Investigation of punch-through bias in 3D sensors

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FONDAZIONE BRUNO KESSLER

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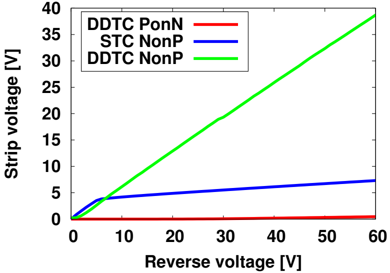
Outline

Introduction and background

Punch-through bias in 3D strip detectors in Trento

- Punch-through bias was used in both 3D-STC (Single Type Column) and 3D-DDTC (Double sided Double Type Column) strip detectors fabricated in Trento
- It always worked in STCs and P-on-N DDTCs
- **Problems were first observed in the DTC-2 and DTC-2b (N-on-P) batches with almost full ohmic columns**

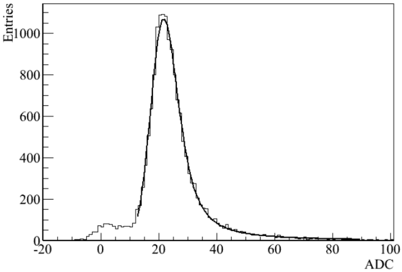


Punch-through measurements on older detectors

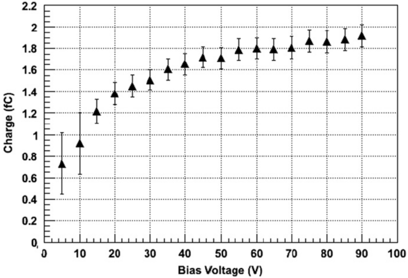
- Excellent results for DDTC P-on-N detectors ($V_{strip} < 1\,V$!)
- Very good result for N-on-P STC detector ($V_{strip} \sim 5\,V$!)
- **Not good for N-on-P DDTC detector!!!**

Pre-irradiation measurements on DTC-2 strip detectors

ADC spectrum @V_{bias}=40V
[Measurements performed at University of Freiburg]



Collected charge from a ^{90}Sr source
[Measurements performed at University of Freiburg, NIMA 624]



2009 test beam results

- Charge saturation at 2.1 fC
- Expected charge: 2.4 fC on a 200μm sensor

β-source measurements

- Collected charge lower than expected
- Charge saturation yet to be reached at 90V of bias

NO SIGNAL COULD BE OBSERVED AFTER IRRADIATION!!!

Motivation, tools and procedure

Motivation for this study

- Understand the dynamics of punch-through bias in 3D strip detectors
- Give explanations to the encountered problems
- Propose a working solution for punch-through bias in 3D strip detectors

Tools

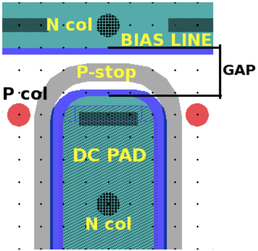
- SYNOPSYS TCAD tools - [http://www.synopsys.com/Tools/TCAD]

Procedure

- Test all the different punch-through solutions currently implemented
- Observe the distribution of different electrical quantities
- Compare simulations and measurements
- Identify and correct the problems with different layouts

DTC-2 strip detectors

LAYOUT



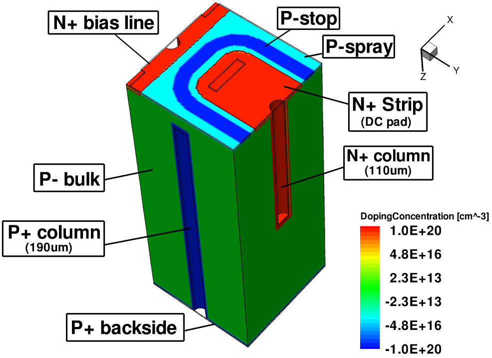
Geometrical dimension

- Bulk thickness 200μm
- Pitch=80μm
- P-stop=8μm
- GAP=21.5μm
- column diameter=10μm

Type of simulation

- Voltage sweep on the backside contact
- Bias line kept grounded
- Strip left floating

SIMULATED STRUCTURE



Doping and oxide characteristics

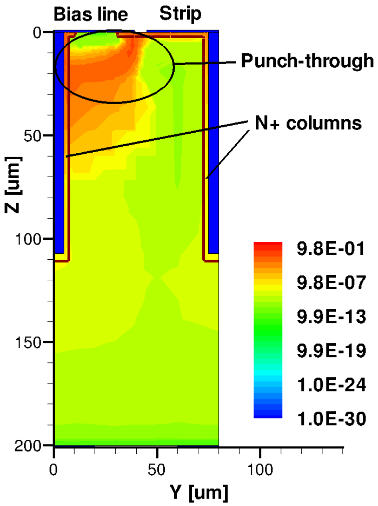
- $N_{bulk} = 2 \times 10^{11} at.P/cm^3$
- $N^+ = 5 \times 10^{19} at.P/cm^{-3}$
- $P^+ = 5 \times 10^{19} at.B/cm^{-3}$
- P-spray peak=$1 \times 10^{16} at.B/cm^3$
- Oxide thickness=1μm
- Oxide charge concentration=$3 \times 10^{11} cm^{-2}$

DTC-2 strip detectors, with p-stop

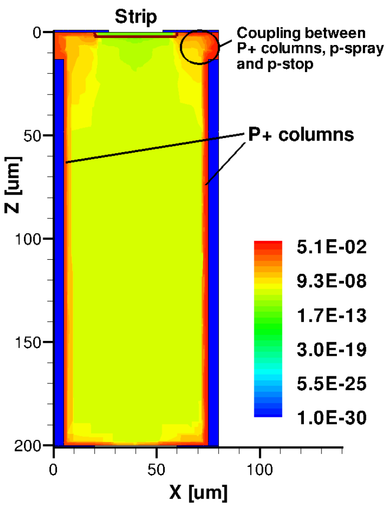
Simulation results at $V_{bias} = -100V$

CUTS BETWEEN COLUMNS OF THE SAME DOPING TYPE

Electrons current density [A/cm^2]



Holes current density [A/cm^2]

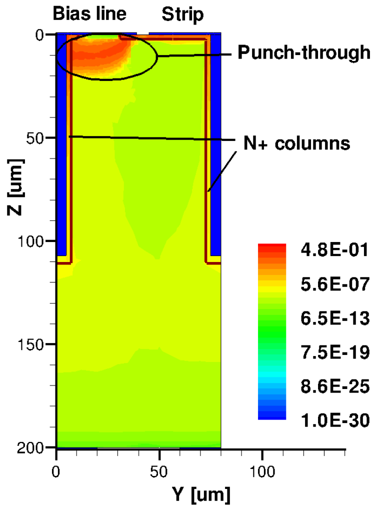


DTC-2 strip detectors, without p-stop

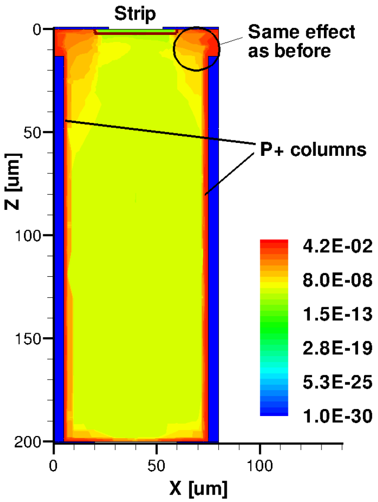
Simulation results at $V_{bias} = -100V$

CUTS BETWEEN COLUMNS OF THE SAME DOPING TYPE

Electrons current density [A/cm^2]



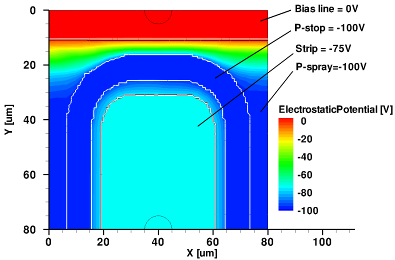
Holes current density [A/cm^2]

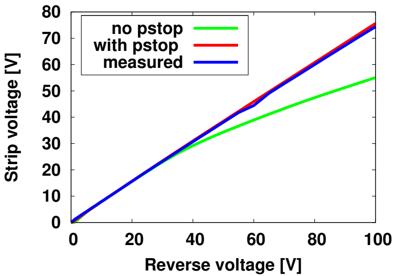


DTC-2 strip detectors

Simulation results at $V_{bias} = -100V$

Electrostatic potential distribution





Results

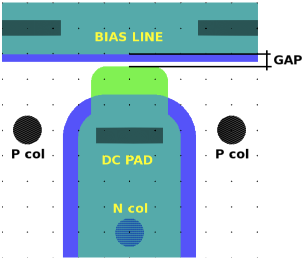
- Ohmic columns close to the opposite surface influence the punch-through
- The strip seems to be strongly coupled to the ohmic columns close to it
- P-spray and p-stop are biased at the same potential of the substrate
- P-stop is not helpful from the punch-through point of view because it further decreases the coupling between strip and bias line

First two modifications

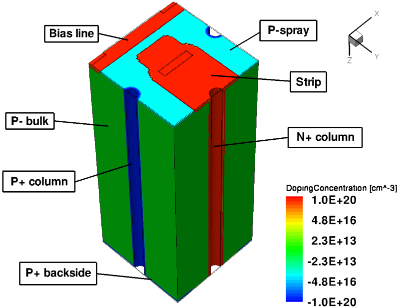
1. Remove p-stop and bring the strip closer to the bias line
2. Modify the shape of the bias line to increase the coupling with the strip

DTC-3 strip detectors
First modification - Reduced GAP

LAYOUT



SIMULATED STRUCTURE



Geometrical dimension

- Bulk thickness 200μm
- Pitch=80μm
- GAP=5μm
- column diameter=11μm

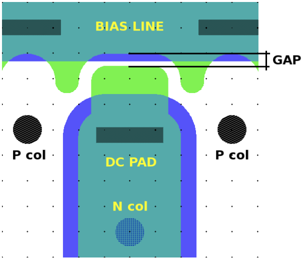
Doping and oxide characteristics

- $N_{bulk} = 7 \times 10^{11} at.P/cm^3$
- $N^+ = 5 \times 10^{19} at.P/cm^{-3}$
- $P^+ = 5 \times 10^{19} at.B/cm^{-3}$
- P-spray peak=1 $\times 10^{16} at.B/cm^3$
- Oxide thickness=1μm
- Oxide charge concentration=3 $\times 10^{11} cm^{-2}$

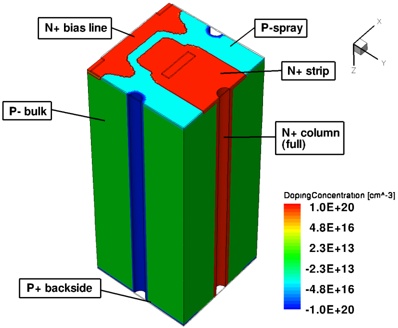
DTC-3 strip detectors

Second modification - Reduced GAP and strip encapsulation

LAYOUT



SIMULATED STRUCTURE



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- Oxide thickness=1μm
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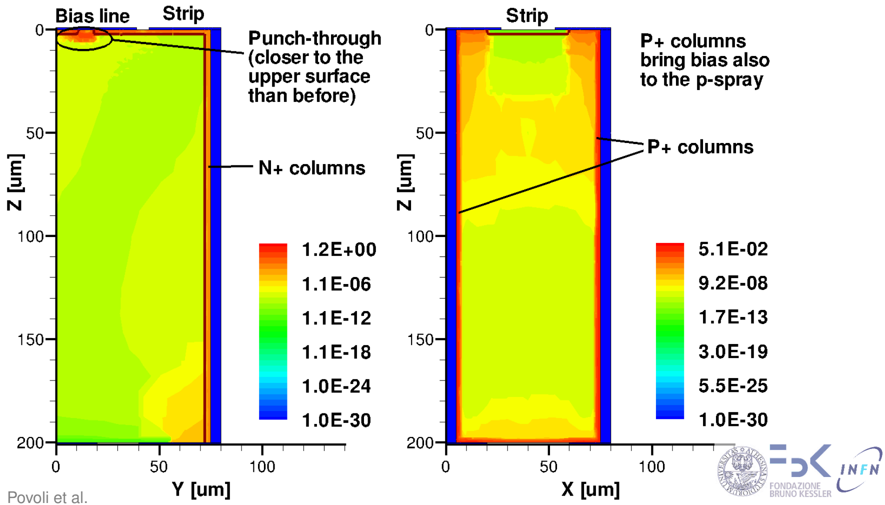
Simulation results at $V_{bias} = -100V$

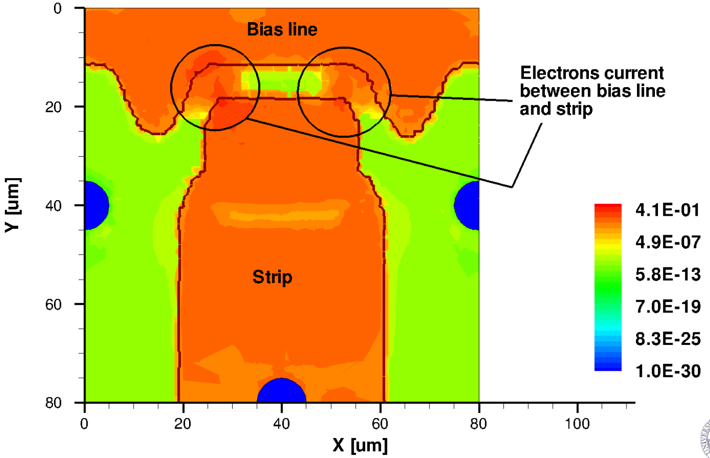
CUTS BETWEEN COLUMNS OF THE SAME DOPING TYPE

Electrons current density [A/cm^2] **Holes current density [A/cm^2]**



CUT ALONG "Z" AT 1μm FROM THE UPPER SURFACE

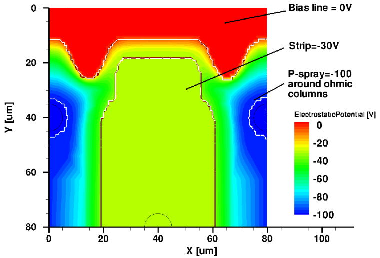
Electrons current density [A/cm^2]

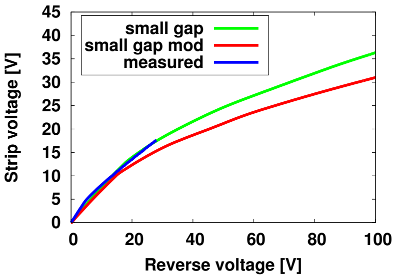


DTC-3 strip detectors

Simulation results at $V_{bias} = -100V$

Electrostatic potential distribution





Results

- Despite being passing-through, ohmic columns influence the potential of the p-spray in a smaller region
- Higher coupling between strip and bias line thanks to the reduced gap and "encapsulation"
- Strip voltage is equal to 30V for a V_{bias} of 100V
- Good results but still margin for improvements

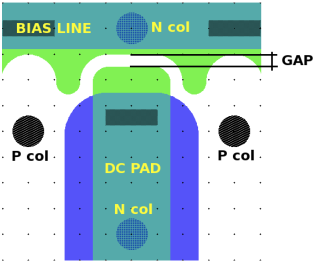
Other possible modification

1. In order to further increase the coupling between strip and bias line it is possible to place an N^+ column inside the bias line

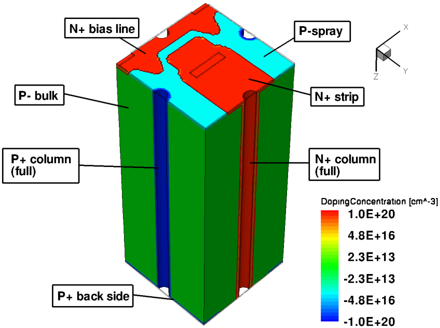
DTC-4 strip detectors

Reduced GAP, strip encapsulation and columns in bias line

LAYOUT



SIMULATED STRUCTURE



Geometrical dimension

- Bulk thickness 200μm
- Pitch=80μm
- GAP=5μm
- column diameter=12μm

Doping and oxide characteristics

- $N_{bulk} = 7 \times 10^{11} at.P/cm^3$
- $N^+ = 5 \times 10^{19} at.P/cm^{-3}$
- $P^+ = 5 \times 10^{19} at.B/cm^{-3}$
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- Oxide thickness=1μm
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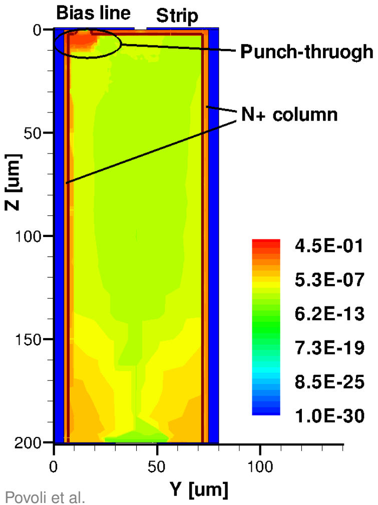
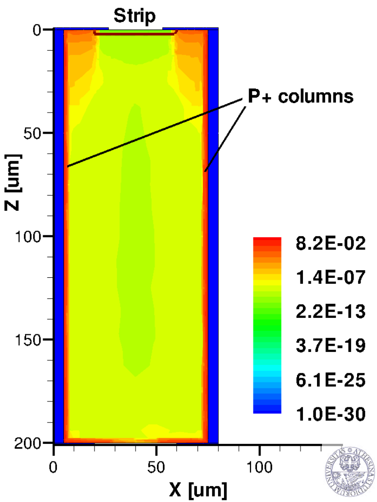
CUTS BETWEEN COLUMNS OF THE SAME DOPING TYPE

Electrons current density [A/cm^2]

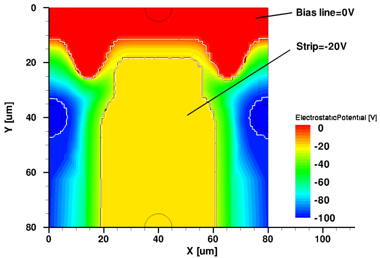


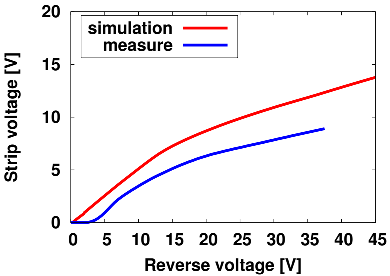
Holes current density [A/cm^2]



Simulation results at $V_{bias} = -100V$

Electrostatic potential distribution

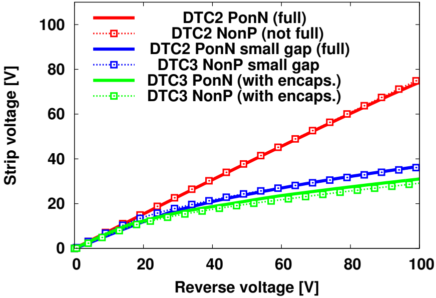


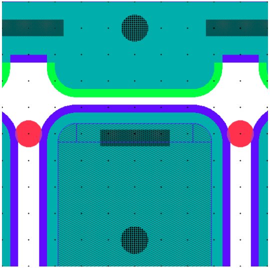


Results

- The presence of the N^+ column in the bias line allows for lower strip voltages
- The strip voltage is equal to 20V: effective V_{bias}@100V equal to 80V
- Measurements on real detectors proved that this layout is actually working

Would punch-through still work in full 3D P-on-N strip detectors?



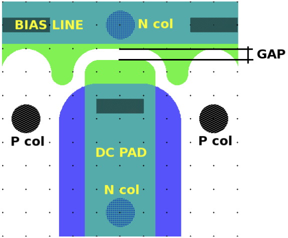


"GAP" in DTC-1 layout was already very small (6μm)

SAME MODIFICATION NEEDED (short GAP and strip "encapsulation")

Conclusions

- Many different layouts were simulated
- We believe most of the critical aspects were understood
- From the latest measurements on DTC-4 strip detectors, problems with punch-through bias seems to be solved
- In order to have a working punch-through bias in full 3D detectors the following aspects should be taken into account:
  - Reduce the gap between strip and bias line as much as possible (avoid p-stop if possible)
  - In order to increase the coupling between strip and bias line encapsulation might be needed
  - Leaving a row of columns also in the bias line definitely helps



Thank you!