Slim edges in double-sided silicon 3D detectors

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Outline

3D Detectors

Full 3D

Simplified approaches - Trento and Barcelona

Slim edge description

Issues with active-edge

Slim-edge - General Idea

Slim edge numerical simulation and design

Type of simulations performed

Simulations results and layout design

Electrical characterization

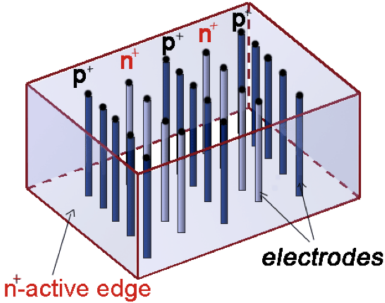
Evaluation of the shielding effectiveness

Functional characterization

Laser scans of the edge region

Full 3D detectors

Original idea - PRO and CONS



[First proposed by S. Parker et. al. in NIMA 395 (1997), 328]

ADVANTAGES

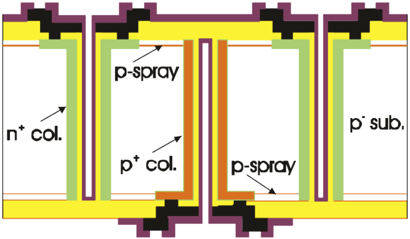
1. Possible to decouple the active volume from the electrode distance
2. Very low full depletion voltage (**<10V**)
3. Very small collection distance (designer choice $\sim$ **$50\mu m$**)
4. Lower trapping probability after irradiation (shorter collection distances)
5. Small dead area along the edges thanks to the active-edge

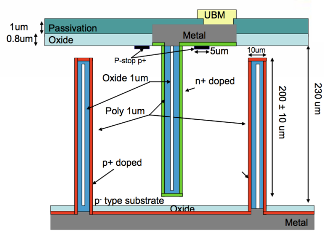
DISADVANTAGES

1. Non uniform response (low field regions present)
2. Higher capacitance (Lower S/N)
3. Complex fabrication process

Simplified approaches - Double Sided Double Type Columns

DDTC - FBK (Trento) and CNM (Barcelona) [3D Processing collaboration]





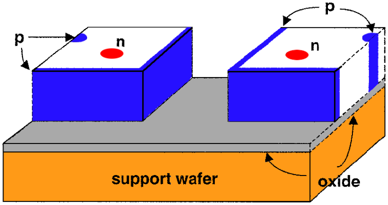
ADVANTAGES

1. Much simpler fabrication process:
   - No need for support wafer
   - Columns are empty
2. Very good mechanical yield
3. Good electrical yield
4. Technologies of choice for the ATLAS-IBL qualification

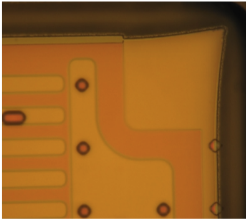
DISADVANTAGES

1. Difficult to fully control the column depth
2. If the distance "d" is too long ($> 25\mu m$) performances after high irradiation are very poor
3. Empty columns $\Rightarrow$ dead regions
4. Not Full 3D $\Rightarrow$ active-edge still missing

Issues with active-edge



[C.J. Kenney, IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 48, NO. 6, DECEMBER 2001]



Active-edge and its implications

- Doped trenches around the detectors by means of Deep Reactive Ion Etching (DRIE)
- Strong reduction of the dead edge area
- Unfortunately it causes several complications in the fabrication process:
  - Support wafer needed
  - Backside of the sensor wafer is not accessible
  - The active-edge is not compatible with a double-sided process

Solution

Different approach aimed at reducing the edge dead area ⇒ SLIM-EDGE

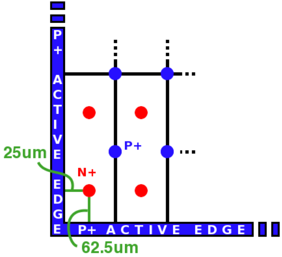
NOTE:

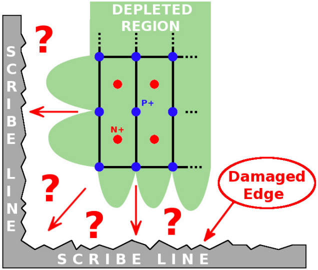
A set of planar detectors with active-edges was also processed at FBK in view of the realization of full 3D detectors, several difficulties were encountered although the final result was good

-[M. Povoli, RESMDD10, Firenze, October 2011]

-[A. Bagolini, Trento Workshop 2011, Trento, March 2011]

Active-edge vs. Slim-edge
General idea





ACTIVE-EDGE

- Dead region along the edge can be reduced down to $20 - 50\mu m$
- 100% edge sensitivity up to few microns away from the physical edge
- Support wafer needed $\Rightarrow$ difficult fabrication process

SLIM-EDGE

- Consists in reducing the edge dead area without making use of the active-edge
- Diamond saw still needed
- Cut region/junction electrode distance?
- Terminating structures?
  - Planar detectors: planar guard-rings (0.5-1mm)
  - Not effective for 3D detectors

Numerical simulations

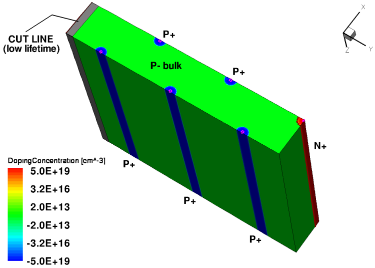
Idea and type of simulations performed

IDEA

Design an ohmic column "fence" able to shield the last junction electrodes from the current coming from the cut region

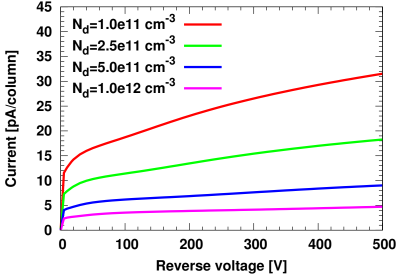
REQUIREMENTS

- Minimize the edge dead area ($\sim 200\mu m$)
- Operating voltages $> 200V$
- Compatibility with a double-sided 3D process (no support wafer)

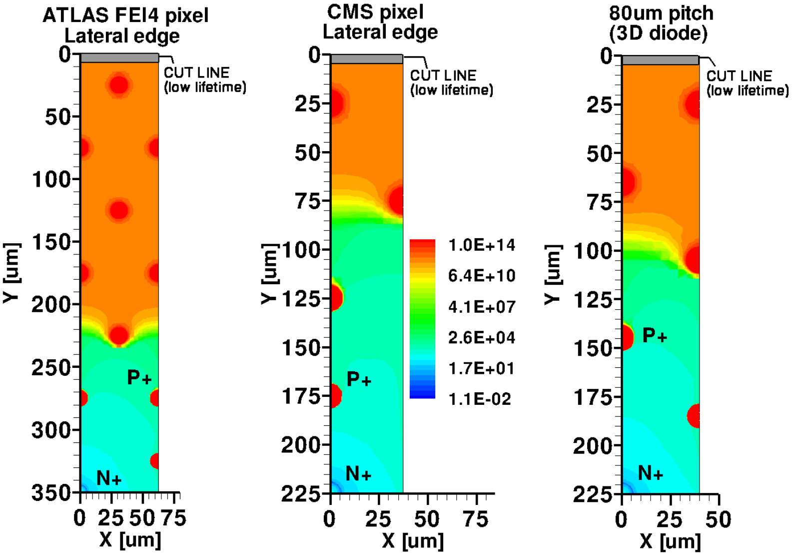


Numerical simulations

- Modeling the scribe with a with a low lifetime region ($\tau < 1ns$)
- Bias voltage scan (up to very high voltages)
- Monitoring the current of the last junction column
- Avalanche models not active to be sure to only observe edge contributions
- No signs of early discharge should be noticed!

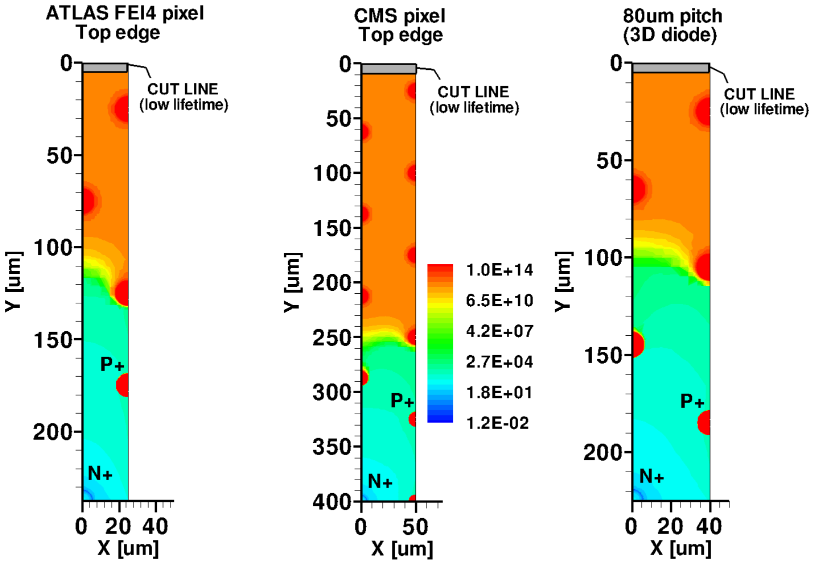


Holes density [cm^{-3}] - Lateral edge - $\mathbf{V_{bias} = -300V}$



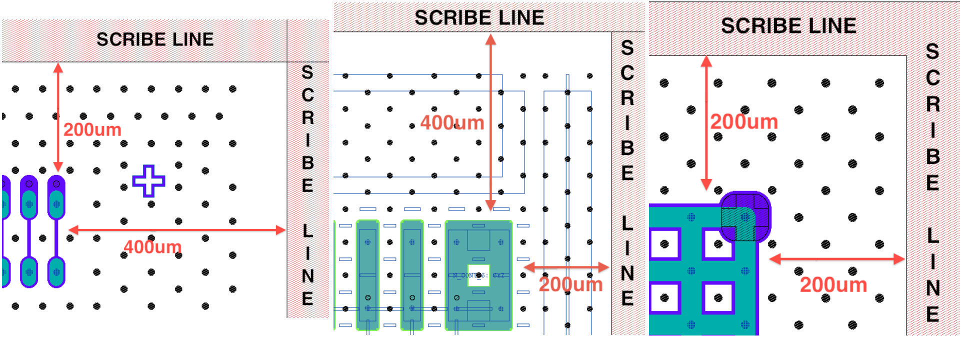
Simulations results

Holes density [cm^{-3}] - Top edge - $\mathbf{V_{bias} = -300V}$



Final layout design - Three different devices

ATLAS FEI4 PIXEL | **CMS PIXEL** | **3D DIODE (80μm pitch)**



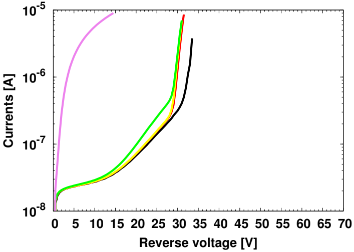
General characteristics

- Long edge: 400μm (200μm for the 3D diode)
- Short edge: 200μm
- ALL THESE LAYOUTS ARE CONSERVATIVE... (see next slide)

Electrical characterization

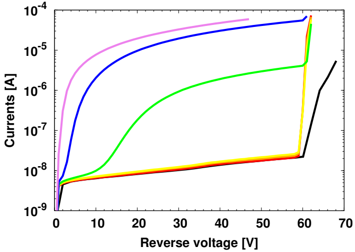
- The goodness of the implemented layout was tested on 3D diodes
- Several cuts repeated, each one closer to the active area
- Last cut takes away the last row of ohmic columns of the active area

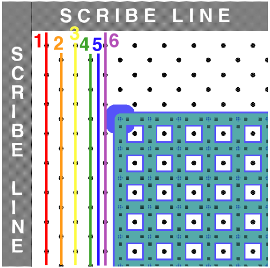
ATLAS07 - Low breakdown



[G. Giacomini, Trento Workshop 2011]

ATLAS09 - Higher breakdown



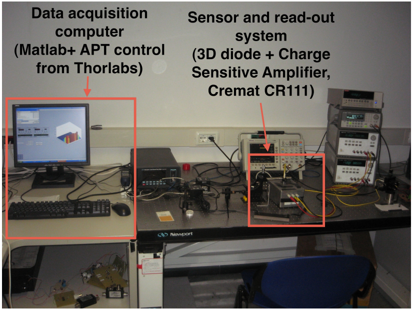


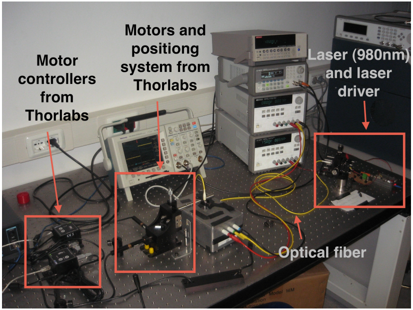
Comments

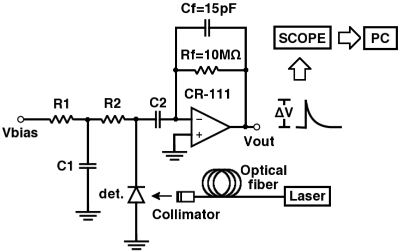
- First test on ATLAS07 devices: low breakdown, not conclusive
- Second test on ATLAS09 devices: higher breakdown, same behaviour
- Possible to reduce the slime-edge to a total of $\sim 100\mu m$

Laser scans of the edge area

Measurement setup



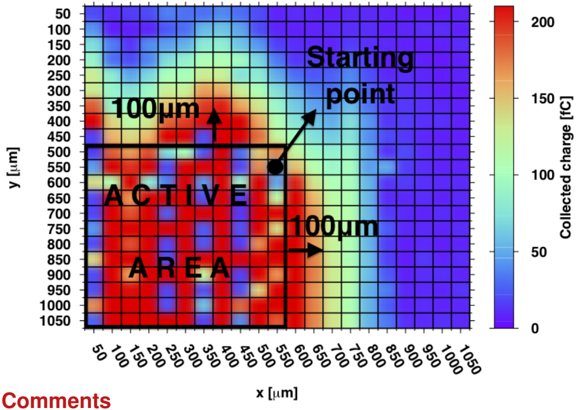




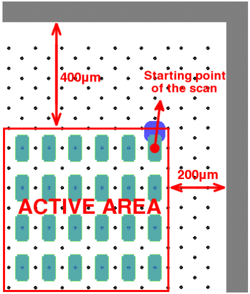
System

- 980nm laser (spot size $\sim 10\mu m$)
- Motors and positioning system (Thorlabs)
- 3D diode, CMS layout (ATLAS07)
- Cremat CR-111, Charge Sensitive Amplifier
- Tektronix 3052B scope
- PC to acquire data and move the laser

COARSE SCAN @$V_{bias} = -15V$ step=50μm



LAYOUT

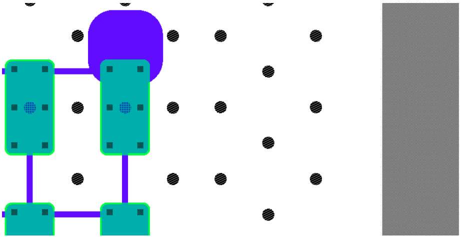


Comments

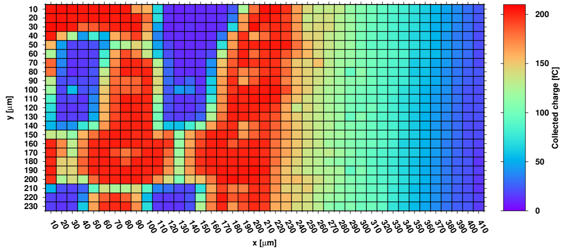
- Metal pattern visible, step too large to see it clearly
- Charge collected from a region $\sim 100\mu m$ outside the active area
- Charge collection in the top region not completely uniform $\Rightarrow$ Software bug? (...investigating)

Laser scans of the edge area - Preliminary results 2

LAYOUT



FINE SCAN $@V_{bias} = -15V$ step=$10\mu m$



Finer scan ($10\mu m$ step) of the lateral edge

- Edge length: $\sim 200\mu m$
- Signal visible up to $\sim 100\mu m$ away from the active area
- Metal pattern recognizable
- Electrodes are also visible (they are empty, less charge)

On the negative side:

- Slight misalignment of the detector
- Spot size $\sim 10\mu m$
- N^+ and P^+ electrodes had a poor alignment in this batch (ATLAS07) due the the high wafer bowing

Conclusions

- We fabricated and tested 3D detectors with passing through columns and slim-edge
- The slim-edge showed to be a very good alternative to the active-edge (easier fabrication, and good reduction of the edge dead area)
- It was understood that the slim-edge can be reduced to a total of $100\mu m$
- Good charge collection efficiency along the edges ($\sim 100\mu m$ away from the active area)
- The slim-edge was also tested on irradiated pixel devices (up to $5 \times 10^{15} n.eq/cm^{-2}$) during June 2011 test beam at CERN with very good results
- We will continue the functional testing and optimization of the slim-edge while designing the next batch of Full 3D detectors at FBK

Thank you!