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Status report on the 3D sensor development @FBK

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Outline

- Process development @ FBK
  - Main technological steps
- Layout
  - Temporary metal
- ATLAS pixel IV characteristics

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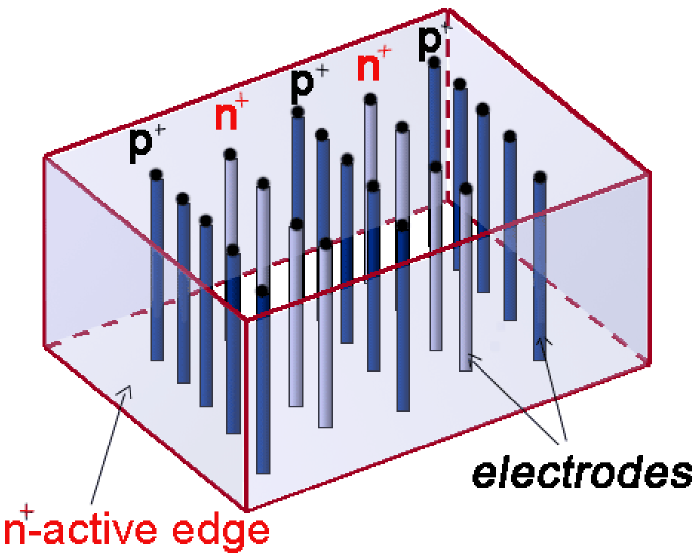
3D detectors

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



Best result:
66% of the original signal after
8.8×10^{15} cm^{-2} 1-MeV $n_{eq.}$ fluence

C. Da Via et. al.
NIMA 604 (2009) 504

ADVANTAGES:

- Electrode distance and substrate thickness decoupled:
  - low depletion voltage
  - high speed
  - good charge collection efficiency

    → **High radiation hardness**

-Active edges:
  - Dead area reduced up to few microns from the edge

DISADVANTAGES:

- Non uniform response due to electrodes
- **Complicated technology**
- Higher capacitance with respect to planar

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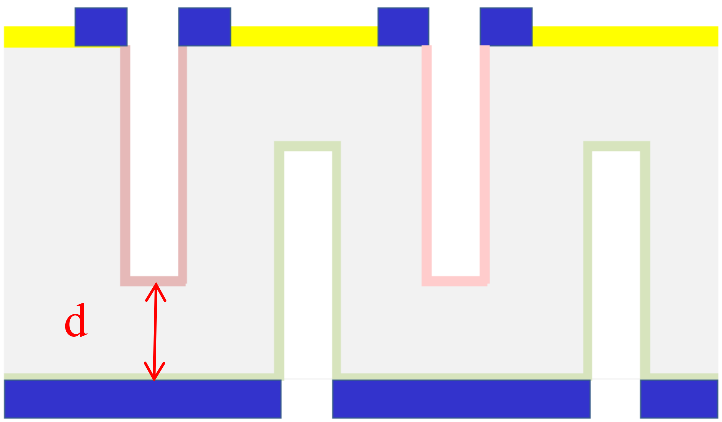
3D Technology Developments @FBK

NON Passing through columns tech.

A. Zoboli et al., IEEE TNS 55-5, 2008



Hole Depth

It’s a critical parameter on 3D devices

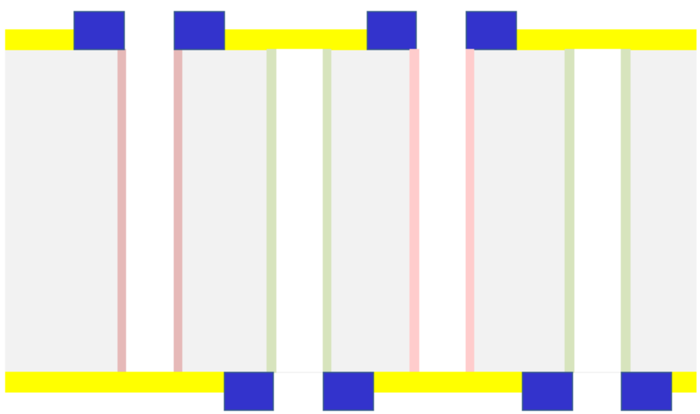
d much smaller than wafer thickness

It’s not easy to control, it depends on:

✓Wafers thickness

✓Etch rate

- ✓equipment status
  - ✓uniformity on wafers
  - ✓uniformity w to w
- ✓Hole diameter (lithography)



Solution

Passing through columns

3D-DTC with passing through columns

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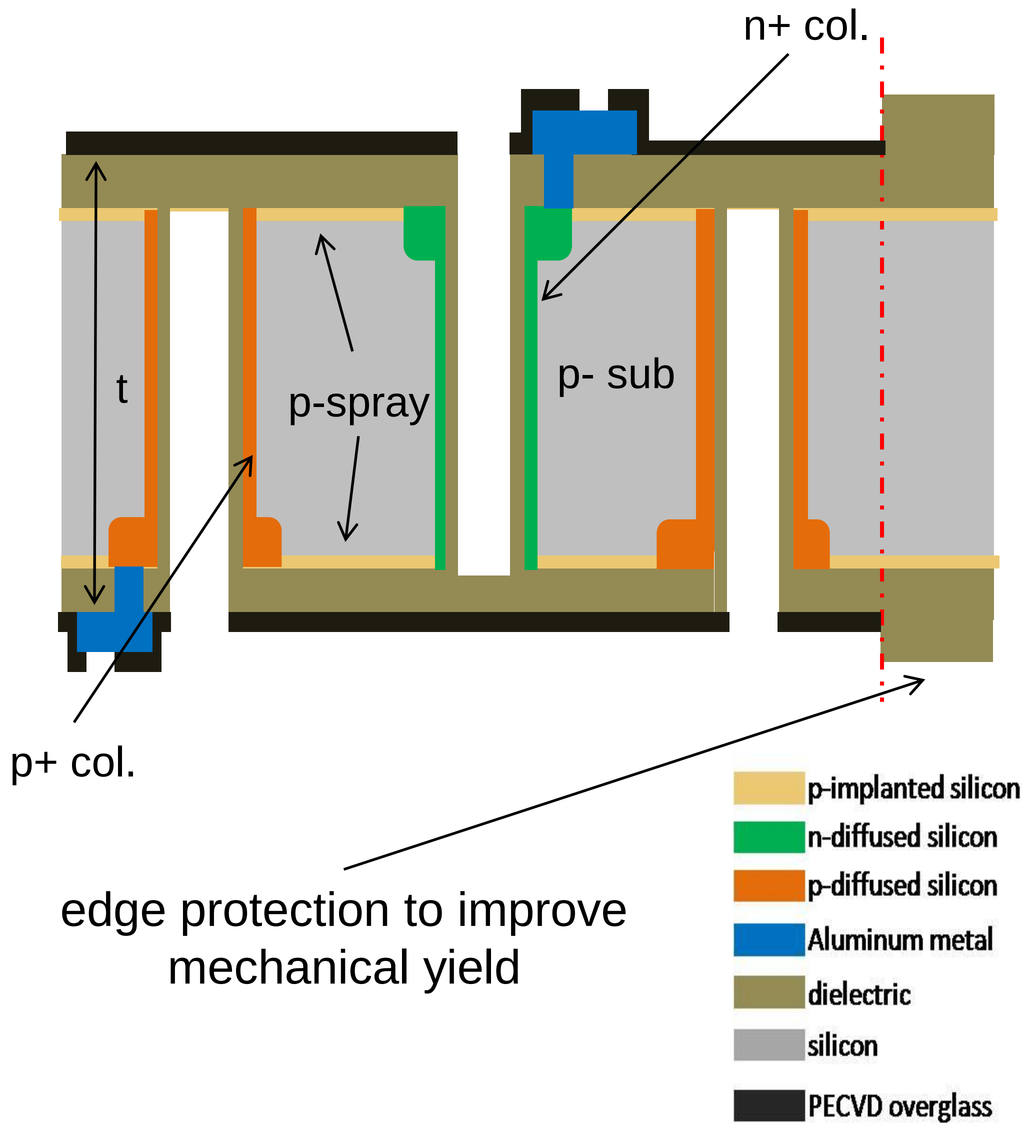
FABRICATION PROCESS

- holes (~11 um diam.) are "empty" (no poly-Si)
- column depth equal to the wafer thickness
- no support wafer

full double side process

- isolation by p-spray
- Edge protection



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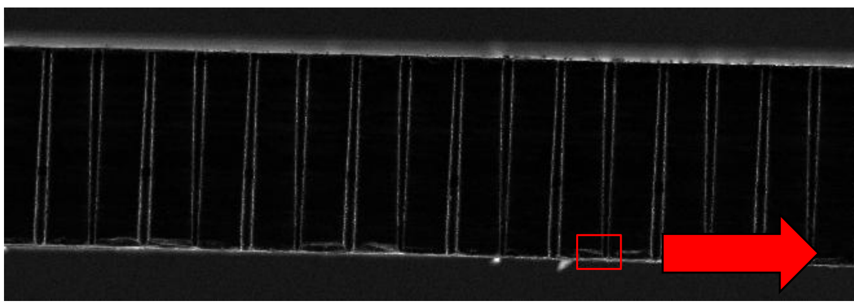
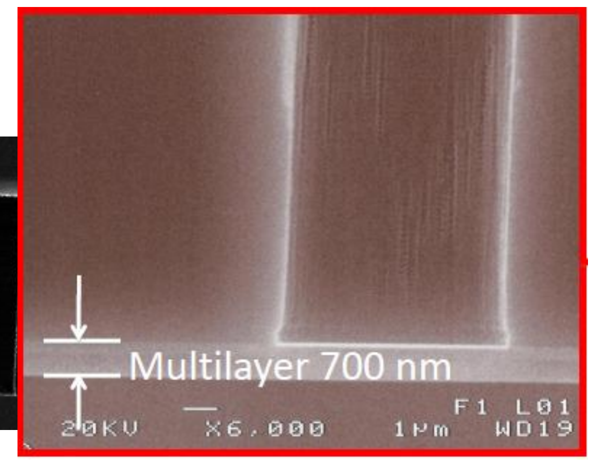
Optimize DRIE recipes for holes with higher aspect ratio

Optimization of DRIE recipes in order to

→ increase the uniformity of the etch rate
→ decrease the overall etching time
→ Increase the aspect ratio
→ Avoid notching

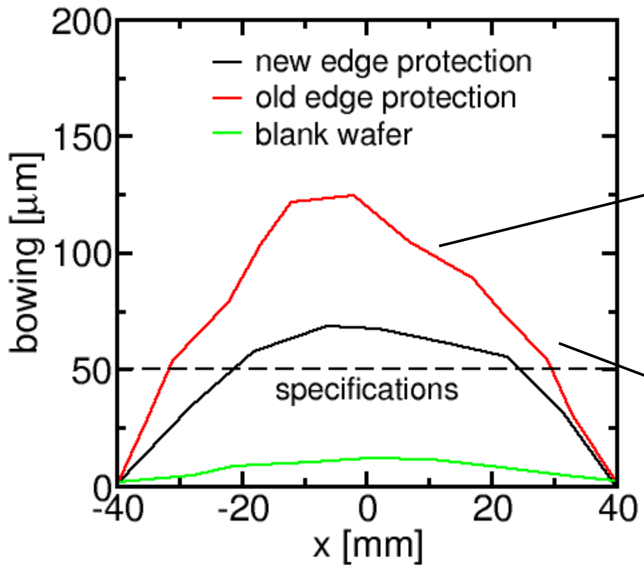




We use a DRIE with electrostatic clamping better thermal contact but we need an edge protection in order to improve the mechanical yield

Wafer bowing: leakage current

the wafer bowing is mainly influenced by the edge protection

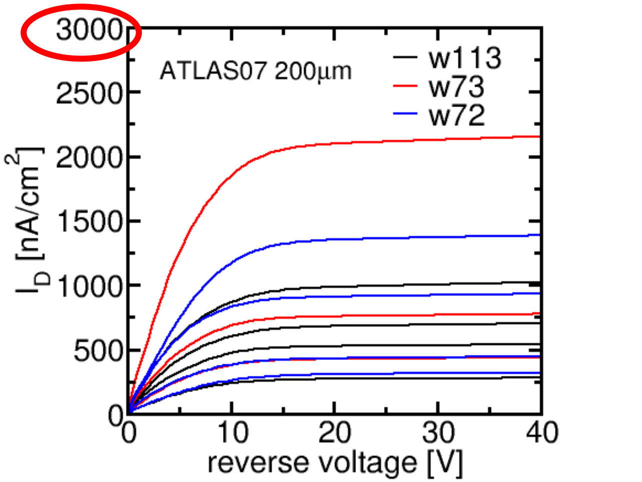


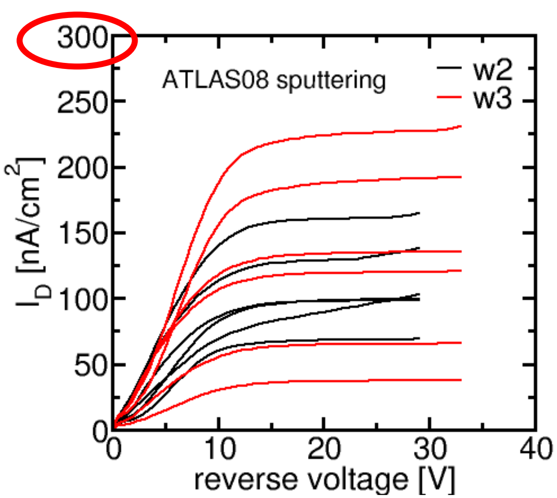
old

new

Leakage current:

planar test diodes (4mm^2)

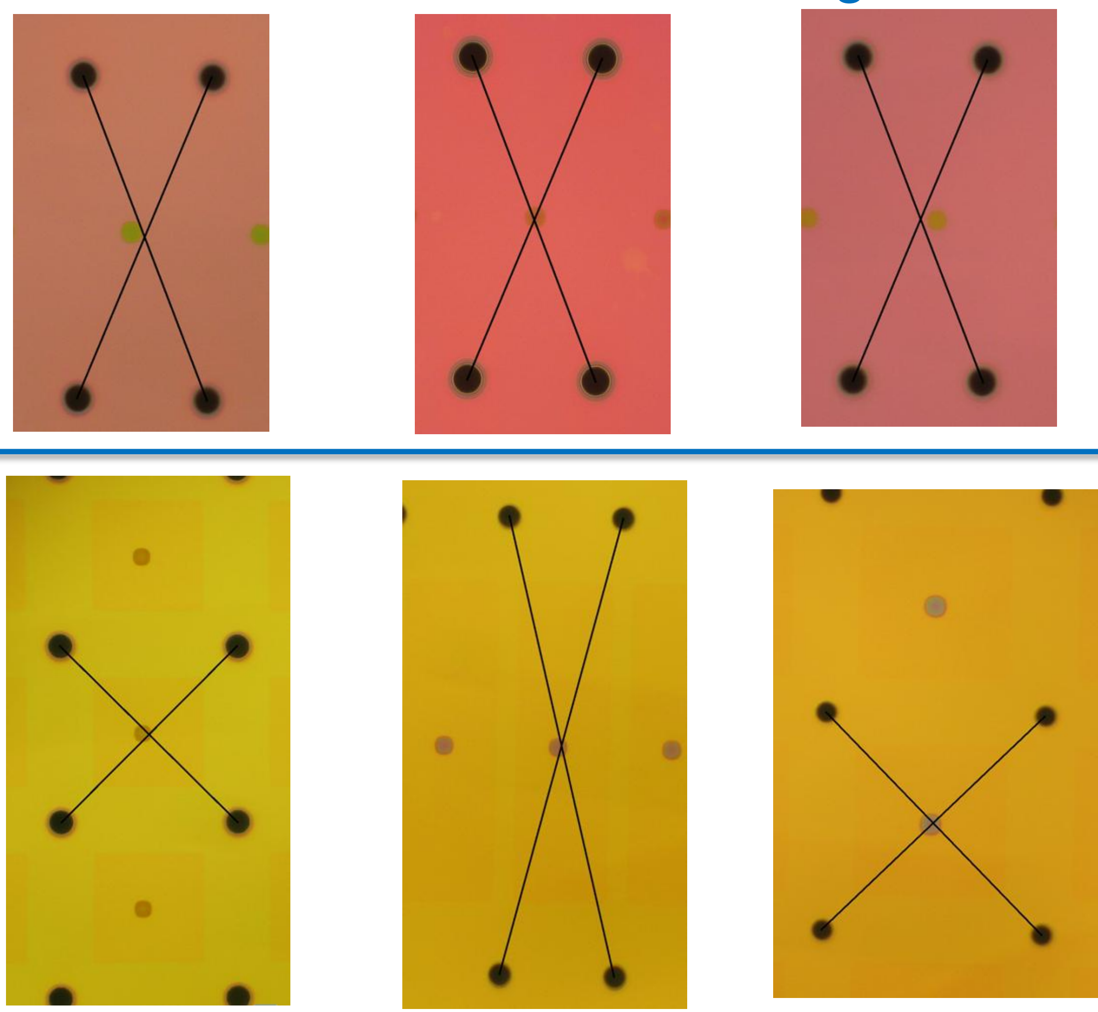




wafer bowing strongly influences the leakage current, in the new process it is reduced by one order of magnitude

Wafer bowing: Column alignment

left side **center** **right side**



old process

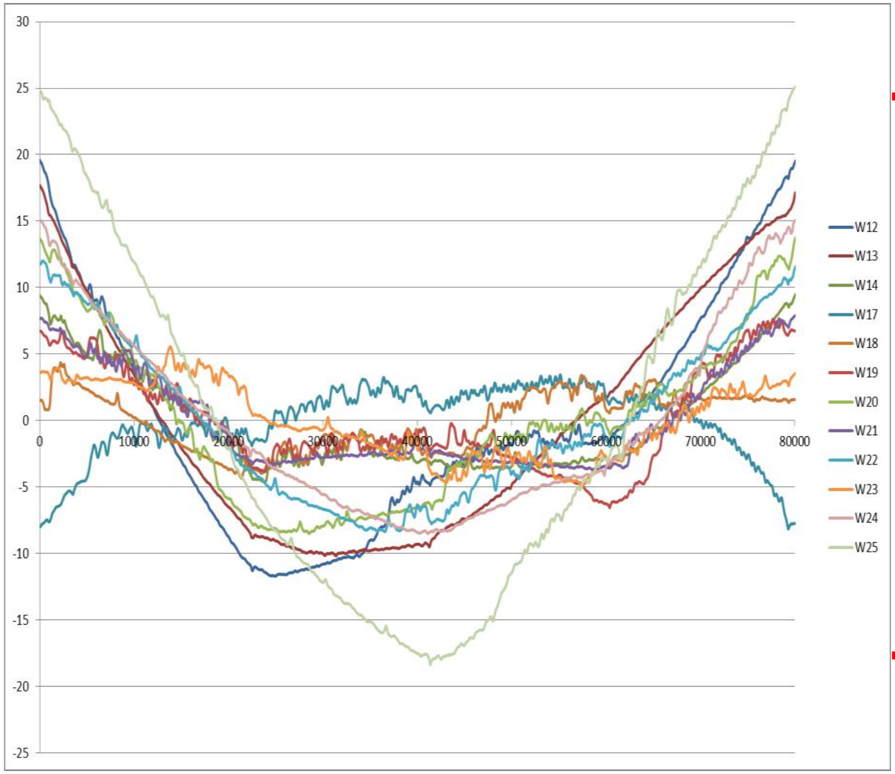
misalignment of a several µm

new process (optimized protection layer)

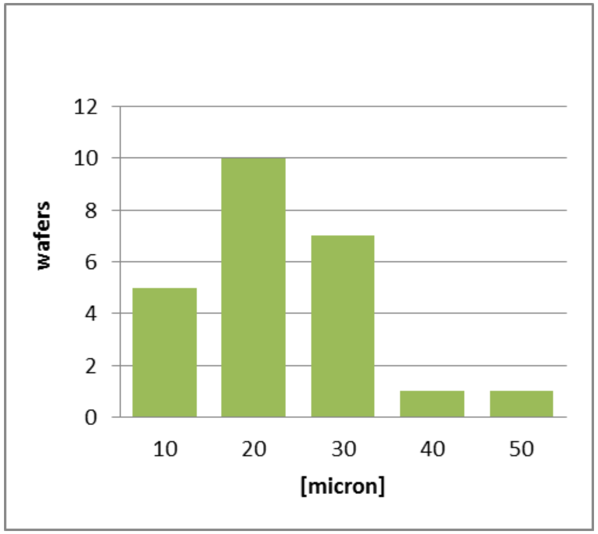
misalignment < 5µm

Optimized process tecnology

- «new» process wafers warp less than 30 micron



8cm



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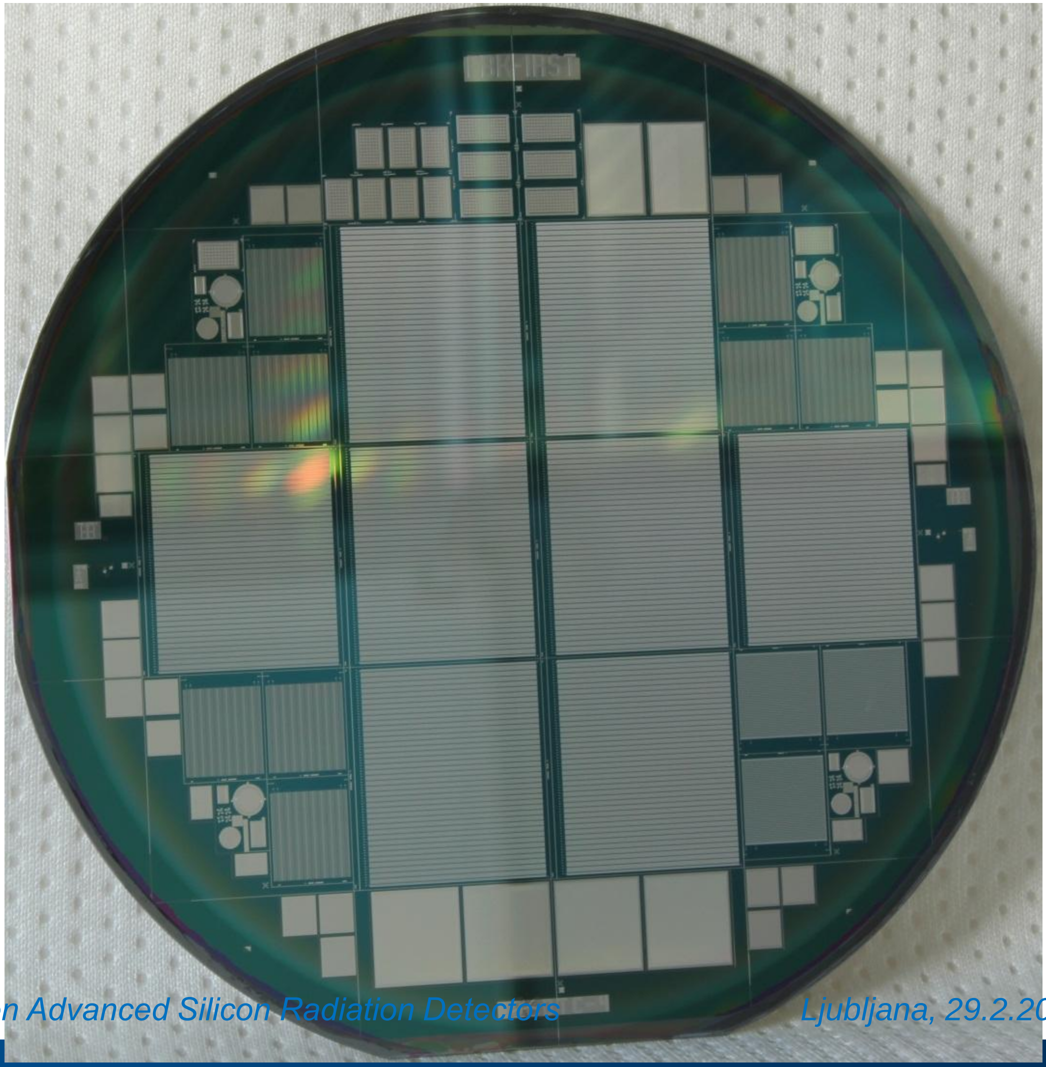
Wafer layout

The layout has been developed in the in the framework of the ATLAS 3D Sensor Collaboration

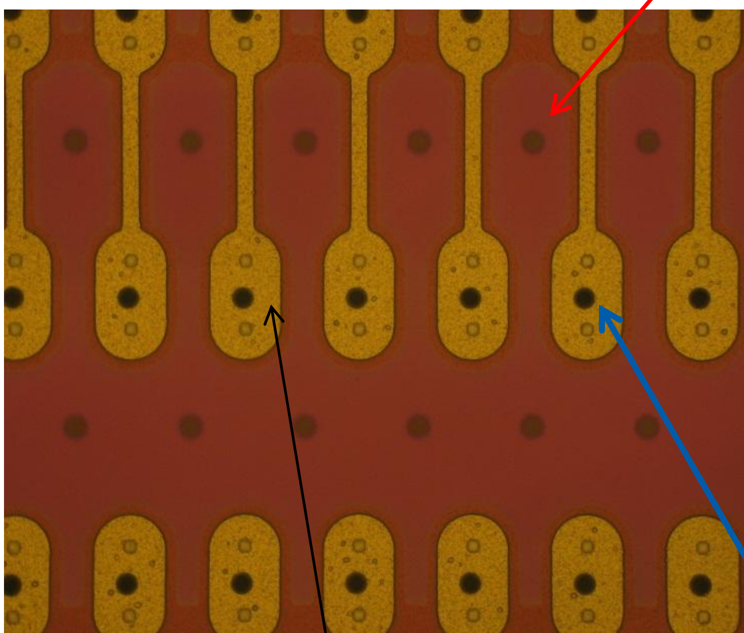
- FE-I4 (8x)
- FE-I3 (9x)
- CMS (3x)
- test structures



Pixel detector

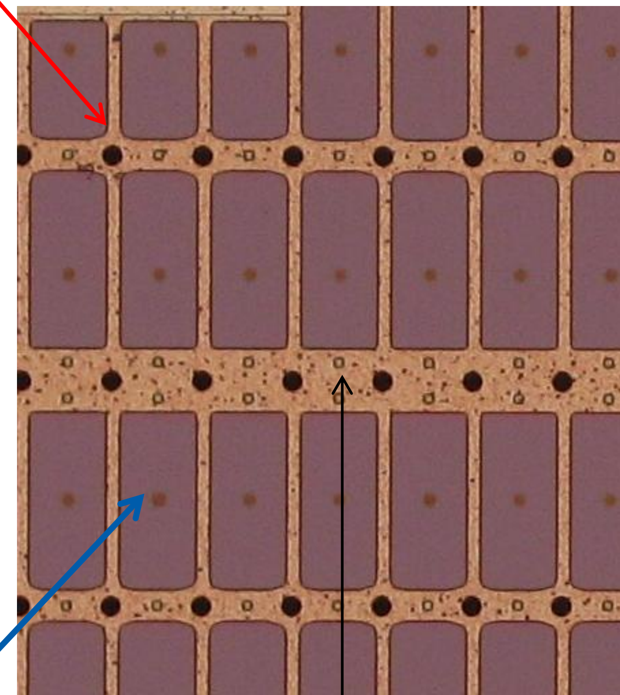
Ohmic columns

Junctions side



metal

Ohmic Side



Junction columns

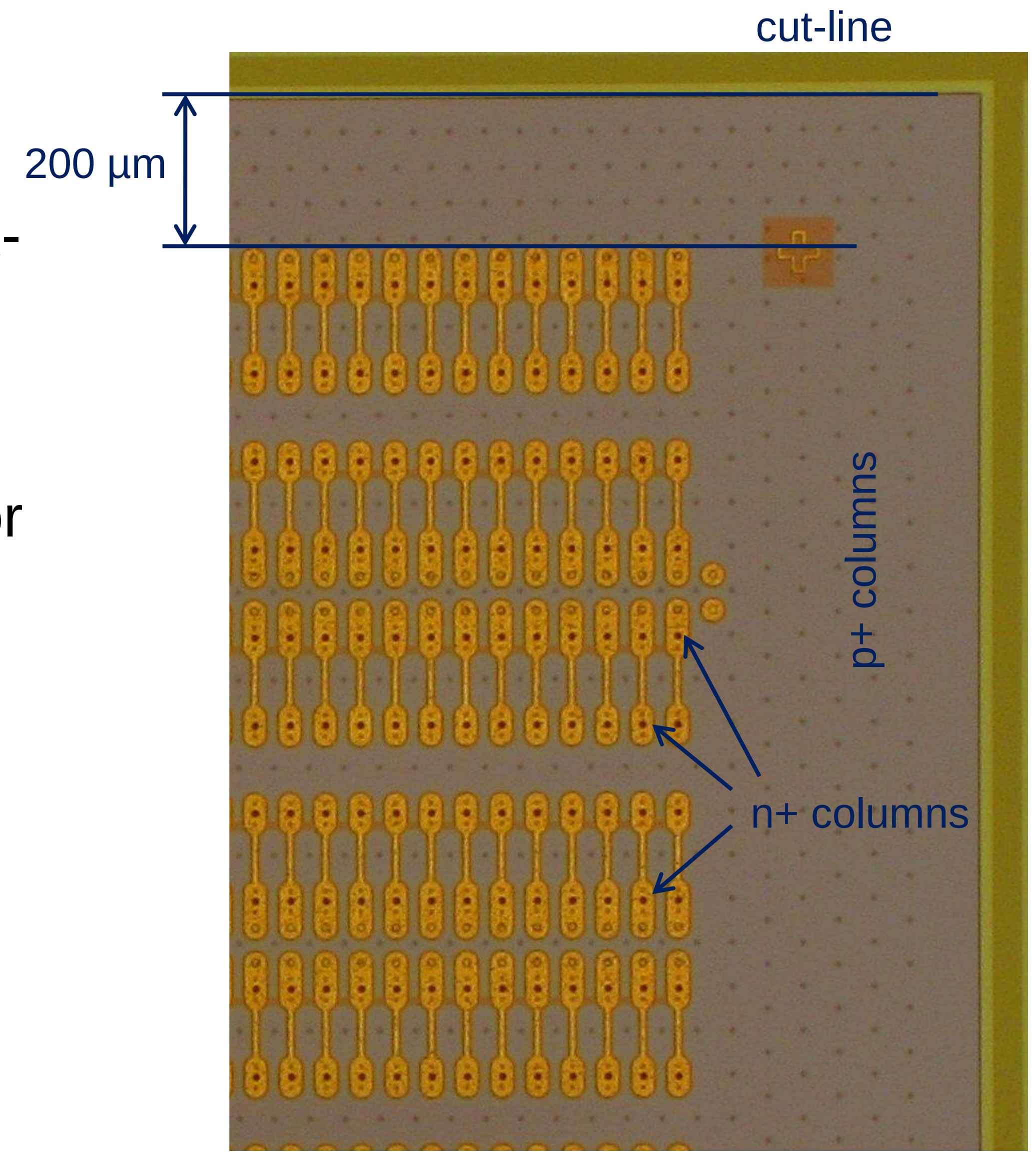
Metal «grid»

Detectors Edge

• Substrate bias from the back-side (also suitable for dual-readout pixel/strip detectors)

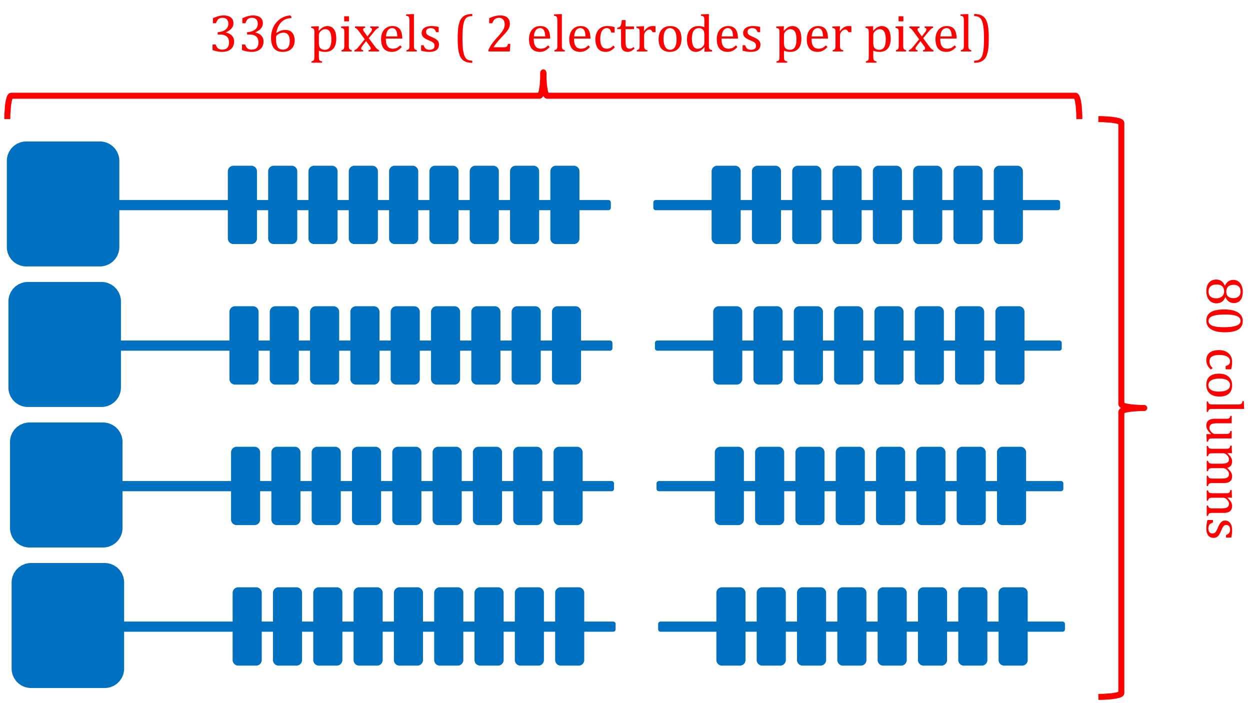
• No active edge, but allows for “slim-edge” detectors

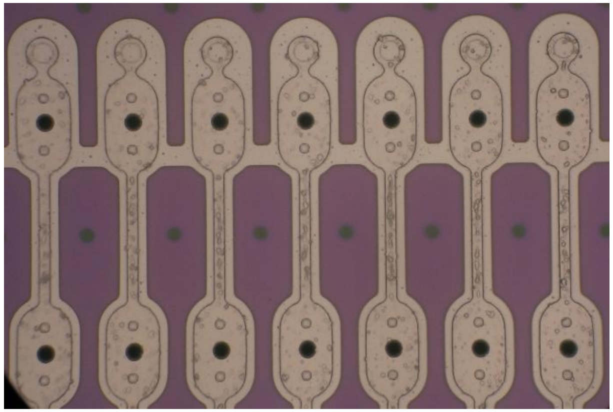
•But It’s not possibile to characterize the detectors before bonding



Temporary metal

- The temporary metal shorts 336 pixels together in a strip
- Allows to perform electrical tests on the FE-I4 pixel sensors before bump-bonding
- The IV characteristics of 80 strips form a FE-I4 pixel sensor





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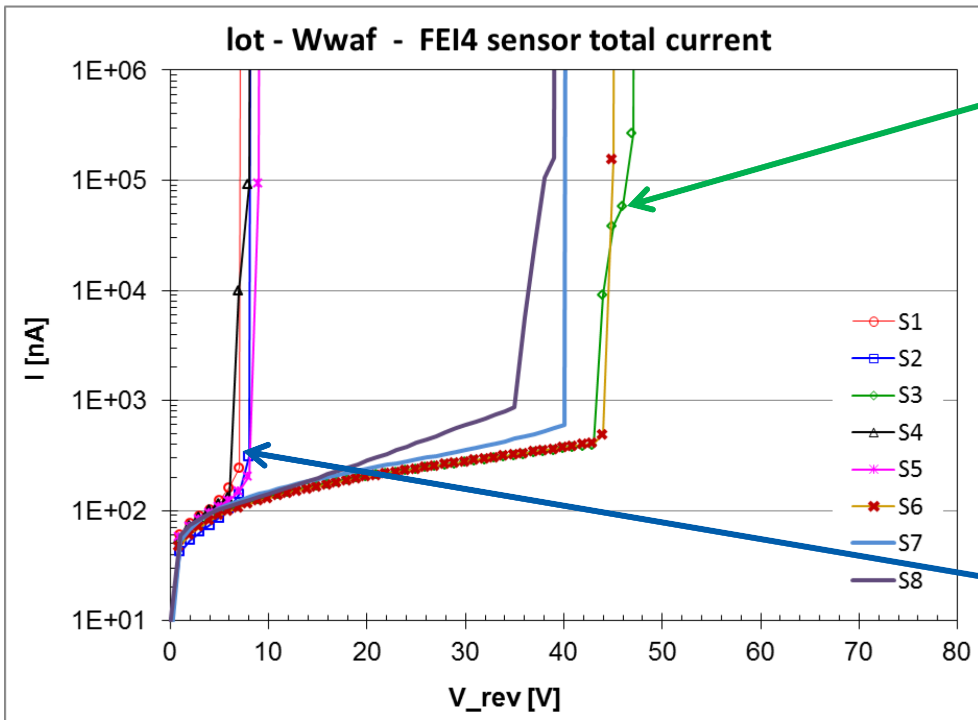
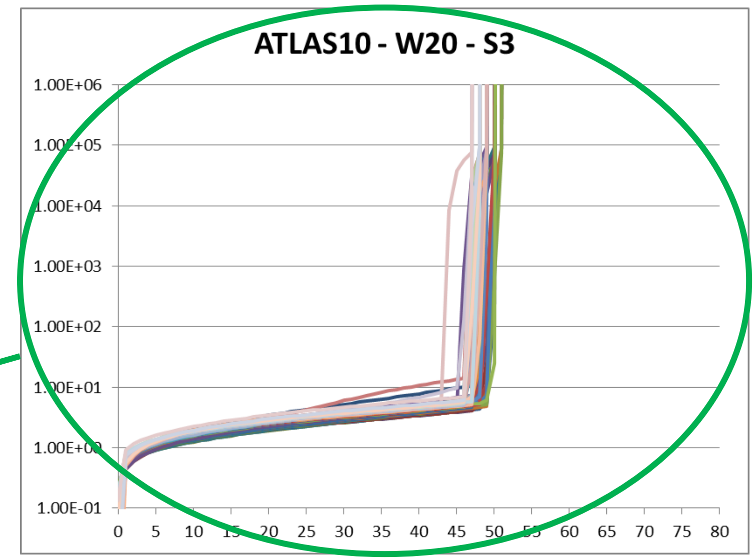
Electrical characterization

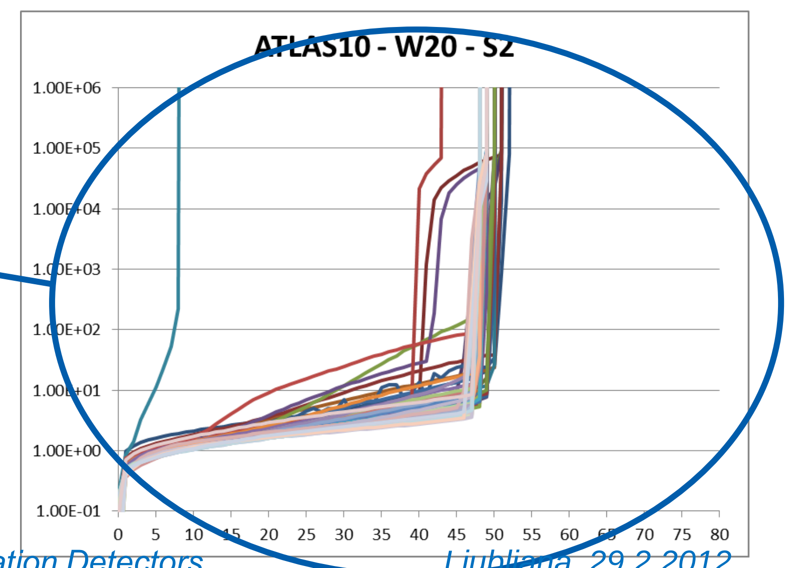
- In the next slides we report some results (IV curves) obtained on the first batch produced for ATLAS IBL 3D pixel
- The IV curves have been obtained using temporary metal realized on detectors compatible with FE I4
- Others two batches are under processing in FBK lab.

The IV characteristics of 80 strips of two sensors

Temporary Metal: IV characteristics







The IV characteristics of FE-I4 pixel sensor as a sum of 80 IV curves

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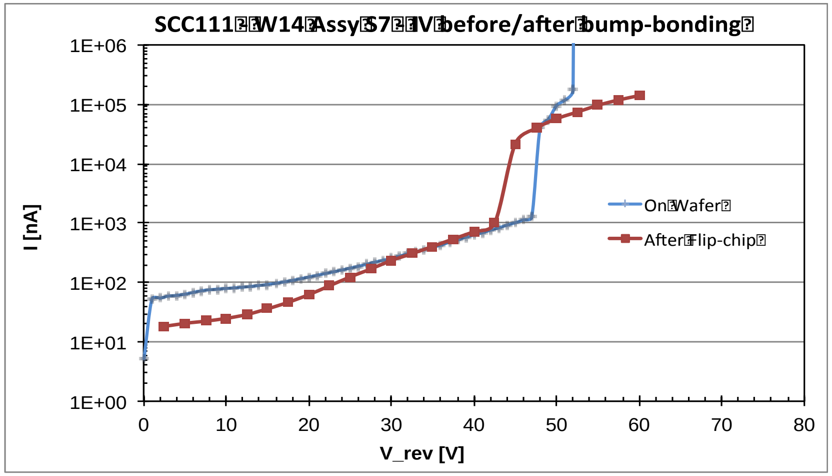
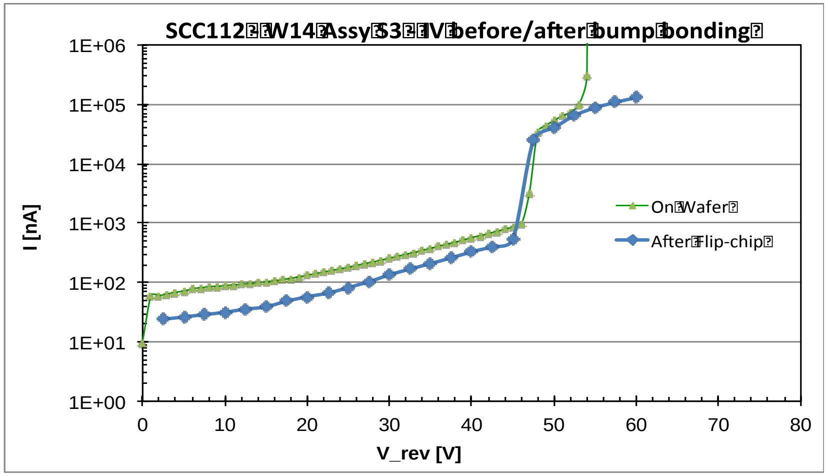
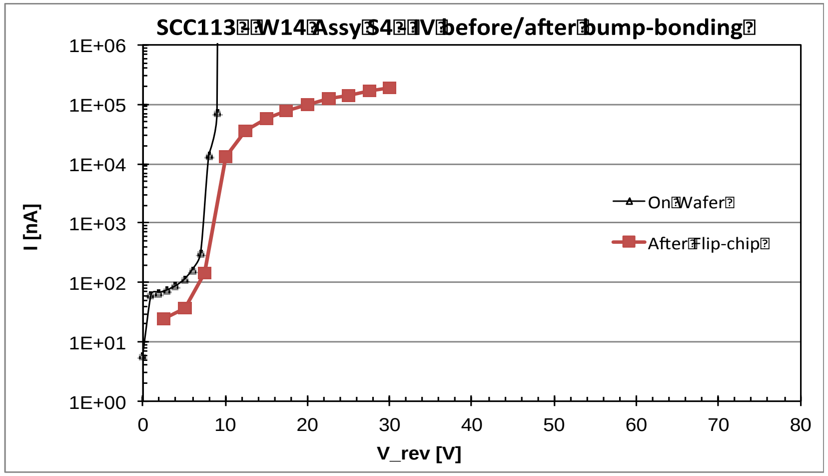
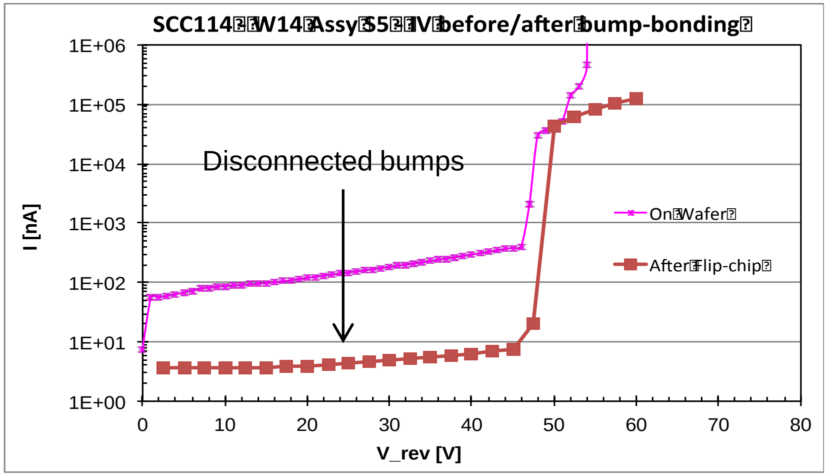
before and after bump-bonding

D-L. Pohl, C. Gemme, G. Darbo









The bump bonding has been performed at IZM (Berlin)

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Yield: a preliminary estimation

The following specifications are required by ATLAS to qualify a device as functioning correctly before bump-bonding:

- $V_{\mathrm{depl}} \leq 15\mathrm{V}$ and
- $V_{op} \geq V_{depl} + 10V$
- $I\ (V_{\mathrm{op}}) < 2\mu\mathrm{A}$ per tile
- $V_{bd} > 25\mathrm{V}$
- $[\mathrm{I}\ (\mathrm{V}_{\mathrm{op}}) / \mathrm{I}(\mathrm{V}_{\mathrm{op}} - 5\mathrm{V})] < 2$

yield (on first production batch)

On 21 wafers (2 broken = mechanical yield)

42% in spec

58% not in spec (but 8% are in at limit condition)

Ongoing Activity

	Total good Wafers *	Total sensors	Good sensors	Yield (%)
A10	12	96	58	60.4
A11**	4	32	14	43.7

FBK is producing two more batches of 3D for ATLAS IBL that will be completed by middle of march and end of april

* Wafers with at least 3 good sensors

** Unfortunately, due to a major problem in the clean-room, a large number of wafers from the FBK2 batch could not be properly completed.

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Summary

- FBK has developed and optimized Si 3D technology based on pass through columns without the use of support wafers

- A temporary metal has been developed to allow a characterization of Si 3D pixel sensors before bump bonding

- FBK is producing two more batches of 3D for ATLAS IBL