Electrical characterization of TI-LGADs production under AIDAinnova

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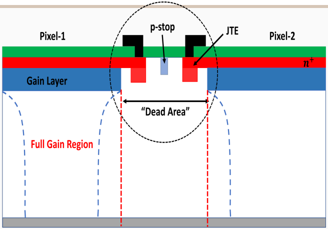
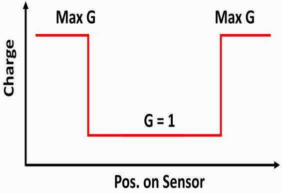
Introduction: Segmentation in LGADs and Fill Factor



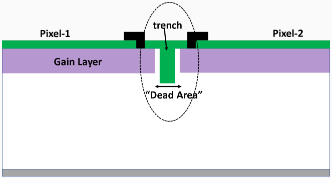


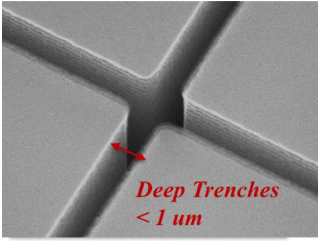
$$FF = \frac{Gain\ Area}{Total\ Area}$$

- Segmentation in LGADs:
  - Junction Termination Extensions (JTEs)
  - p-Stop, and virtual Guard-Rings
- Pixel border is a dead region.
- The no-gain width depends on:
  - technology (photolithography) constraints
  - physical limits (maximum E fields) to fulfill operational requirements (VBD)
- Intrinsic limit in reducing the inter-pad region (*Early edge breakdown*).

$$\text{Standard LGADs} \rightarrow \begin{cases} \text{Good timing resolution} \\ \text{Poor spatial resolution} \end{cases}$$

Trench-Isolated LGADs



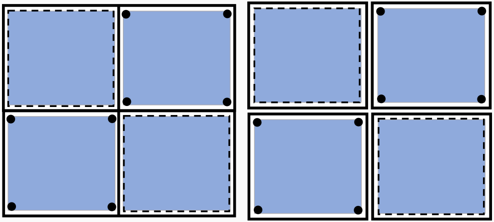


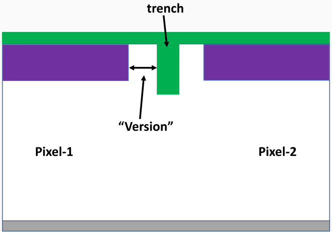
- New LGAD technology :
  - **JTE and p-stop → trench**
  - Trenches → drift/diffusion barrier
- Dead region is significantly reduced
- The trenches are < 1 µm wide and few microns deep.
- Trenches are filled with SiO_2
- Fill factor close to 100%

$$\mathrm{TI-LGADs} \rightarrow \begin{cases} \text{Good timing resolution} \\ \text{Smaller gain-loss region} \\ \text{Improved spatial resolution} \end{cases}$$

G. Paternoster et al., "Trench-Isolated Low Gain Avalanche Diodes (TI-LGADs)"

Layout variations





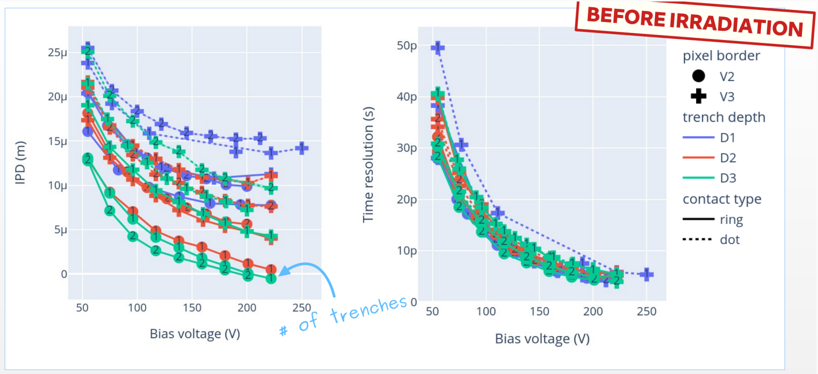
- 1-Trench
- 2-Trenches
- Contact Types: Ring/Dots
- Inter-Pixel Distance (IPD):
  $\rightarrow$ defined as the no-gain region between the pixels

Versions:

- V1, V2, V3, and V4
- V1 $\rightarrow$ Aggressive
- V4 $\rightarrow$ Safe

TI-LGADs: Inter pixel distance and Timing resolution

[M. Senger VCI 2022]



- Border V2 is always better
- Deeper trenches are better
- Contact type "ring" is better than "dots"
- Time resolution does not depend on the design parameters

For more detailed study, see dedicated talk of Anna Macchiolo

AIDAinnova TI-LGADs production: split table

- The aim is to produce pixel sensors with high fill factor and check scalability to produce large area sensors.
- First production to study radiation hardness of TI-LGADs

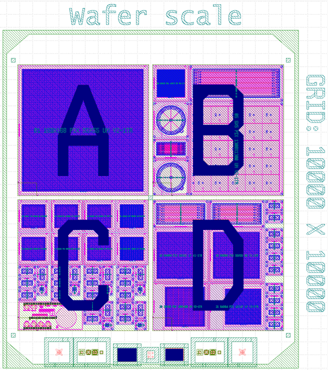
Wafer	Thickness	Gain dose	Carbon	Trench depth	Trench process
1	45	1	Y	D2	P2
2	45	1	Y	D2	P2
3	45	1	Y	D1	P2
4	45	1	Y	D1	P1
5	45	1	Y	D2	P1
6	45	1		D2	P2
7	45	1		D2	P2
8	45	1		D1	P1
9	55	1.02	Y	D3	P2
10	55	1.02	Y	D2	P2
11	55	1.02	Y	D2	P2
12	55	1.02		D2	P2

AIDAinnova TI-LGADs production: measurements

- IV curves are measured with an automatic probe setup at FBK laboratory
- Measurements performed at 24° C
- Breakdown is calculated on good sensors with gain using the k-factor method

$$k(V, I) = \frac{\Delta I}{\Delta V} \frac{V}{I}$$

with $k_{bd} = 8$ and possible $V_{bd} > 100$ V



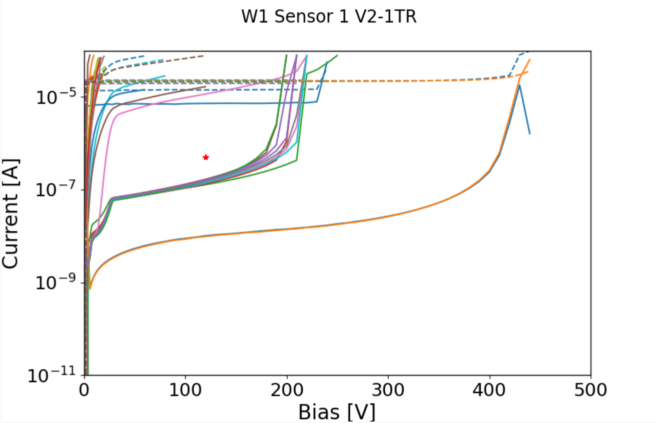
Devices without layout variation

- Device A: 169 × 168 pixel sensor (Area: 1 cm^2)
  Pitch: 55 µm

Devices with layout variations

- Device C: 32 × 32 pixel sensor
  Pitch: 55 µm
- Device C: 2 × 1 pixel sensor
  250 × 375 µm^2

IV curves: 169 × 168 pixel sensor (Pitch: 55 µm)



- The design layout for 1 cm^2 device is V2-1TR
  → baseline design from previous studies
- The pixels are connected using temporary metal
- Marker signifies the bias voltage at which the sensor is considered bad if the leakage current exceeds the value.

Carbon vs no-Carbon: 169 $\times$ 168 pixel sensor (Pitch: 55 µm)

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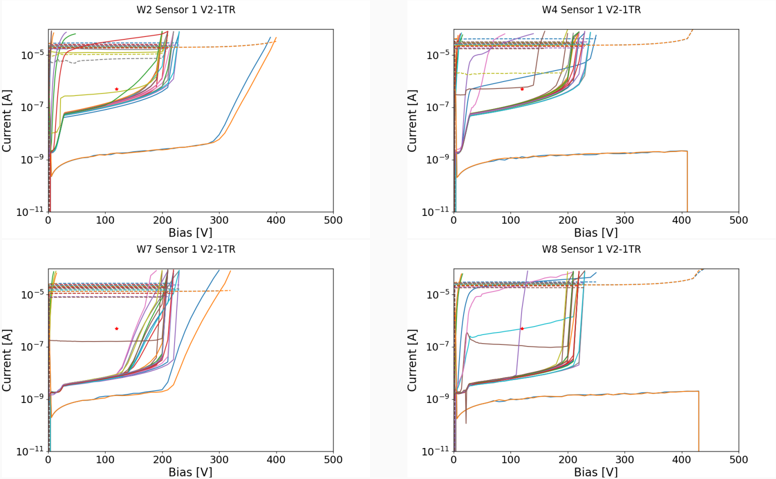
D2-P2 | D1-P1

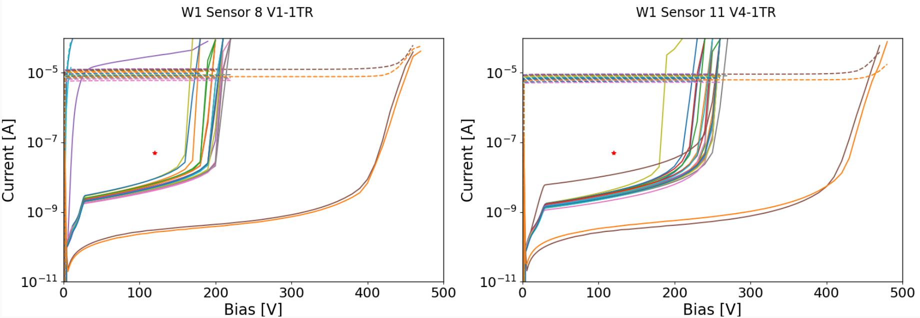
Carbon

No-Carbon



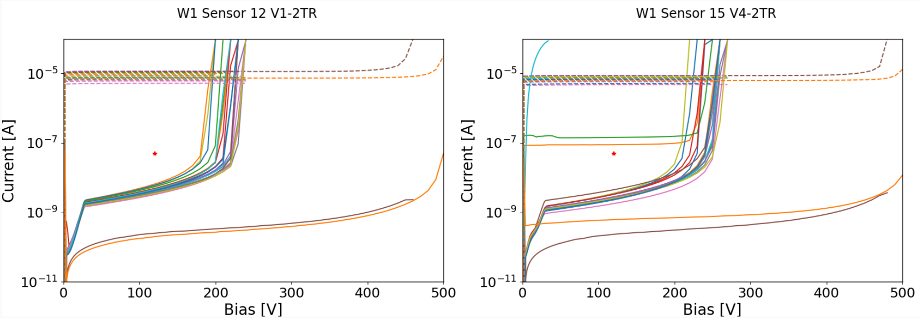
- Leakage current in carbon co-implanted wafer is higher compared to the wafer with no-carbon.
- D2-P2 PIN sensors go into an early breakdown than D1-P1

1-Trench: 32 $\times$ 32 pixel sensor (Pitch: 55 μm)



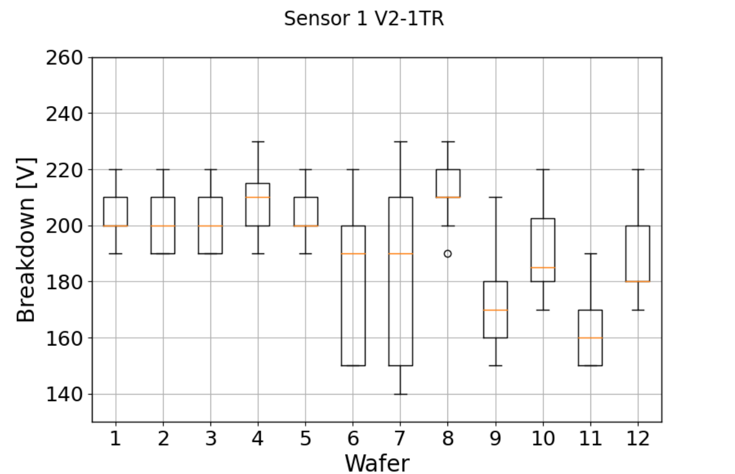
- The leakage current does not seem to depend on the distance between the gain layer and trenches
- GR current is also similar for all versions
- The only change is in the breakdown voltage for both LGADs and PIN sensors

2-Trenches: 32 × 32 pixel sensor (Pitch: 55 µm)



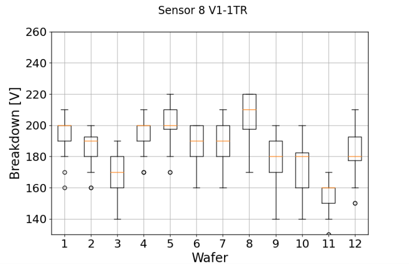
- Same as 1-Trench design the leakage current does not seem to depend on the distance between the gain layer and trenches
- GR current is also similar for all versions
- The only change is in the breakdown voltage for both LGADs and PIN sensors

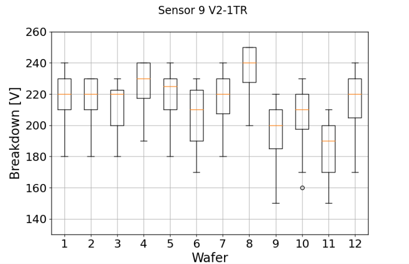
Breakdown: large sensors

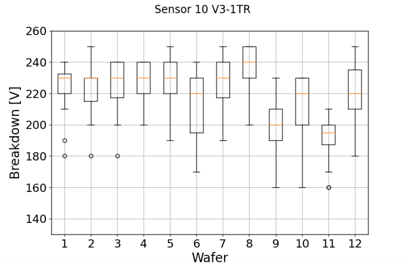


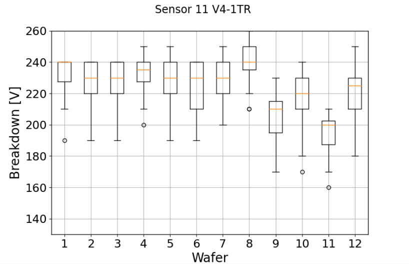
- The average median breakdown value is around 200 V.
- D1-P1 have higher breakdown value compared to D2-P2
  → (Wafer 4 vs 3 and Wafer 8 vs 7)
- 55 µm thick sensors have lower breakdown compared to 45 µm
  → higher gain dose

Breakdown: small sensors (1-Trench)

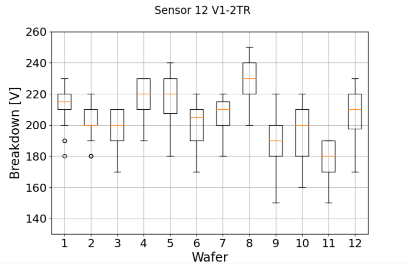


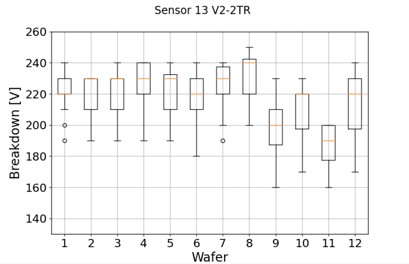


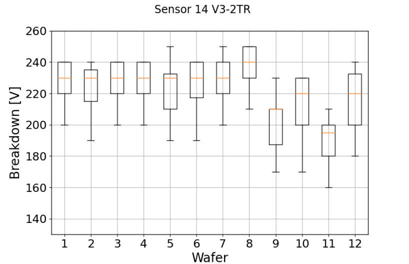


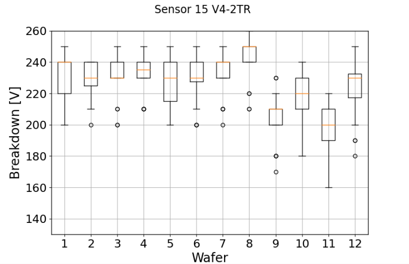


Breakdown: small sensors (2-Trench)





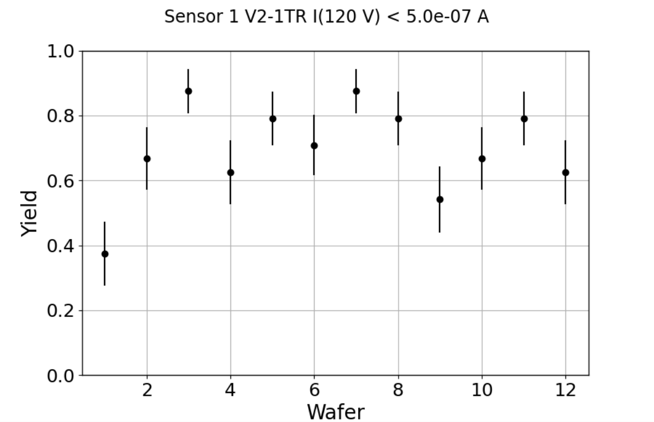




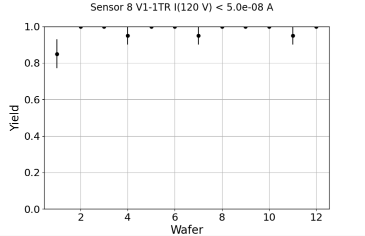
Yield: large sensors

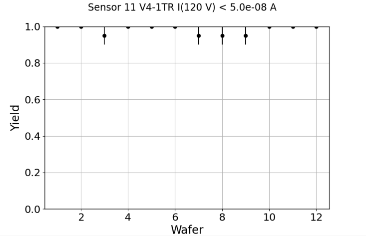
The yield is defined as:

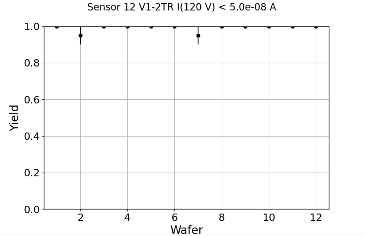
$$\text{Yield} = \frac{\text{N}_{\text{working sensors}}}{\text{N}_{\text{total sensors}}}, \text{Working sensors are} \begin{cases} I_{leakage} < 0.05\ \mu A @ V_{bias} = 120\ V, \text{Small} \\ I_{leakage} < 0.5\ \mu A @ V_{bias} = 120\ V, \text{Large} \end{cases}$$

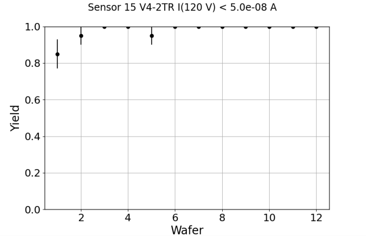


Yield: small sensors



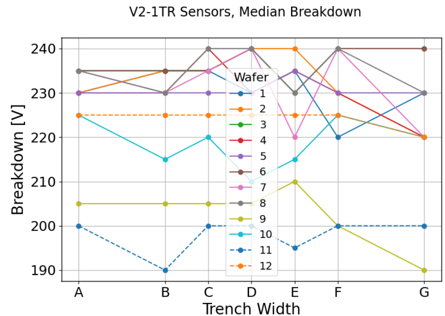


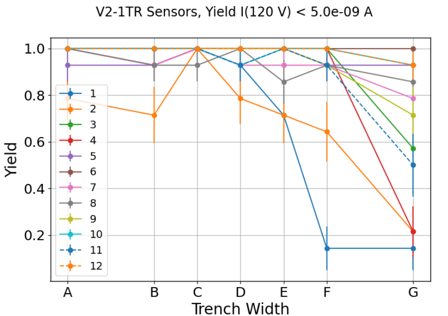




- The yield of small sensors is almost 100% for most of the wafers
- No significant difference in different versions and number of trenches

Variation in trench width: 2×1 Pixel (250×375 μm^2)





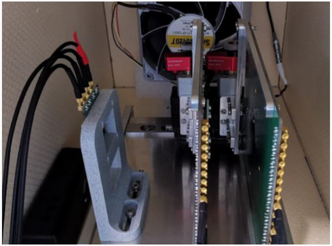
- Trench width increases while moving from ‘A’ towards ‘G’
- The yield starts to decrease as the width of the trench increases.
- Trench width - ‘D’ was used as standard width for this batch.

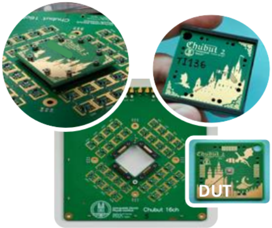
Summary and Conclusions

- A total of 12 wafers have been produced with the TI-LGADs technology and electrical characterization was performed in FBK
- The IV characterization shows that sensors with the most aggressive design (V1-1TR) go into early breakdown compared to the other layouts
- The leakage current of carbon co-implanted wafers is higher compared to no-carbon wafers
- The breakdown of larger sensor is comparable to the smaller one with good yield values
- The variation of trench width helps in choosing best trench width to be used for future productions.

Testing plans for AIDAinnova TI-LGAD production

- FBK AIDAinnova TI-LGAD sensors are presently being tested at the AIDAinnova TB in DESY
  → Multi-pad structures irradiated at 1e15, 1.5e15, 2e15
- Three wafers (W1, W6, W10) diced after wafer level testing
- Possible interconnection to read-out chips by Anisotropic Conductive films and Adhesive that allow for a chip to chip processing
- The other wafers are being sent to IZM for UBM hybridization
- Plans to flip-chip to ASICs with good timing capabilities
  - Timespot
  - Picopix
  - Timepix4
- Characterization at module level before and after irradiation





Chubut board, 16 channels with carrier board

Acknowledgements

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THANK YOU FOR YOUR ATTENTION

BACK-UP

LGADs: Fill Factor

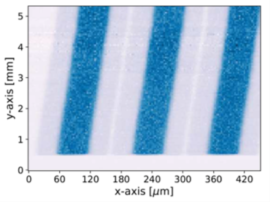
$$\text{Fill Factor} = \text{Area}_{\text{gain}}/\text{Area}_{\text{total}}$$

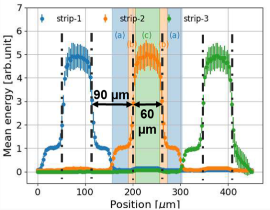
Measurements with a micro-focused X-ray beam (width $\sim 2\ \mu m$, 20 keV)

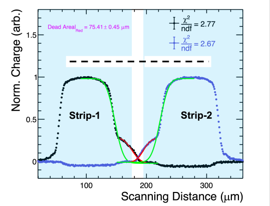
- LGAD μ-strip sensor (146 μm pitch)
- Nominal gain region: $80\ \mu m \rightarrow$ Nominal FF: 55%
- Measured FF: 40%

Measurements with a pulsed laser.

- 180 μm pitch
- Nominal FF: 63%
- Measured FF: 58%







M. Andrä et al., "Development of low-energy X-ray detectors using LGAD sensors"