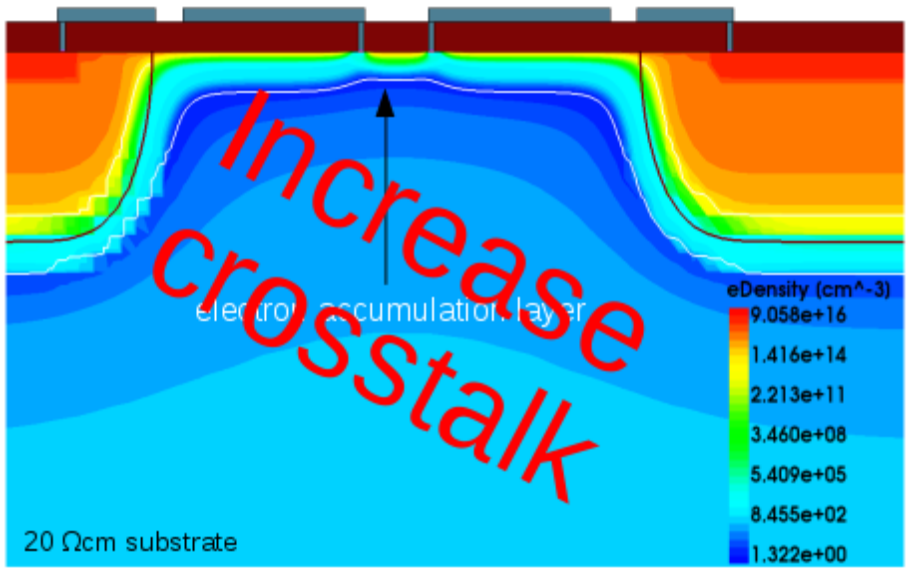
- Simple Pixel Structure



Ionizing radiation damage in the Si-SiO2 interface*



eDensity



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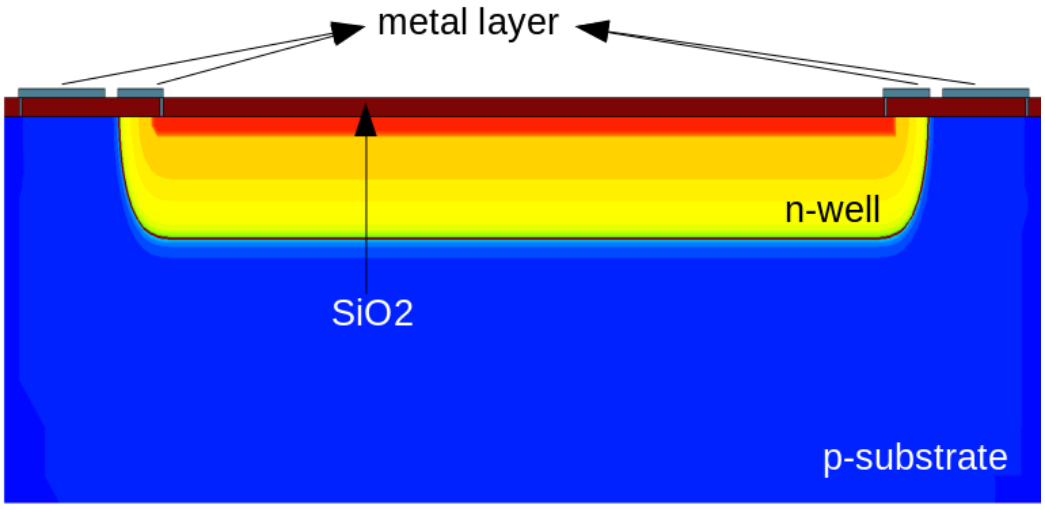
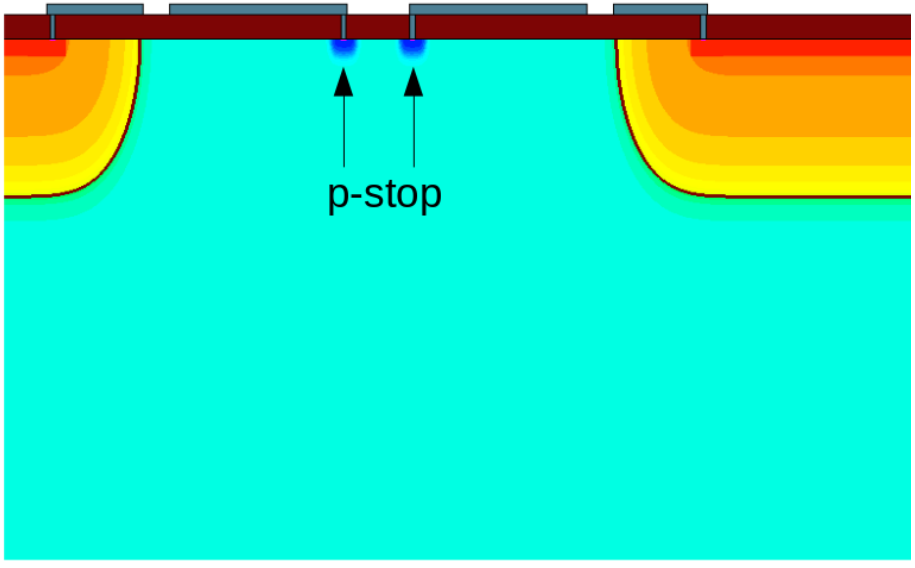
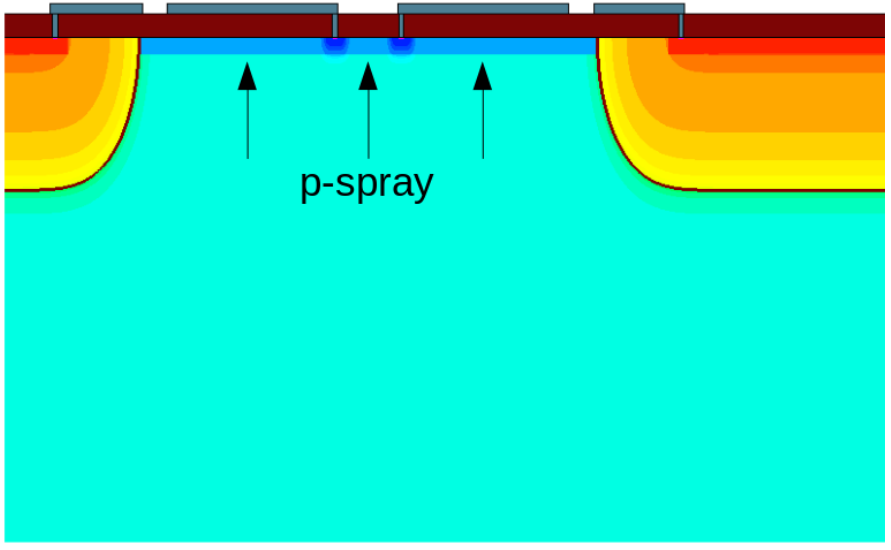
TCAD Simulation

- Simple Pixel Structure



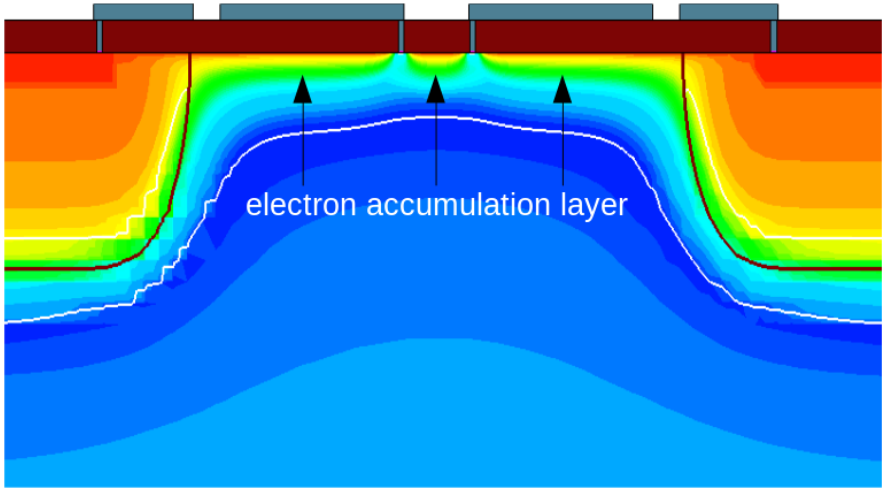
- Pixel Isolation



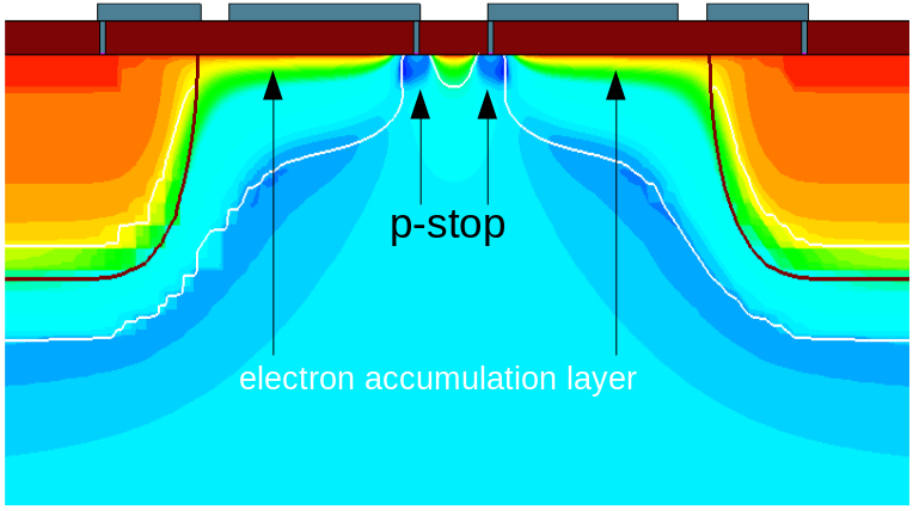


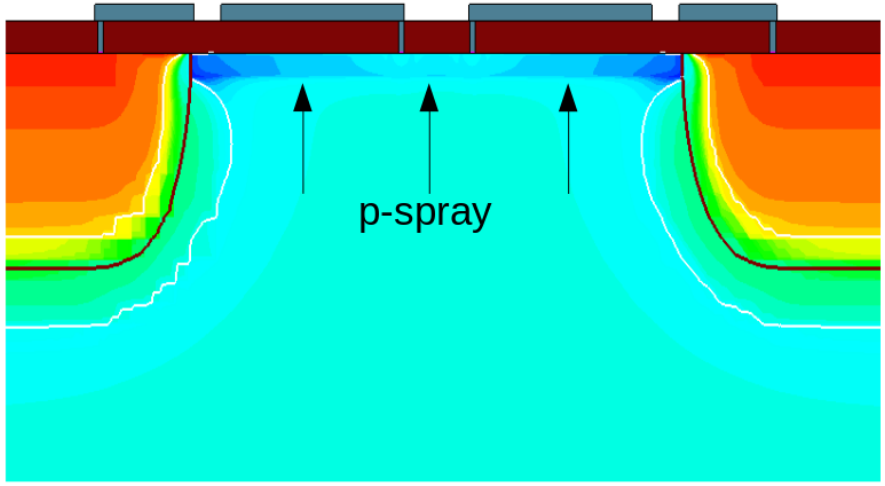
TCAD Simulation

- Simple Pixel Structure



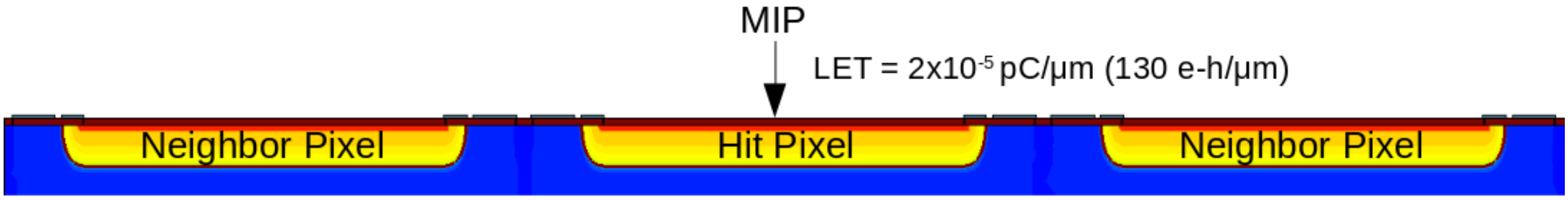
- Pixel Isolation

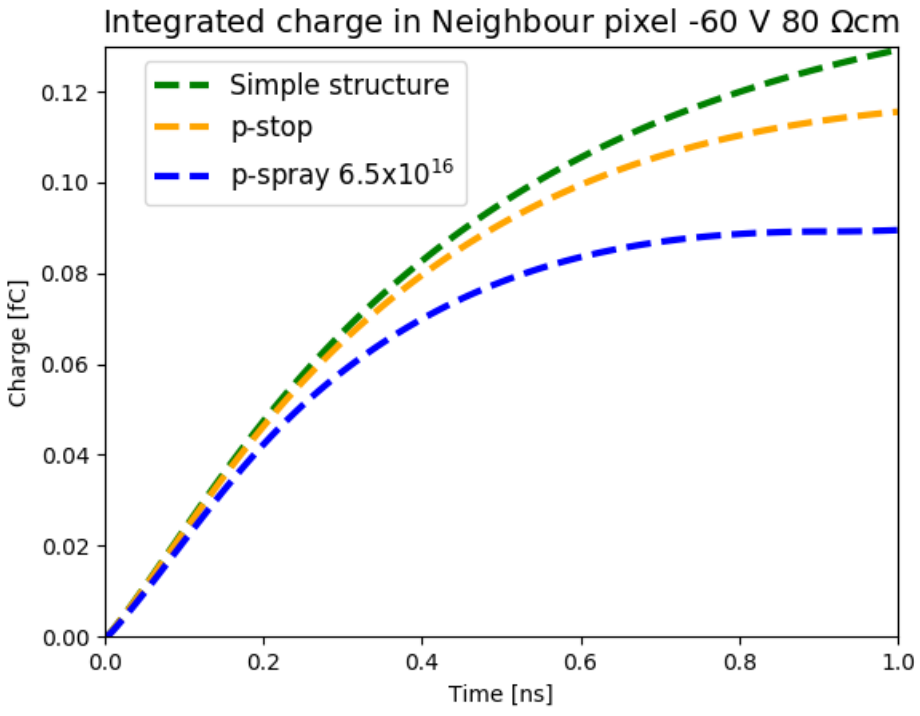


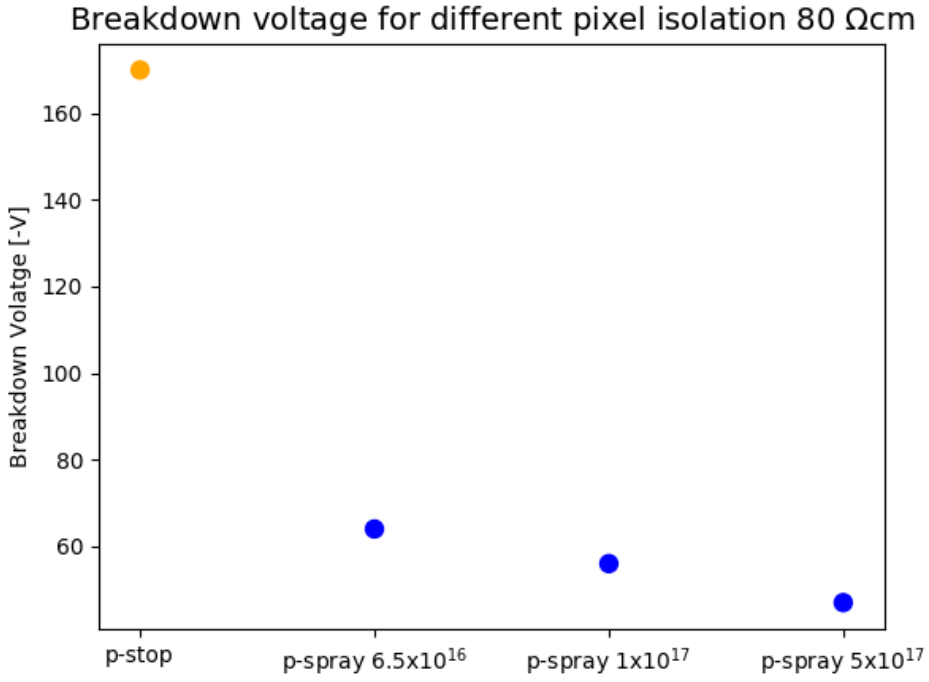


eDensity @ 20 Ωcm @ 10^{11} density of charge in Si-SiO2 interface

TCAD Simulation

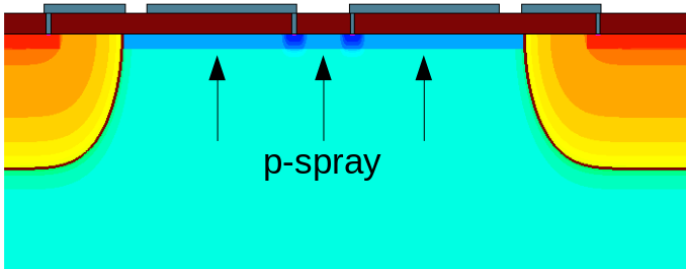






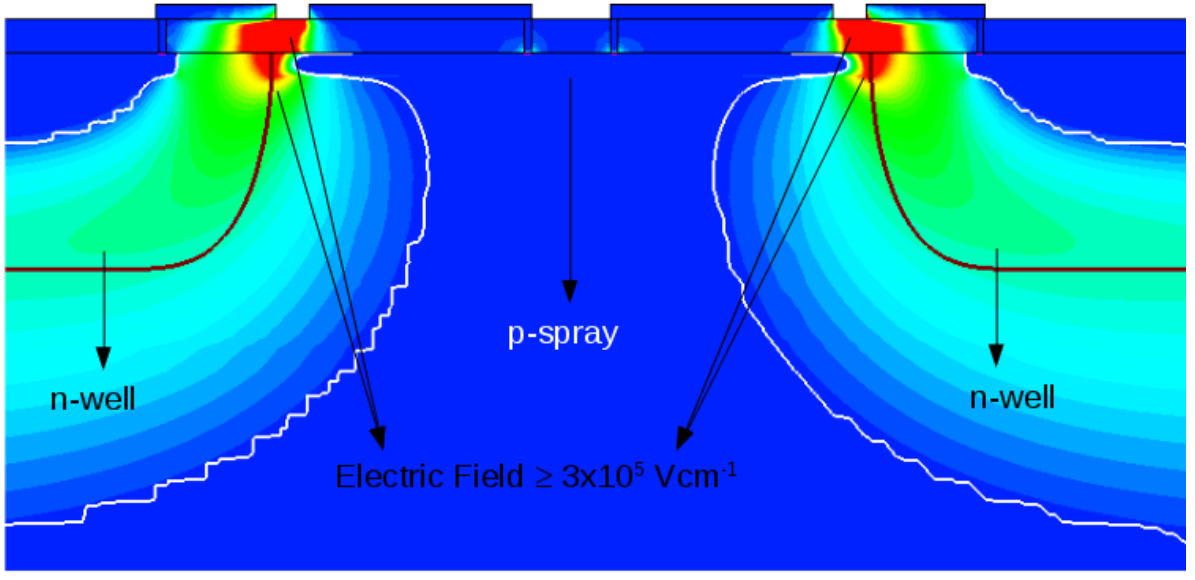
- p-spray: Decrease of crosstalk.
- p-spray: Breakdown Voltage have to be optimize

TCAD Simulation



@ 20 Ωcm

@ 10^{11} Si-SiO2 interface charge

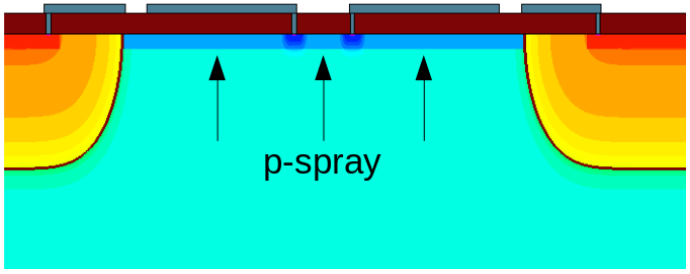


Electric Field

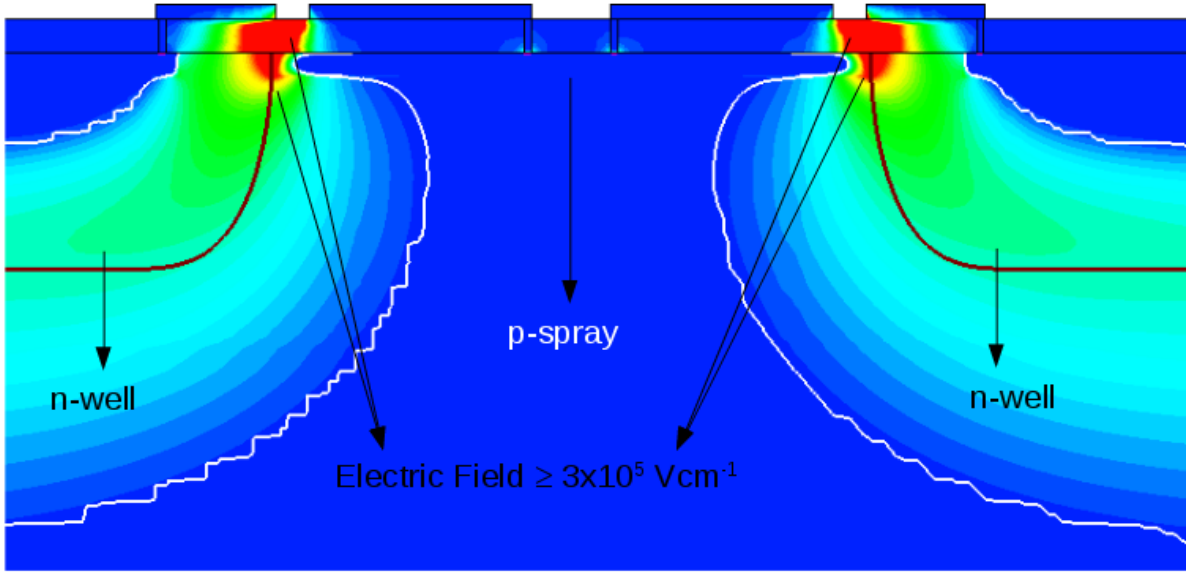
Breakdown:

1. n-well p-spray junction
2. SiO2 gap between metal layers

TCAD Simulation



@ 20 Ωcm
@ 10^{11} Si-SiO2 interface charge



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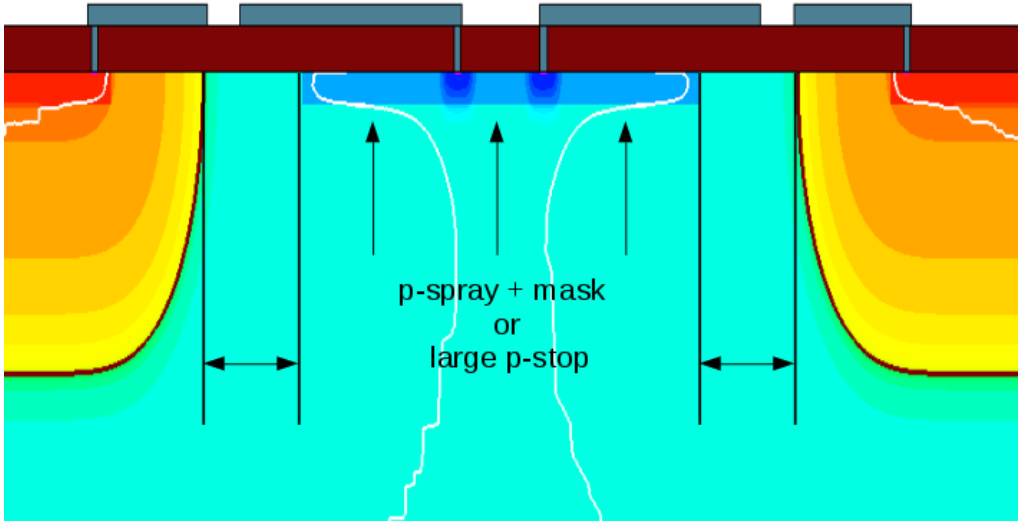
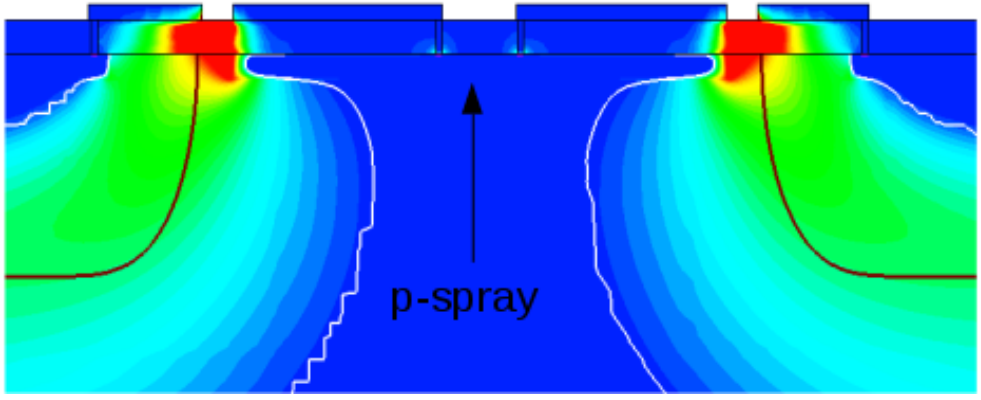


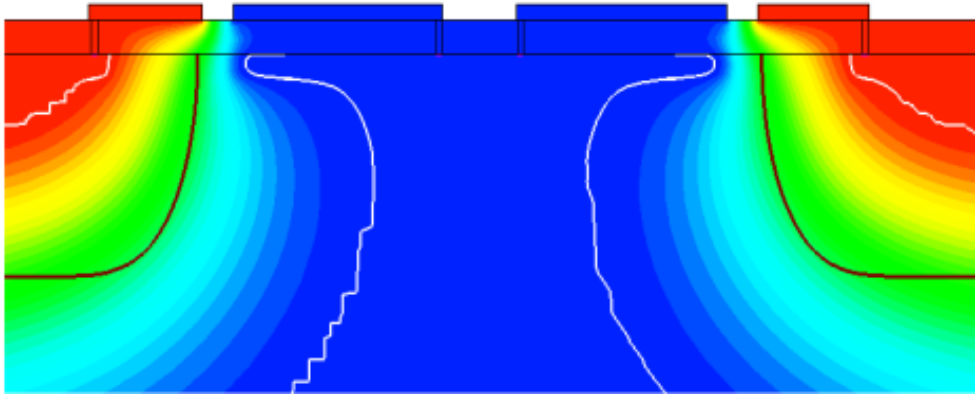
TCAD Simulation

Electric Field

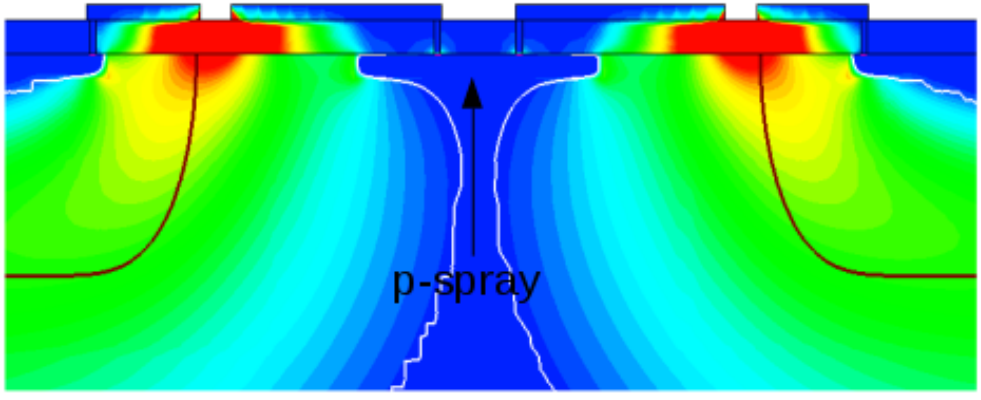
Electrostatic Potential

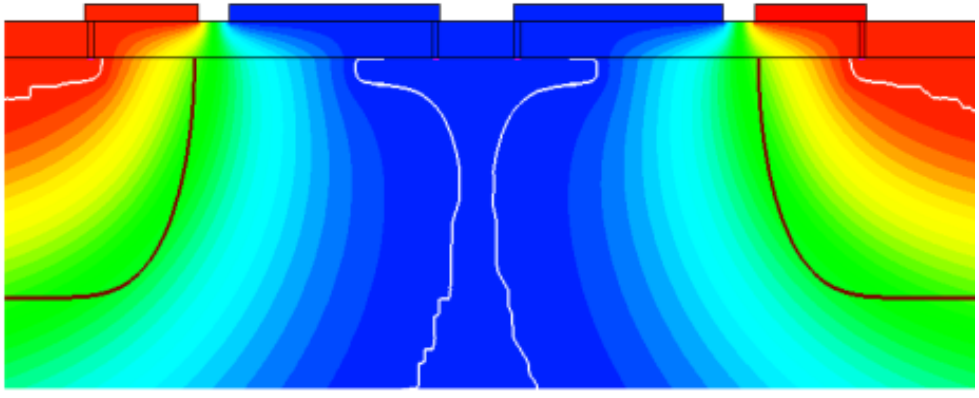
- 1 μm mask





- 4 μm mask



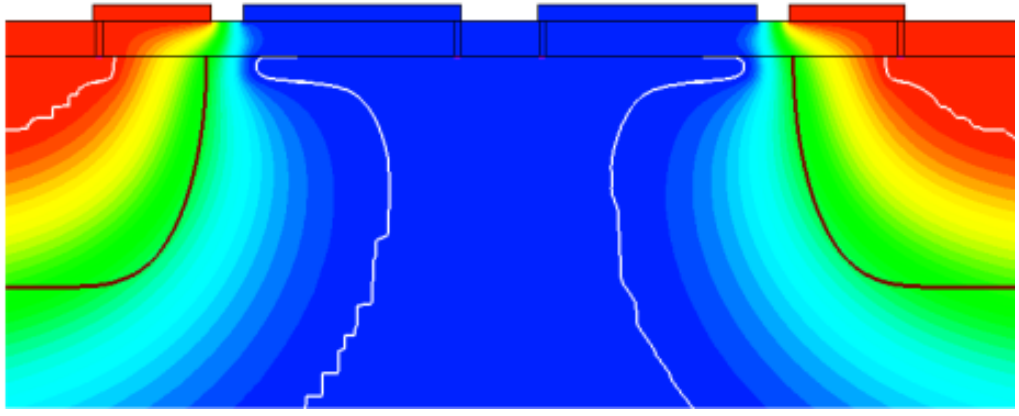


@ 20 Ωcm @ 10^{11} Si-SiO2 interface charge

TCAD Simulation

Electrostatic Potential

- 1 μm mask



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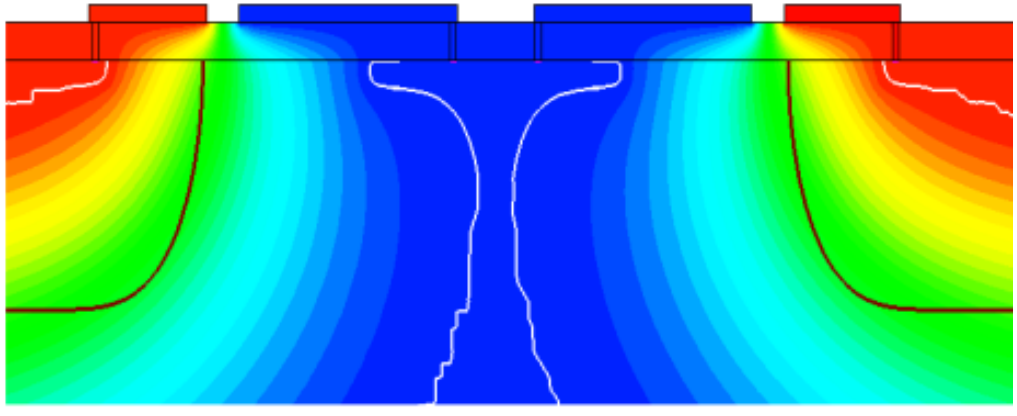
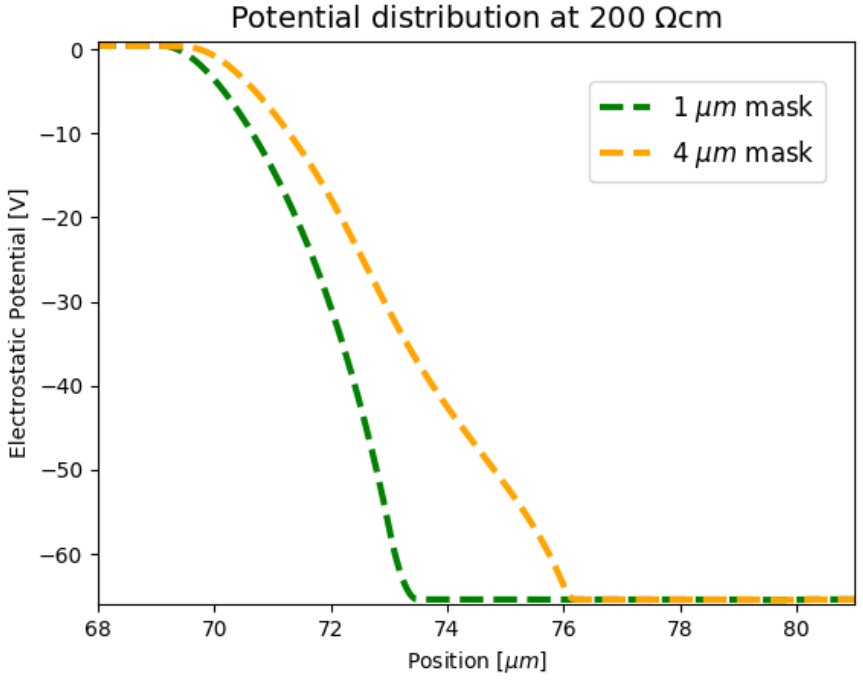
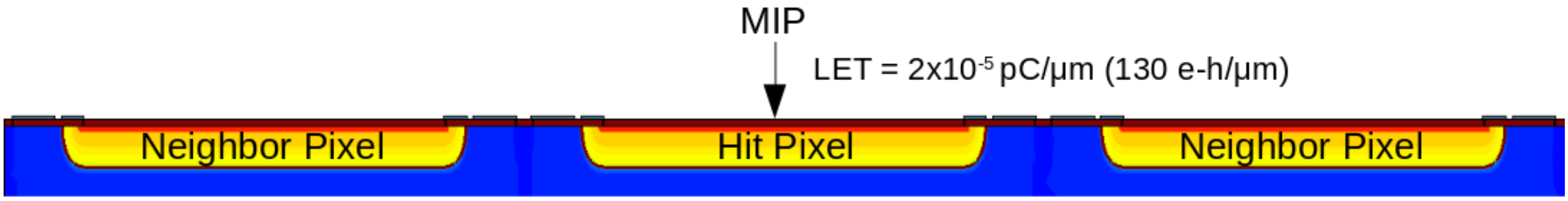
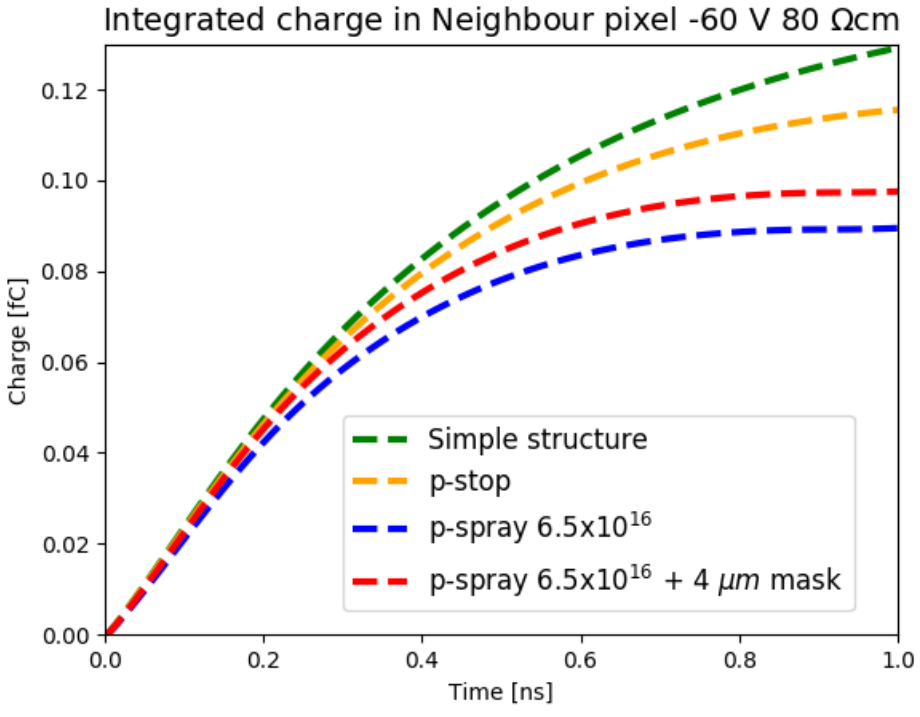


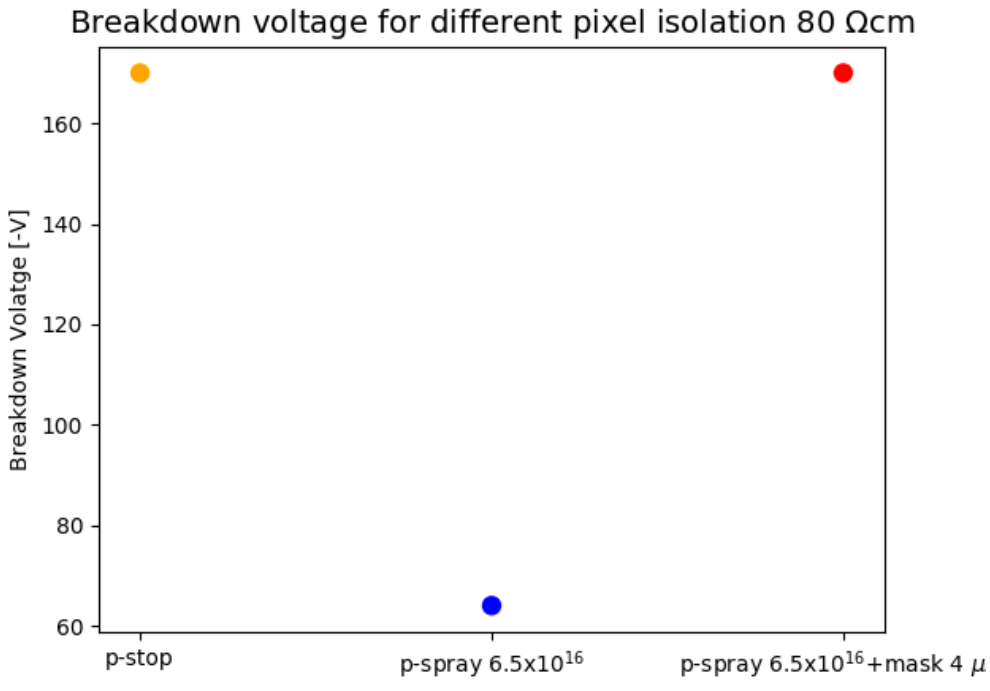


@ 20 Ωcm @ 10^{11} Si-SiO2 interface charge

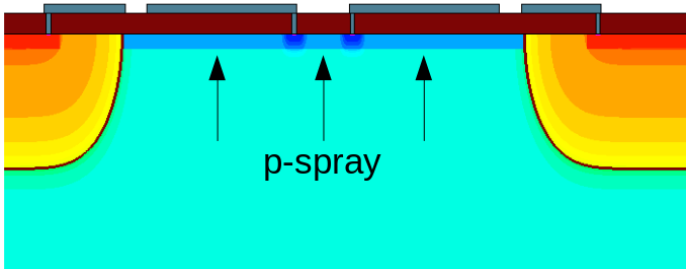
TCAD Simulation



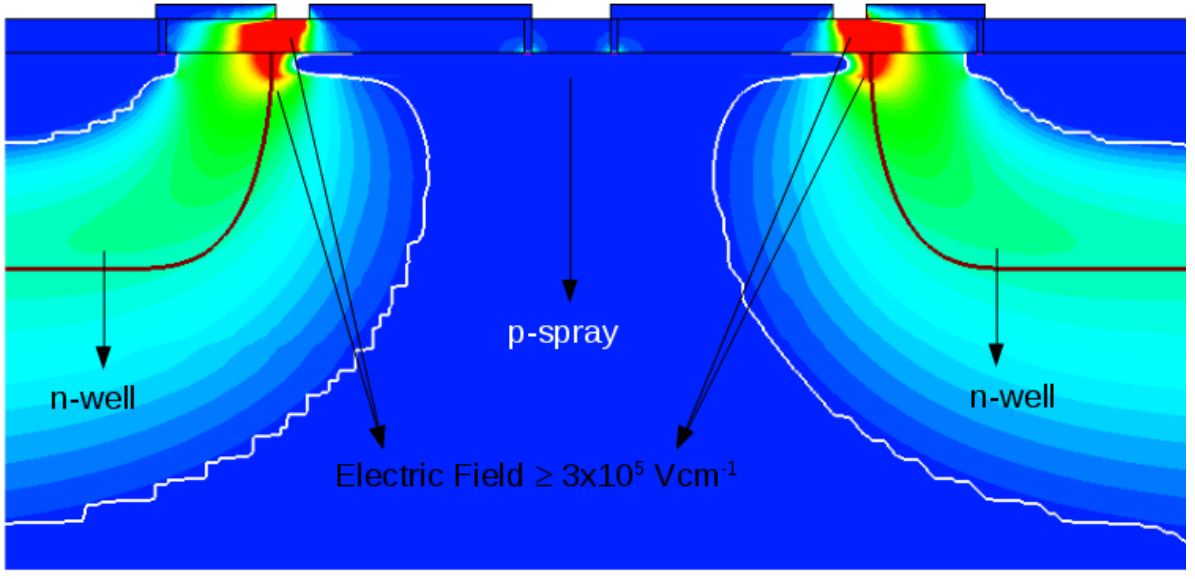




TCAD Simulation



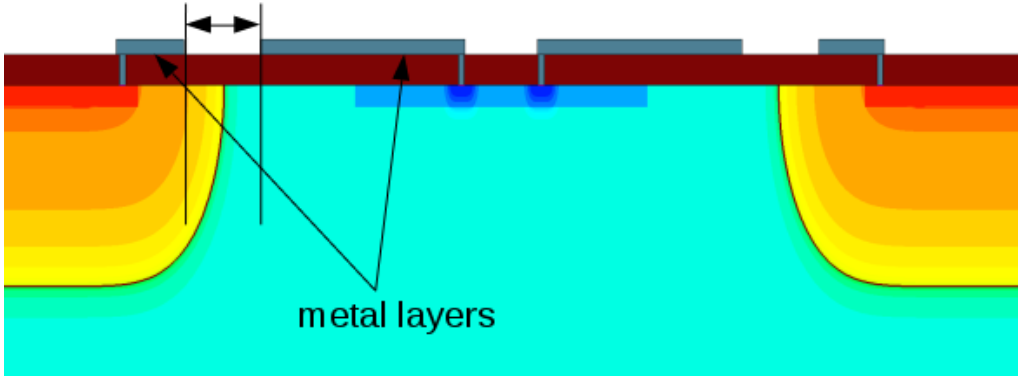
@ 20 Ωcm
@ 10^{11} Si-SiO2 interface charge



Electric Field

Breakdown:

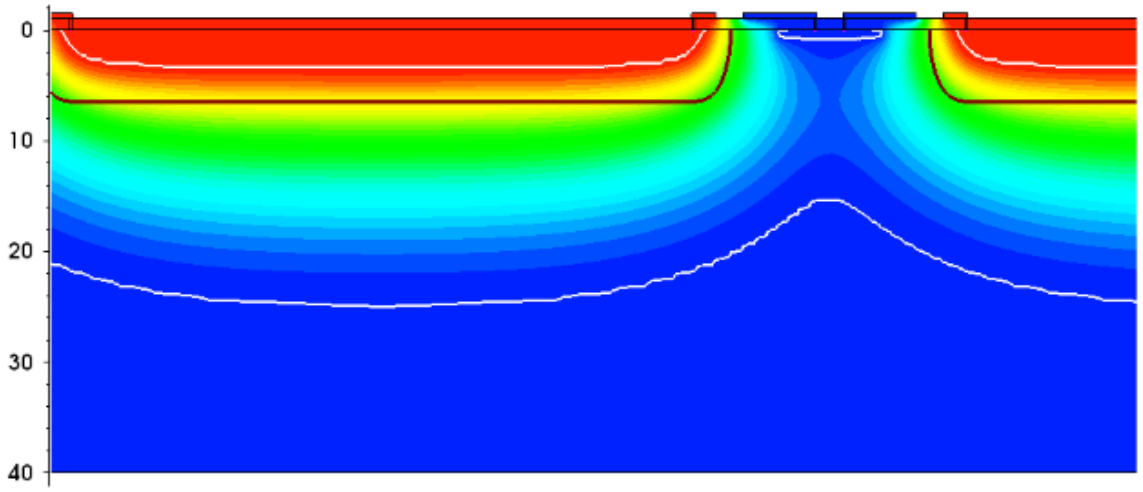
1. n-well p-spray junction
2. SiO2 gap between metal layers
   1 μm gap BDV: -170 V
   2 μm gap BDV: -180 V



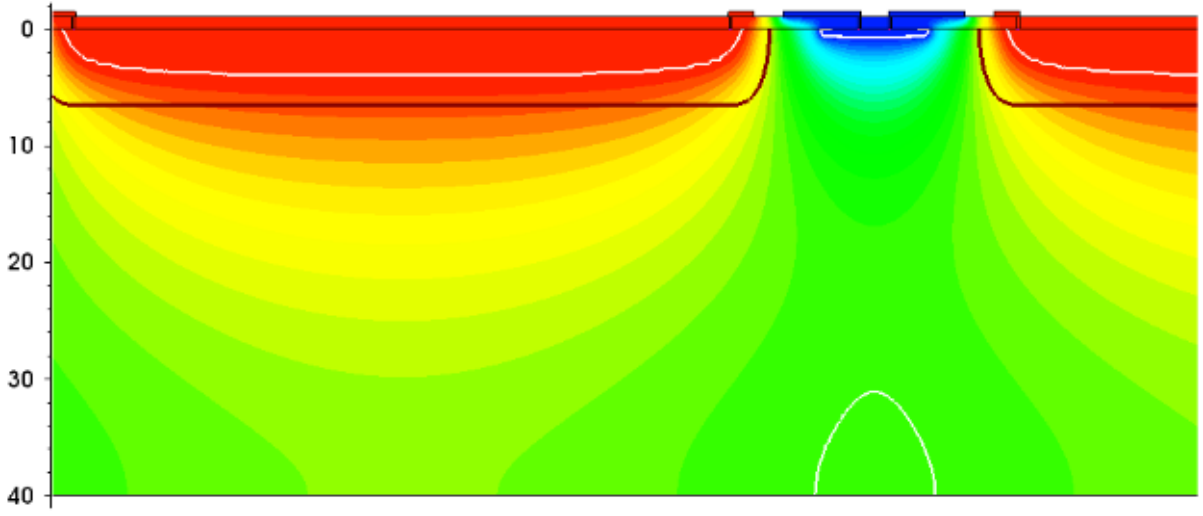
TCAD Simulation

- Depletion depth at -60 V
  1. 20 $\Omega cm \rightarrow 15\ \mu m$
  2. 80 $\Omega cm \rightarrow 25\ \mu m$
  3. 200 $\Omega cm \rightarrow 33\ \mu m$
  4. 1000 $\Omega cm \rightarrow \geq 40\ \mu m$

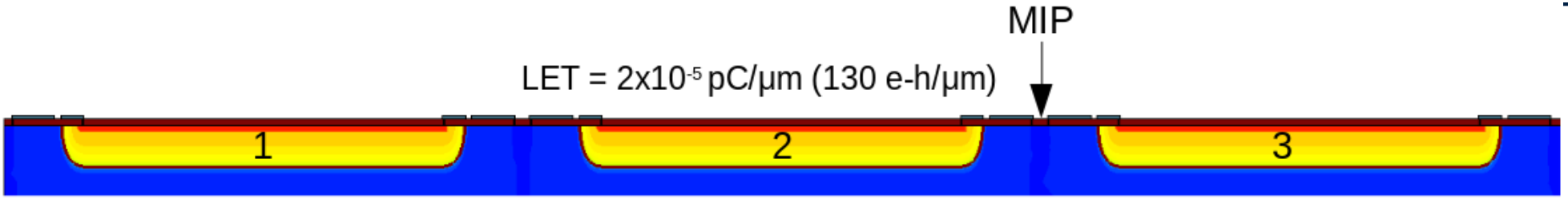
80 Ωcm

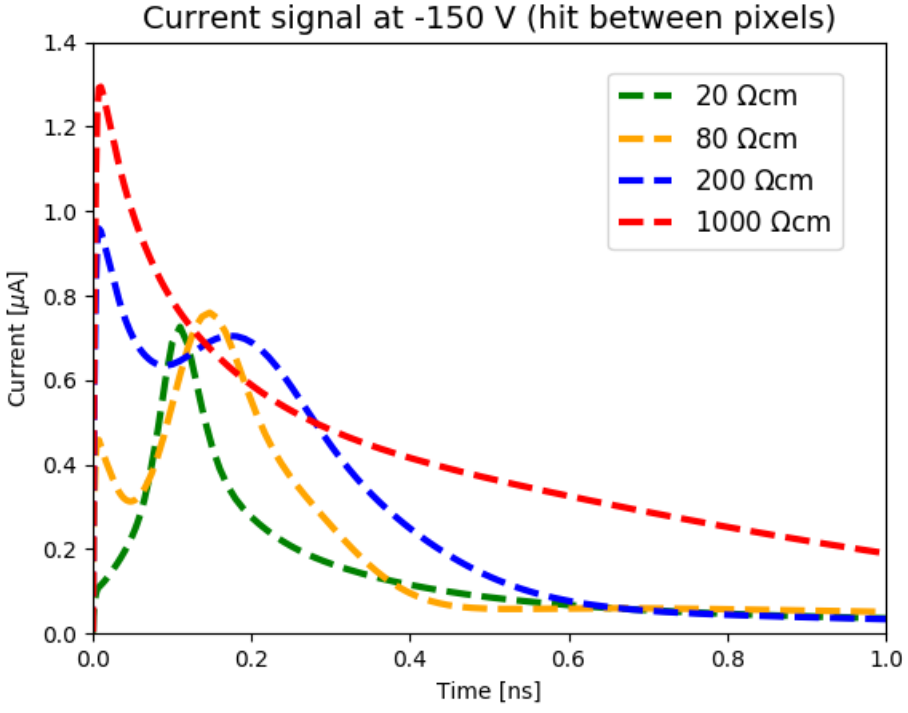


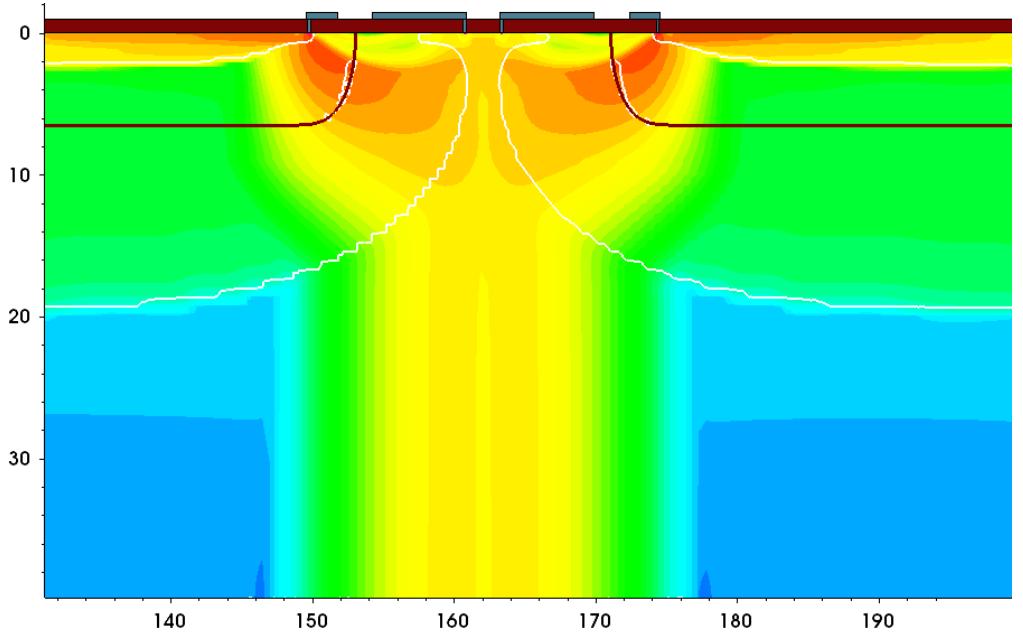
1000 Ωcm



TCAD Simulation





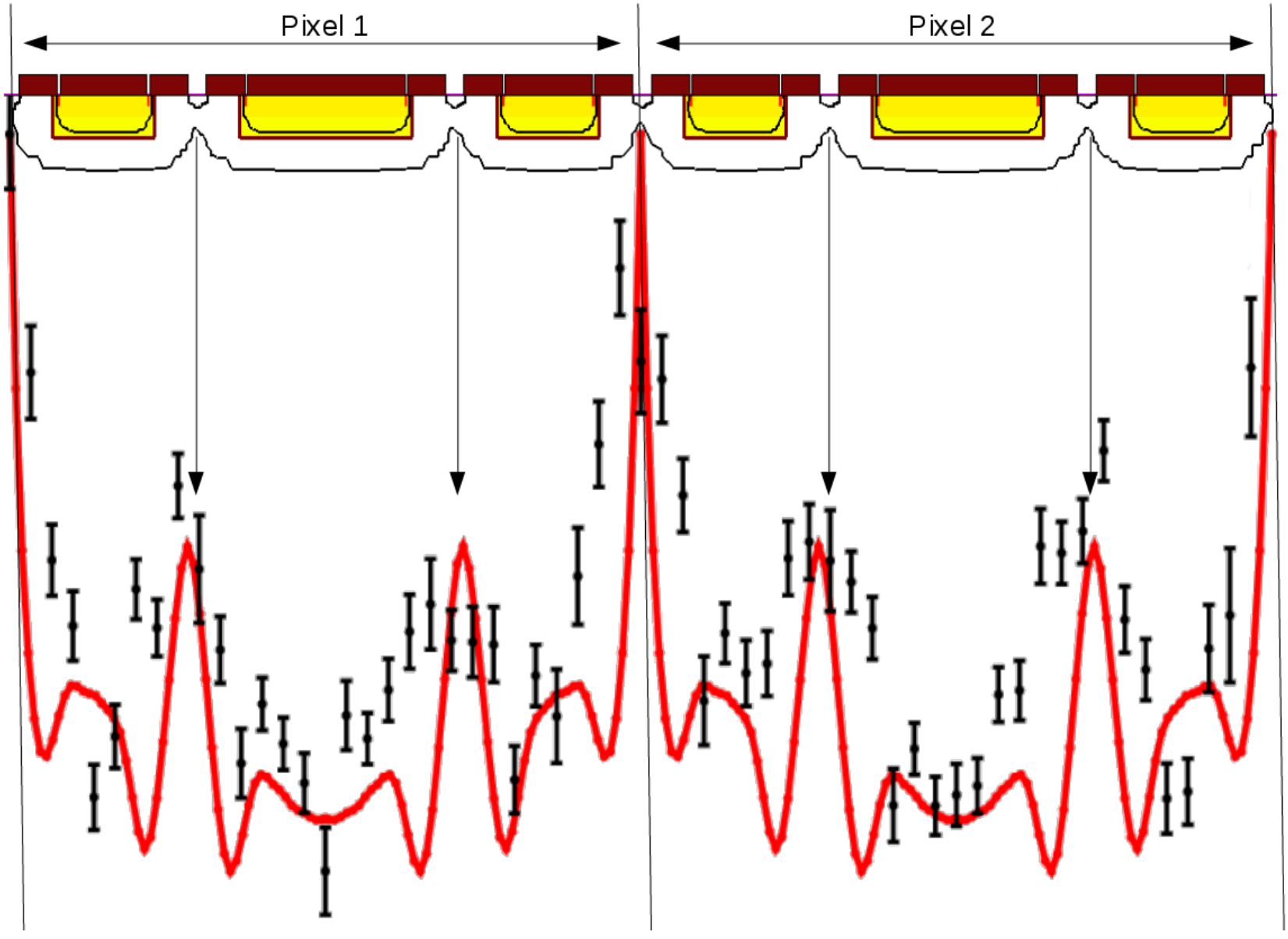


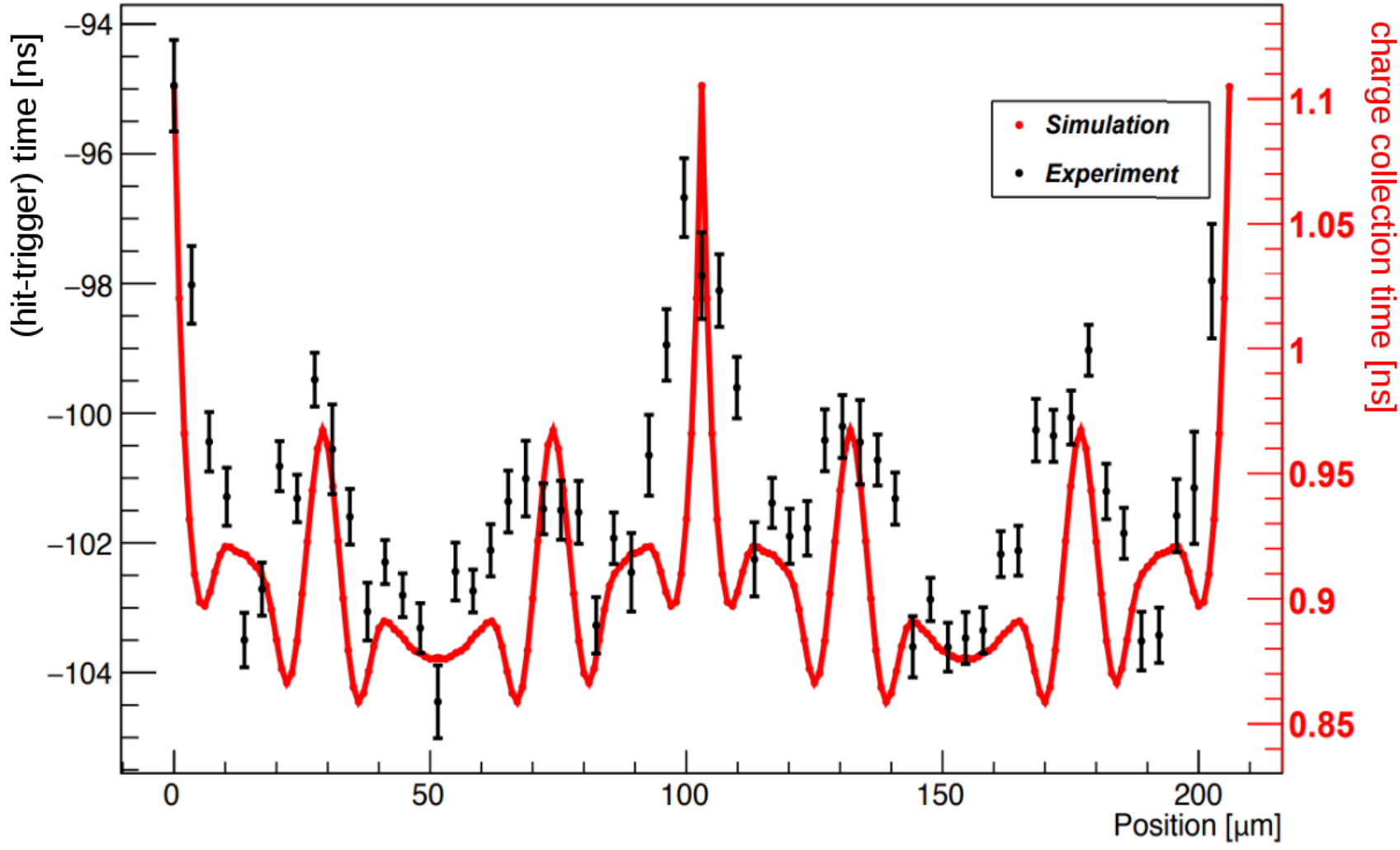
eCurrentDensity
@ 20 Ωcm
@ -150 V
@ 10^{11} Si-SiO2 interface charge

Conclusions

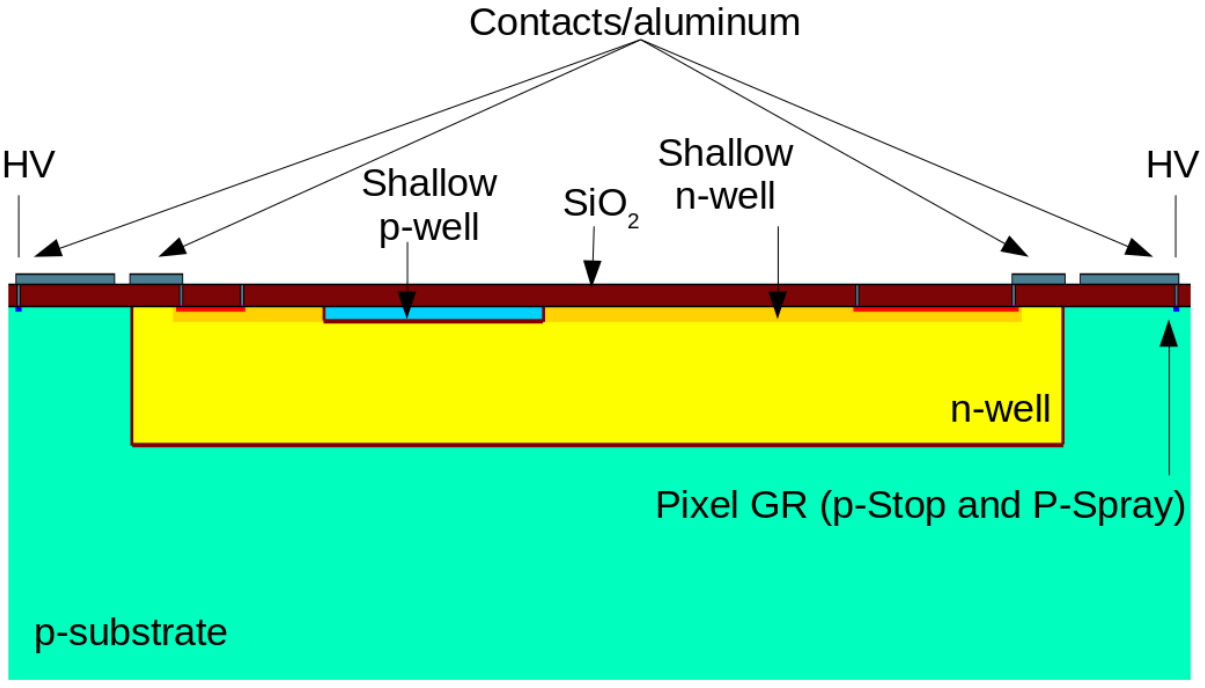
- TCAD simulation is a powerful tool for designing and optimization of semiconductor detectors.
- Better understanding of the detector performance.
- Ongoing studies of pixel estructure (pixel size, inter pixel distance, guardring, radiation damage) to improve the performance of the MuPix and ATLASPix prototypes.
- ATLASPix3 design includes modifications based on the results of this study.

Backup


Pixel 1
Pixel 2


(hit-trigger) time [ns]
−94
−96
−98
−100
−102
−104
0
50
100
150
200
Position [μm]
charge collection time [ns]
1.1
1.05
1
0.95
0.9
0.85
Simulation
Experiment

HV-MAPS structure



- Si p-substrate

  Resistivity:
  80, 200 and 1000 Ωcm

  Depth: 40 μm

- n-well

  Concentration: $6.5*10^{15}$ cm^{-2}

  Depth: 6.5 μm

- shallow n-well

  Concentration: $6.5*10^{16}$ cm^{-2}

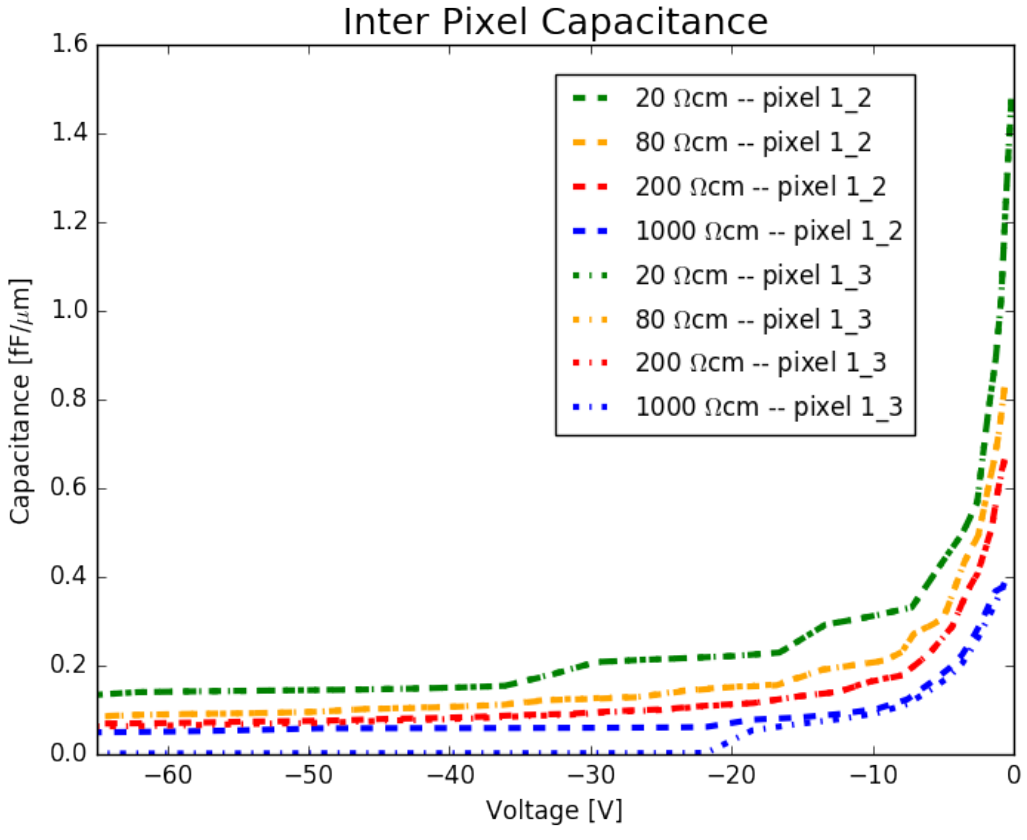
  Depth: 0.7 μm

- Aluminum Contacts
- Silicon Dioxide

  Depth: 1.0 μm

- Pixel Guardring

Simple structure, Inter Pixel Capacitance



Inter Pixel Capacitance at -60 V

pixel 1 2 20 Ωcm: 8 fF
pixel 1 3 20 Ωcm: 8 fF

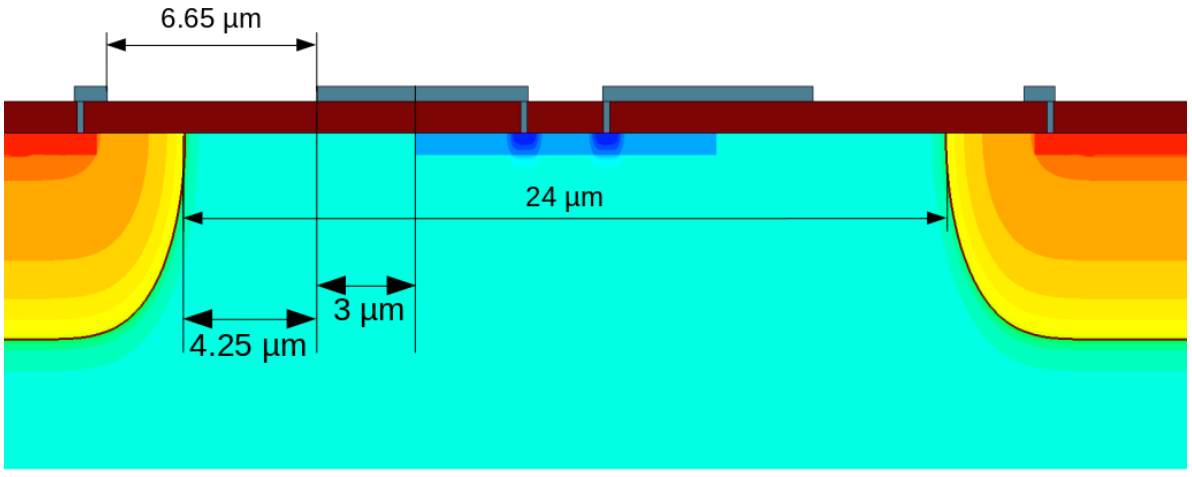
pixel 1 2 80 Ωcm: 5 ff
pixel 1 3 80 Ωcm: 5 fF

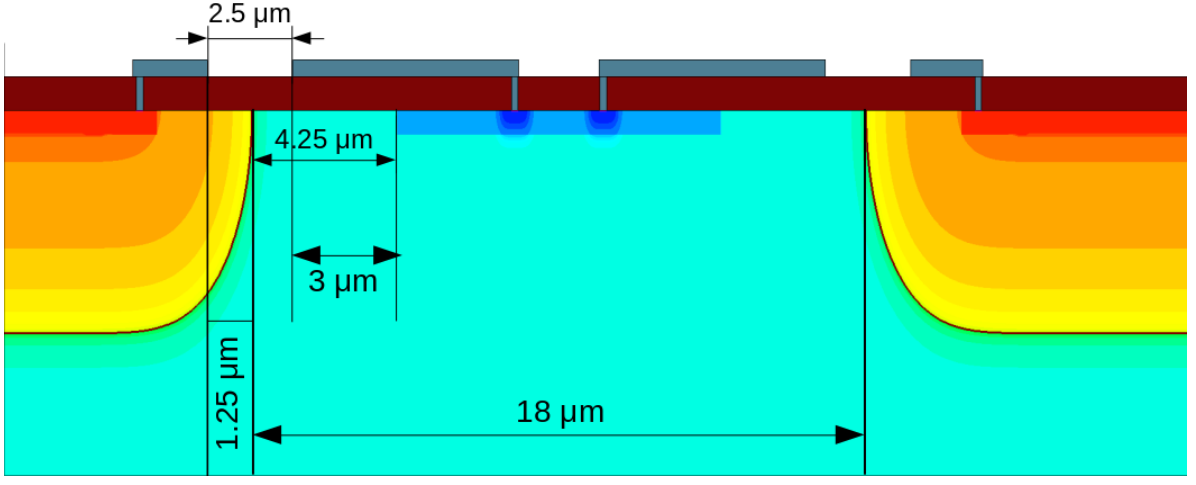
pixel 1 2 200 Ωcm: 4 fF
pixel 1 3 200 Ωcm: 3.5 fF

pixel 1 2 1000 Ωcm: 3 fF
pixel 1 3 1000 Ωcm: 57 aF

@ 1MHz

New Structure 3





Last Design