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

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Overview

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

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

• 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 \(^1\) \((1\times10^{15} \text{n}_{eq}/\text{cm}^2)\)
    • bulk damage: 2 acceptor, 1 donor trap, different e/h cross sections and introduction rates
    • surface damage: fixed oxide charge of \(5\times10^{10}\text{cm}^{-2}\) for not-irradiated and \(1\times10^{12}\text{cm}^{-2}\) 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

21.02.18
J.Beyer, TCAD Simulation and MPP Productions
TCAD Simulation
structure of interest

insulation layers:

- LTO
- Nitride
- SiO$_2$
TCAD Simulation
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high resistivity p-type bulk material ($5 \times 10^{12}$ cm$^{-3}$)
TCAD Simulation

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thickness: 100 µm
TCAD Simulation
structure of interest

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high resistivity p-type bulk material ($5 \times 10^{12} \text{ cm}^{-3}$)

thickness: 100 µm

n$^+$ pixel implant
TCAD Simulation

structure of interest

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high resistivity p-type bulk material ($5 \times 10^{12} \text{ cm}^{-3}$)

via to connect electrical contact with implant

n⁺ pixel implant

thickness: 100 µm
TCAD Simulation
structure of interest

- high resistivity p-type bulk material ($5 \times 10^{12}$ cm$^{-3}$)
- electrical contact on top of the pixel plus 2µm overhang
- via to connect electrical contact with implant
- n$^+$ pixel implant
- insulation layers: LTO, Nitride, SiO$_2$
- thickness: 100 µm
TCAD Simulation

structure of interest

- high resistivity p-type bulk material ($5 \times 10^{12} \text{ cm}^{-3}$)
- p-spray inter-pixel isolation
- insulation layers: LTO, Nitride, SiO$_2$
- electrical contact on top of the pixel plus 2µm overhang
- via to connect electrical contact with implant
- n$^+$ pixel implant
- thickness: 100 µm
TCAD Simulation
influence of implant size: general

- the new RD53 read-out chip will have a 50x50μm² 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)
TCAD Simulation
influence of implant size: breakdown behaviour

IV, $\Phi = 0$, Comparison of pixel sizes

- 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

- 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 25-45\(\mu\)m after depletion
- at low voltages, significantly more charge collected by larger pixel implants
- larger pixel implants have earlier depletion voltages
TCAD Simulation

influence of implant size: charge collection efficiency

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- 10µm shows that very small pixel cells cannot be used due to much later depletion
TCAD Simulation
influence of implant size: charge collect

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

![Graph showing charge collection efficiency (CCE) versus bias voltage (Vbias) for different implant sizes (25µm, 35µm, 45µm). The equation CCE, Φ = 1e15 n_{eq}/cm^2 is also given.]
TCAD Simulation

charge collection efficiency after irradiation

25-45µm

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• very small differences at 250V
  • smaller implants beneficial (charge multiplication)

10µm

• much lower collected charge below 100V

• charge multiplication above 100V

CCE, Φ = 1e15 n_{eq}/cm^2

\begin{align*}
\text{CCE} & = 1.0 \\
\text{V_{bias}} & \text{[V]} \\
\end{align*}
TCAD Simulation and MPP Productions

Charge collection efficiency after irradiation

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- small differences at 25V
- larger implants beneficial
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10µm
- much lower collected charge below 100V
- charge multiplication above 100V

CE, $\Phi = 1 \times 10^{15}$ n$_{eq}$/cm$^2$

IT, $\Phi = 1 \times 10^{15}$ n$_{eq}$/cm$^2$ comparison
Sensor productions by MPP
SOI4 production at MPG-HLL

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

- production to investigate:
  - different bias rail potential
  - RD53 compatible geometries
    - 25x100 \(\mu\)m\(^2\) / 50x50 \(\mu\)m\(^2\)
    - PT and PT with Al overhang and no PT
    - 250 \(\mu\)m / 450 \(\mu\)m 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
Sensor productions by MPP
Outlook: SOI5 production

• 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

- 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 $1 \times 10^{15}$ $n_{eq}/cm^2$ 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

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Backup
Noise vs input capacity
FE-I3

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• text
Title
subtitle

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