1st DRD3 week on Solid State Detectors R&D
18th June 2024

First characterisation of Trench Isolated LGADs fabricated at Micron Semiconductor Ltd

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Outline

- Motivation
- Segmentation Techniques
- Fabrication
  - TCAD simulations
  - Run
  - Electrical Measurements
- TCT Measurements
  - Gain
  - Pixel Isolation
  - Inter-pixel distance (IPD)
- Discussion
- Summary & Future Work

Motivation

- To develop a fast-timing silicon hybrid pixel detector (sub 100ps) , within the working group **PixeLGAD**, a UK based effort to develop LGAD technology.
- We must understand the LGAD technology, build simulation models and develop a fabrication process in collaboration with Micron Semiconductor.
- Detector should be for HEP experiments with modest radiation levels which require fast timing and good spatial resolution **(i.e. LHCb Velo Ⅱ Upgrade).**
- Detector applications include imaging **"soft"** or **"tender"** (< 5 keV) energy x-rays, with focus on the water window (~500 eV).
- The detectors will be applicable to and demonstrated on **synchrotron beamlines** and for **electron microscopy**.
- We do not target a given experiment but aim to push the small pixel LGAD technology and demonstrate this with start-of-the-art small pixel fast timing pixel chips.
- We want to create an imaging detector in collaboration with the **Timepix4** readout ASIC.

Pixel Segmentation

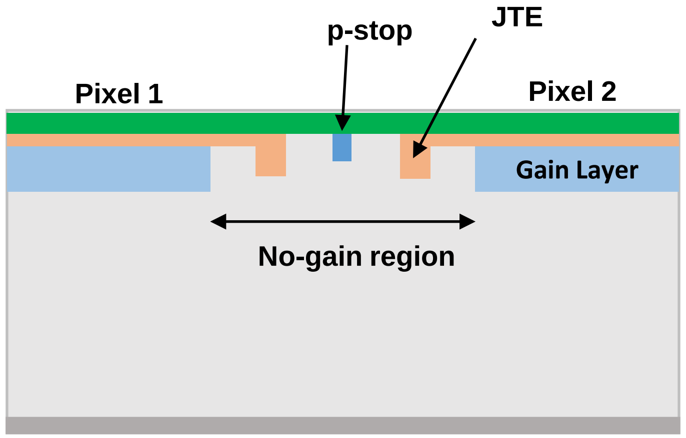


Fig 1(a): Standard LGAD

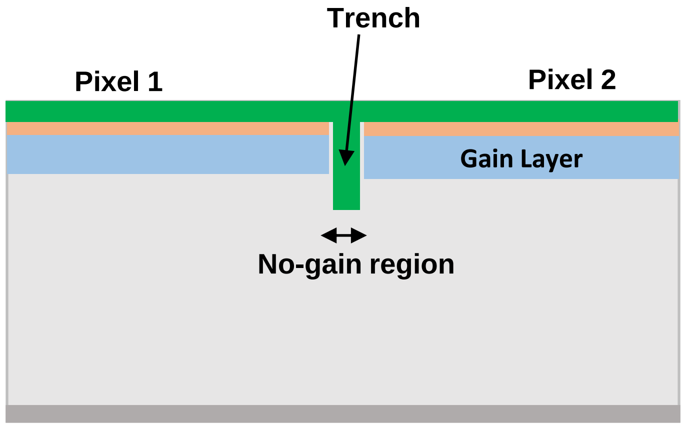


Fig 1(b): Trench-isolated LGAD

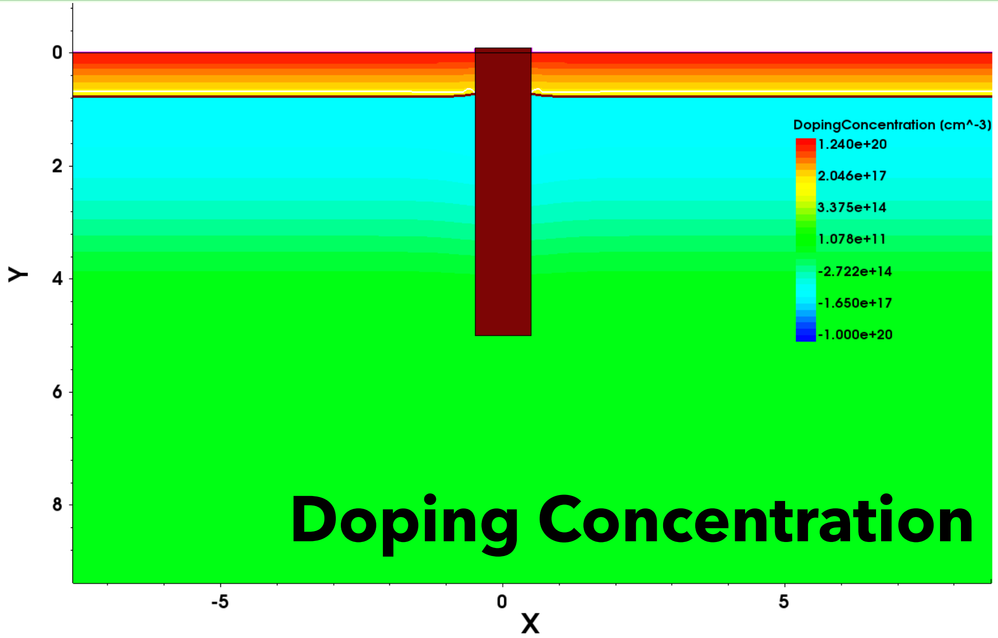
- **Standard LGADs:**
  - Segmentation → Junction Termination Extension (JTE), p-stop, virtual Guard-Rings
  - Large "no-gain region"
  - IPD ~ 50 µm (G. Paternoster et. al., 2021)
  - Low fill-factor

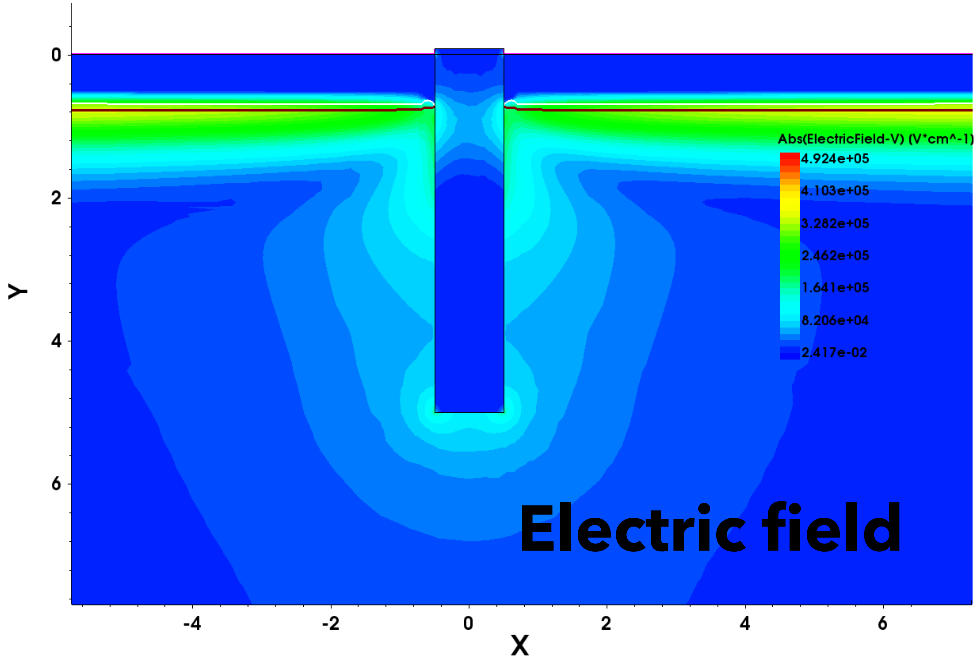
- **Trench-Isolated LGADs:**
  - Segmentation → Trenches (SiO_2 filled)
  - 1 µm wide, and a few microns deep
  - "no-gain region" is significantly reduced
  - Fill-factor is increased
  - Enhanced spatial resolution

G. Paternoster, et. al., 2017

Simulations (I)

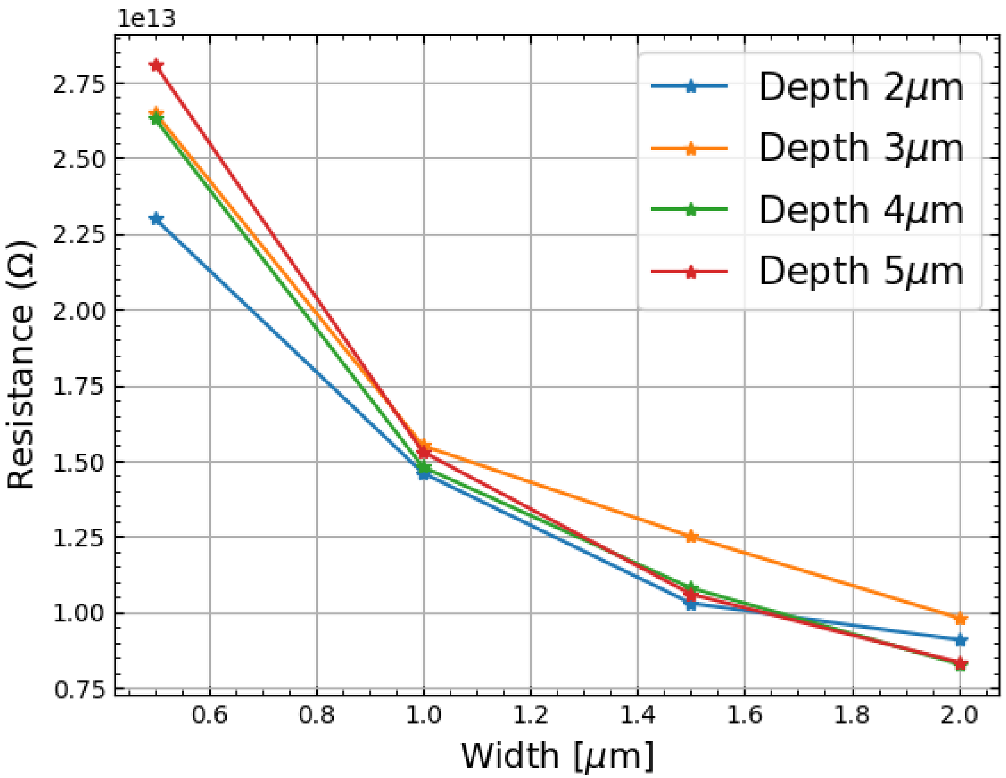
- Sentaurus TCAD model used to create two adjacent pixels.
- Trench used to isolate the pixels.
- Trenched etched in silicon – No gap between trench and implantations



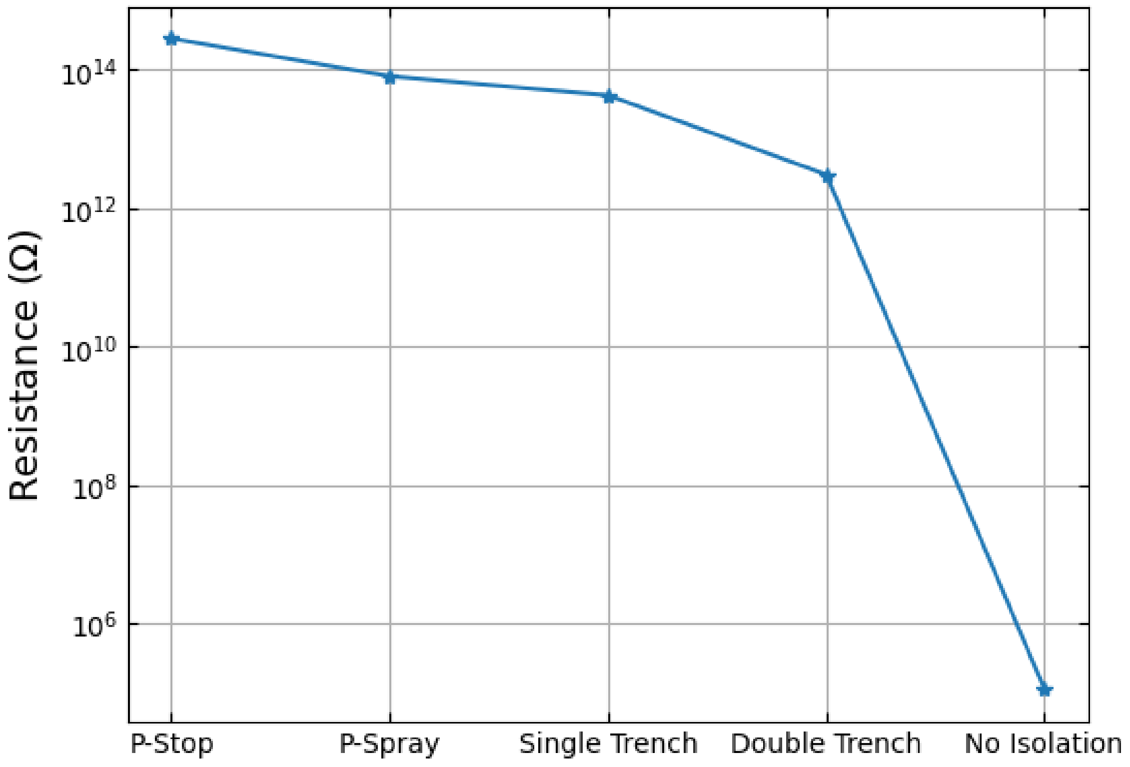


Simulations (II)

- Isolation determined by the resistance between the adjacent pixels. **Must be high resistance up to oxide charge saturation.**
- Isolation compared to standard isolation methods. i.e. p-spray and p stop.

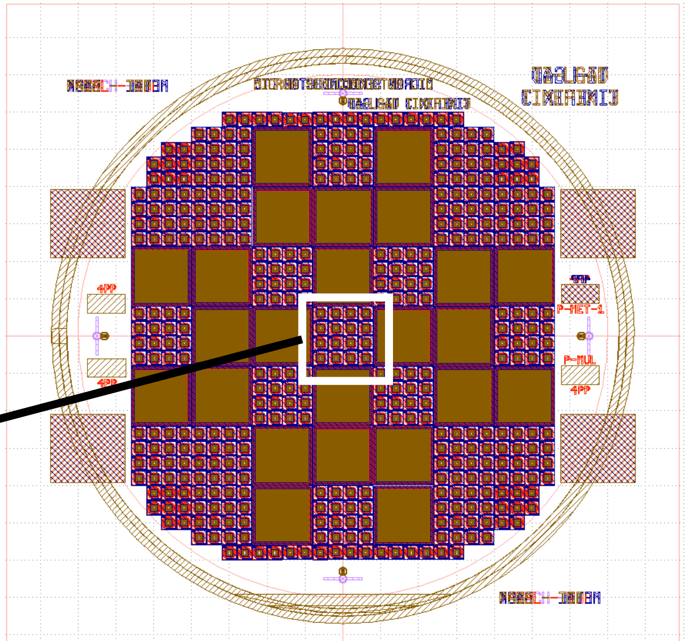


Trench parameters optimised for highest isolation



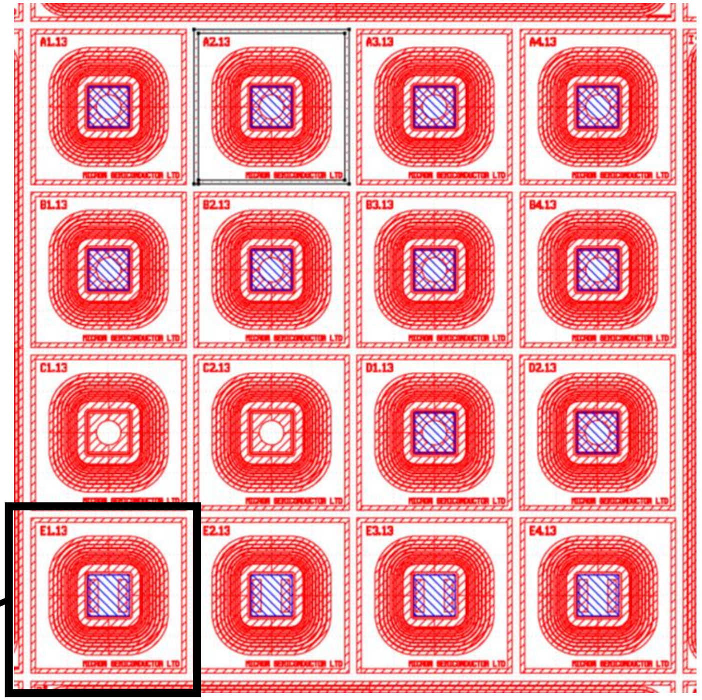
Comparison of isolation methods between adjacent pixels: p-spray, p-stop, no-isolation, single-trench, double-trench

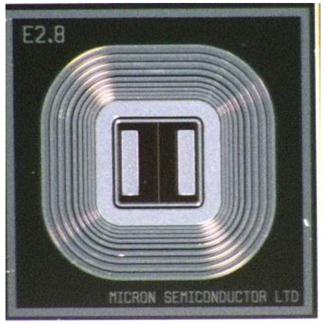
Production of TI-LGADs

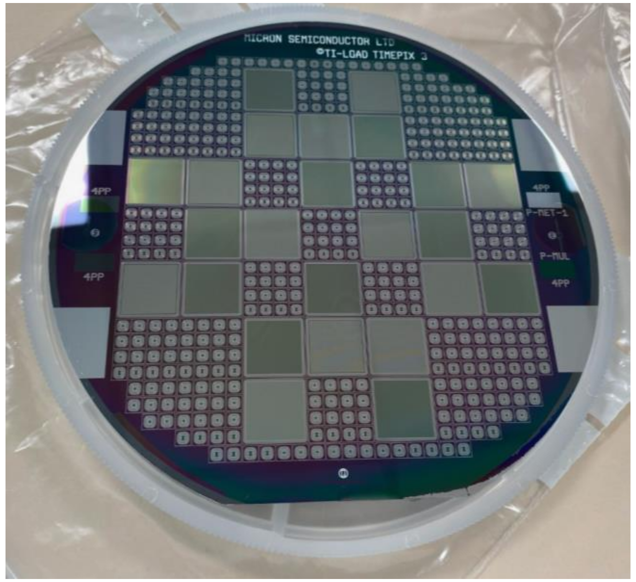


Run-3455 produced by Micron Semiconductor Ltd:

- Wafer production based on increasing gain layer doping
- Active thickness = 250µm
- Pad area = 1x1 mm^2
- Devices:
  - A: 1x1 LGADs with JTE
  - B: 1x1 LGADs with JTE + Trench
  - C: 1x1 PIN (no gain)
  - D: 1x1 LGADs with Trench
  - E: 1x2 Pixels, isolated with Trench
- Medipix Arrays:
  - 55 µm pitch
  - 110 µm pitch

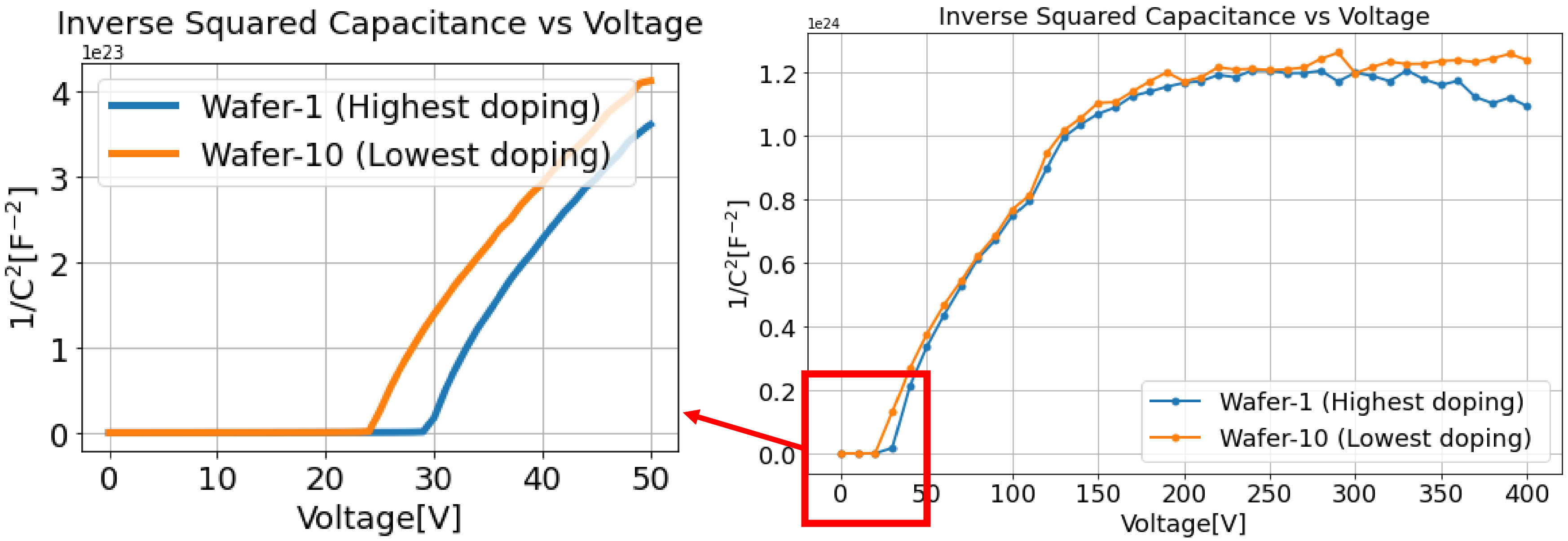






Electrical Measurements (I)

- Capacitance-Voltage (CV):
  - Gain layer depletion voltage, V_{GL}= 25-30 V
  - Full depletion ~ 120V



Electrical Measurements (II)

- Capacitance-Voltage (CV):
  - Gain layer depletion voltage, V_{GL}= 25-30 V
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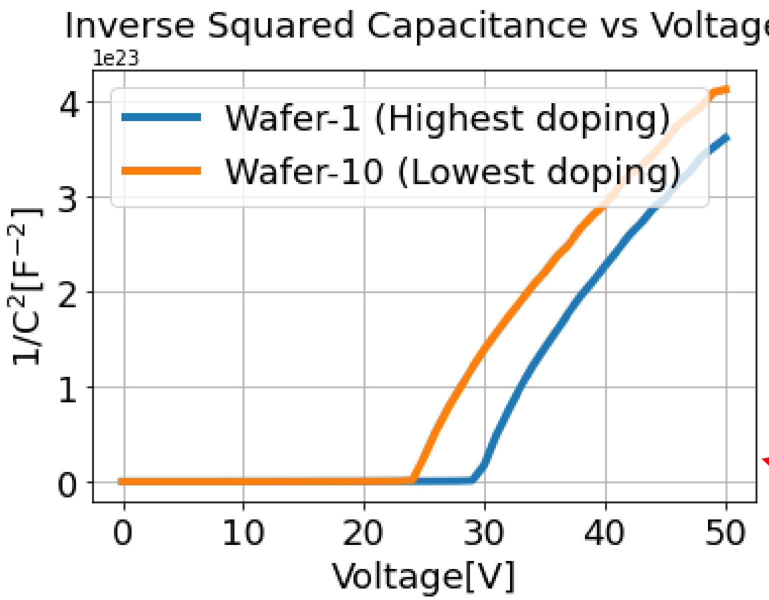
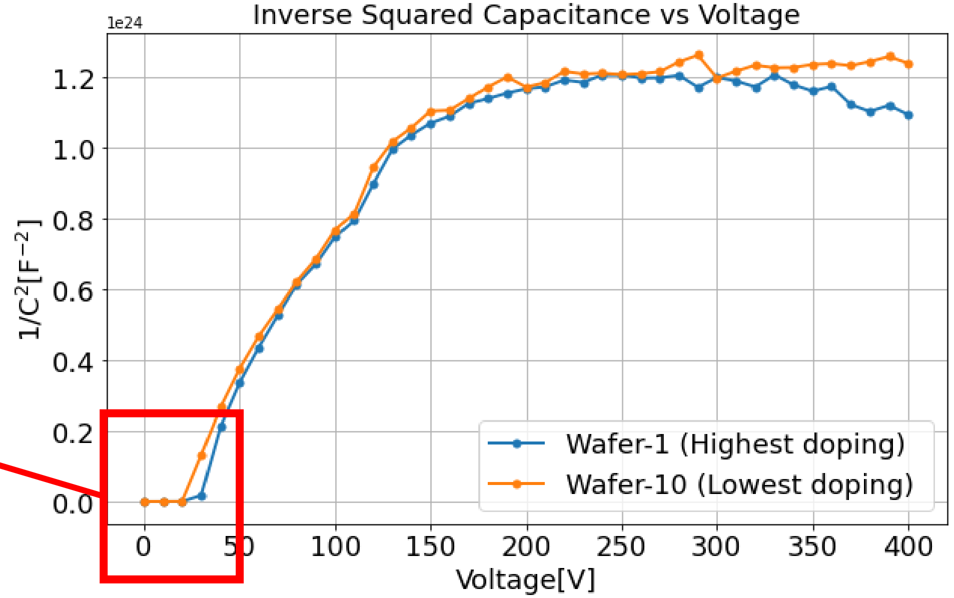
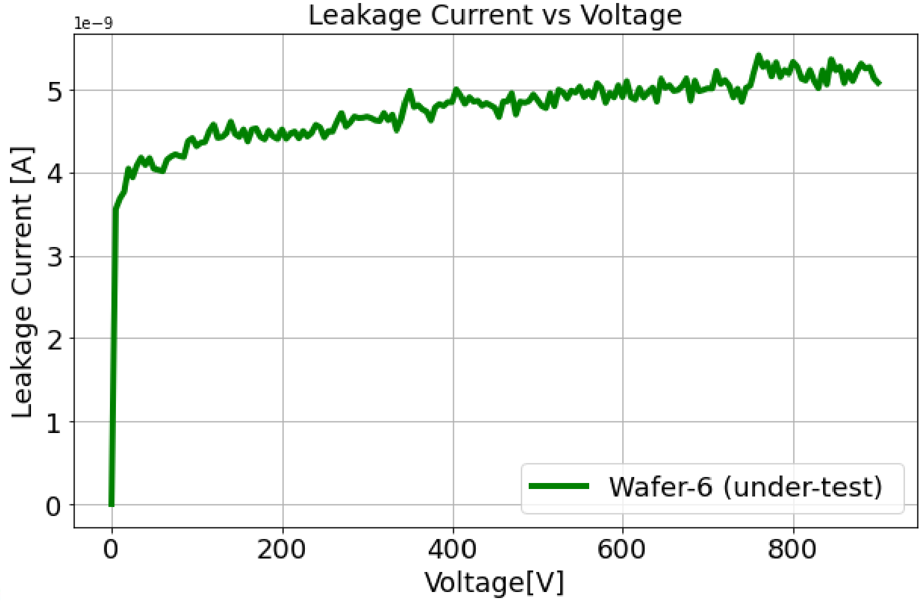
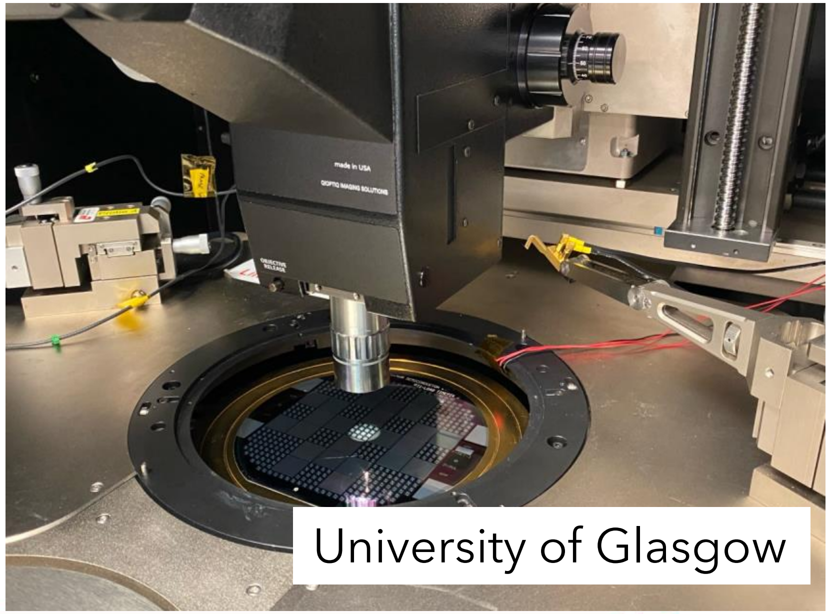




- Current-Voltage (IV):
  - No sign of breakdown up to 1000V
  - Leakage current is in nA's



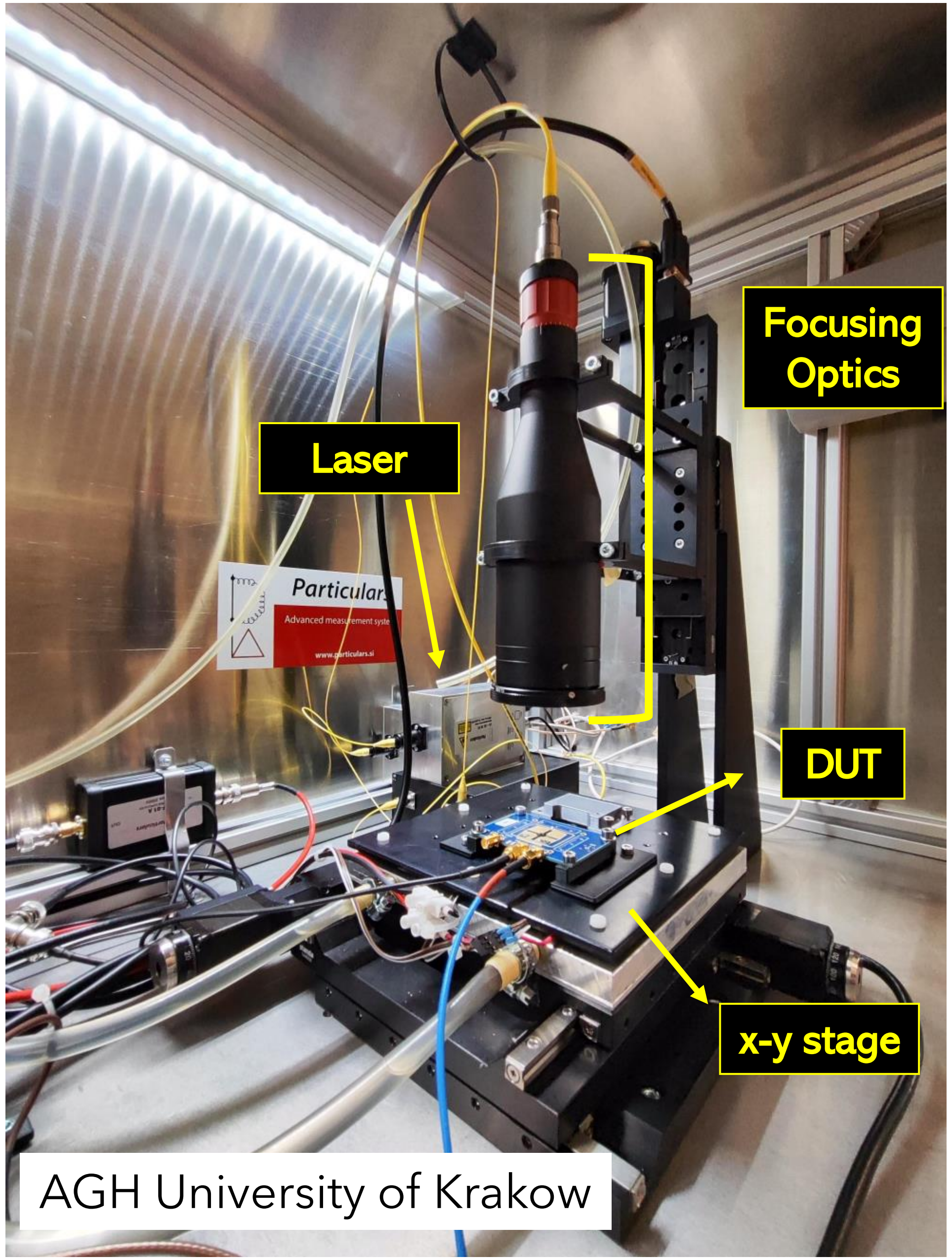


➢ Devices are working!

Transient Current Technique (TCT)

Particulars TCT Setup:

- IR pulsed laser (1064 nm) → 8-10 μm spot
- Broadband amplifier → 35 db
- Laser calibrated to minimum ionizing particles (MIPs)
- xy-stage with sub-μm precision

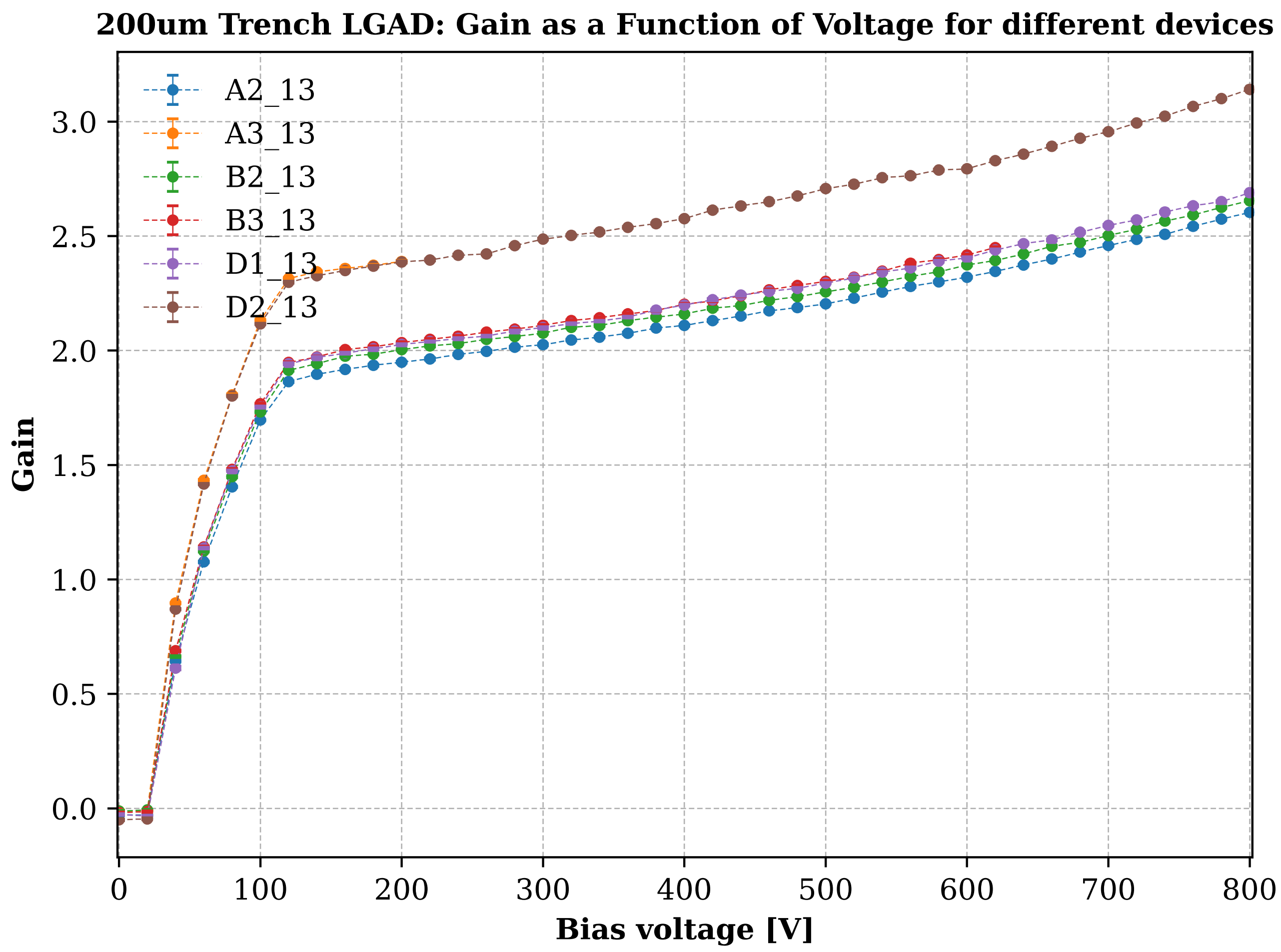


TCT: Gain Measurements

- Gain is calculated by:

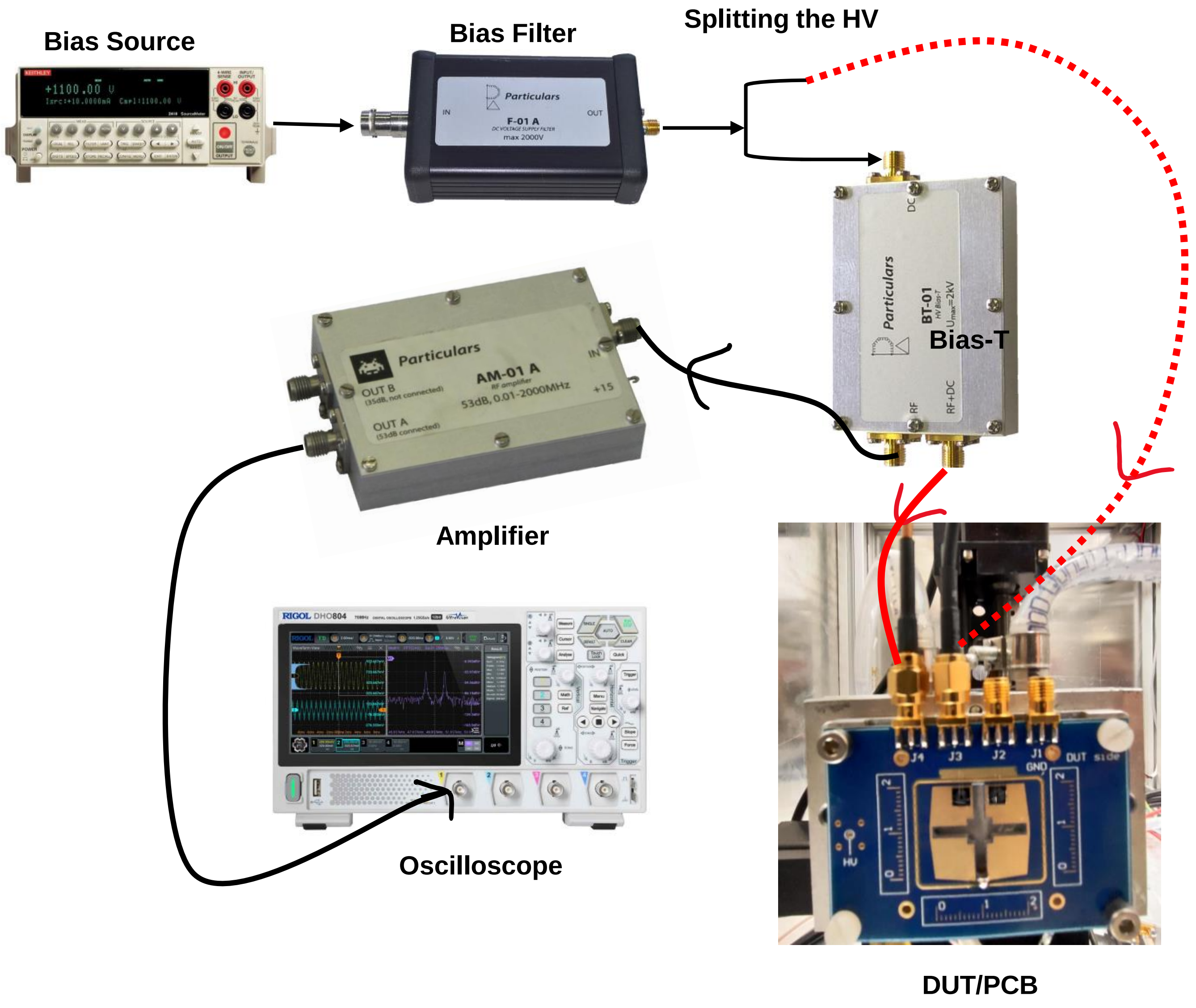
$$Gain = \frac{Q_{LGAD}}{Q_{PIN}}$$

- Gain of the tested wafer (2nd lowest GL doping) is between 2-3.



TCT: Pixel Isolation

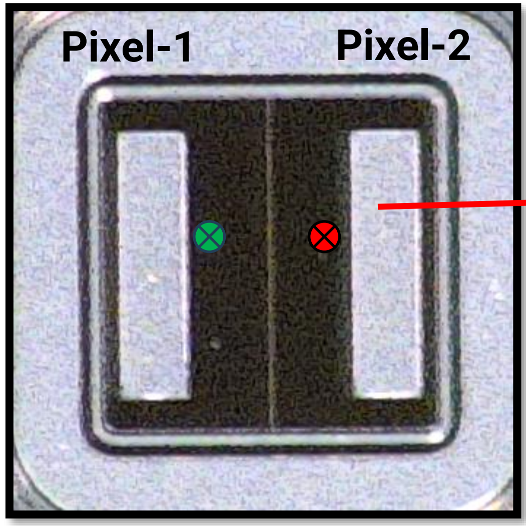
- One pixel connected to the readout
- Other pixel is only connected to bias voltage



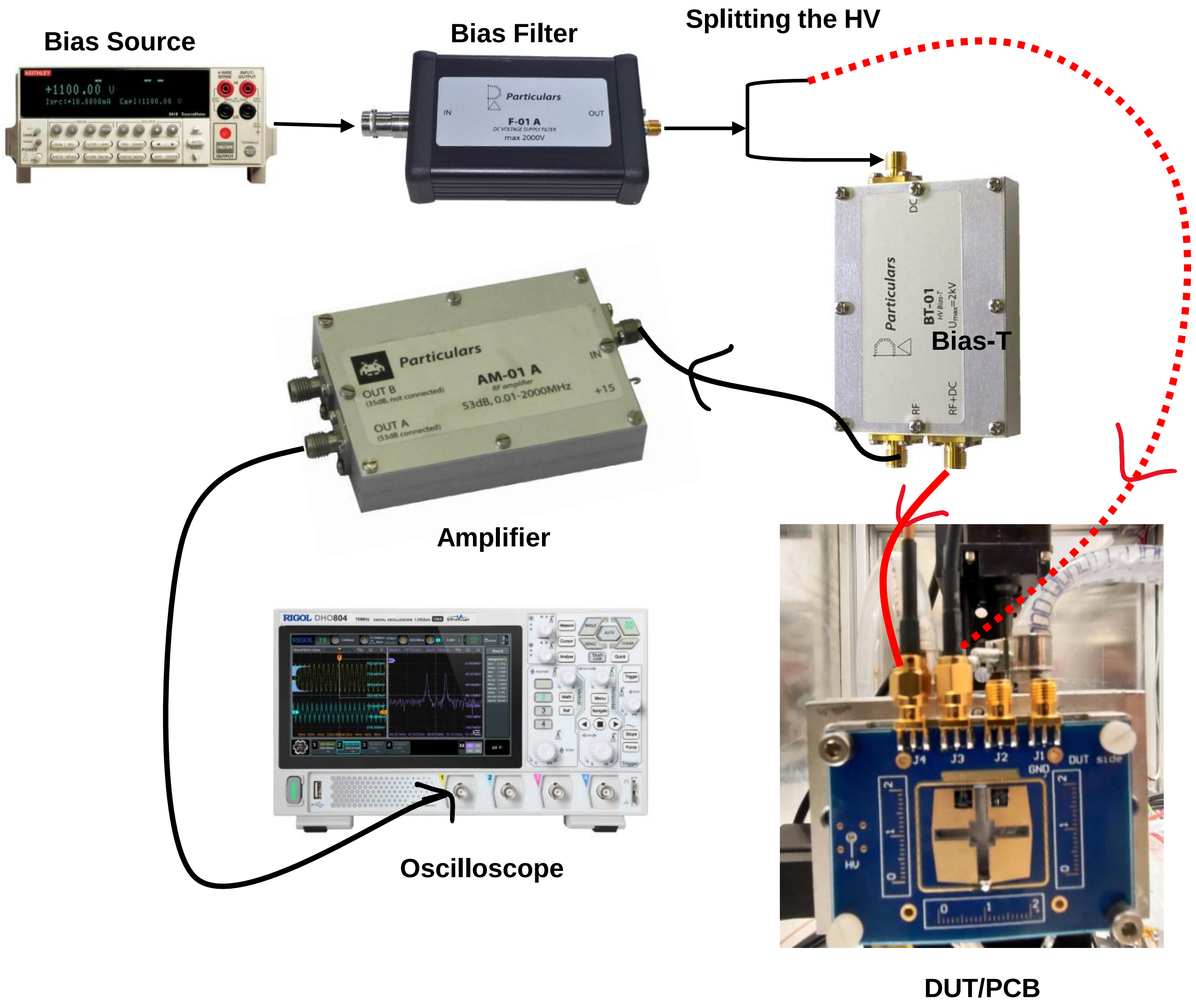
Schematics of measurement setup for pixel isolation

TCT: Pixel Isolation (II)

- One pixel connected to the readout
- Other pixel is only connected to bias voltage



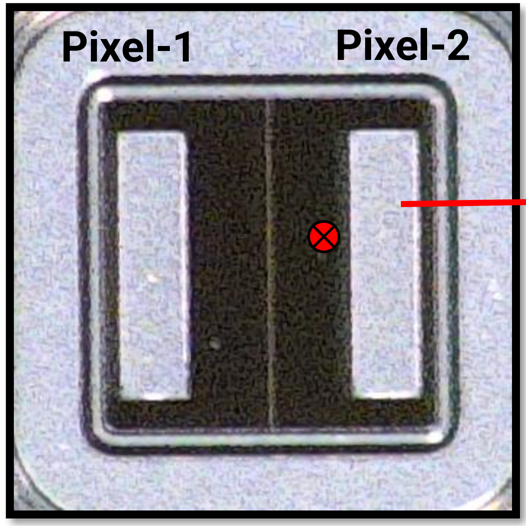
Connected to readout



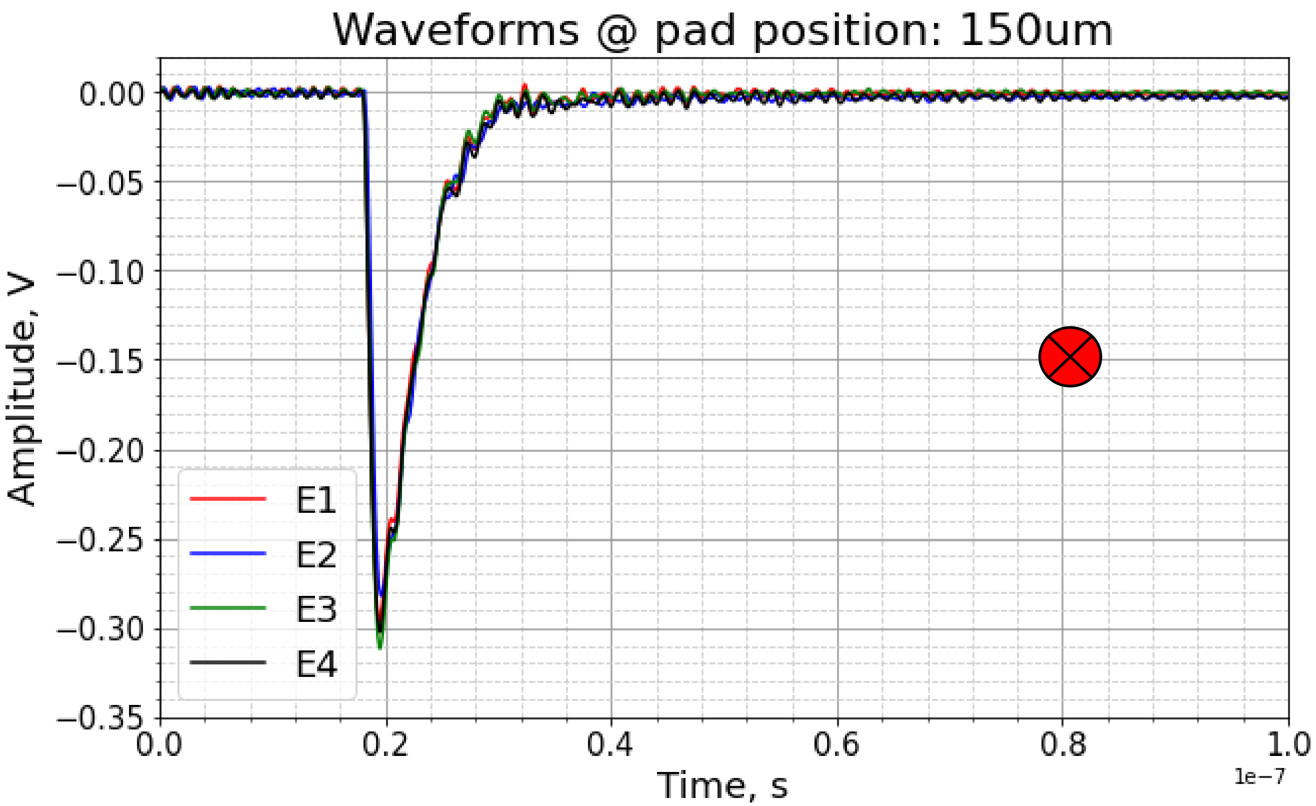
Schematics of measurement setup for pixel isolation

TCT: Pixel Isolation (III)

- Laser is shot on **pixel-2**, which is connected to readout.
- Signal is observed for all the devices.

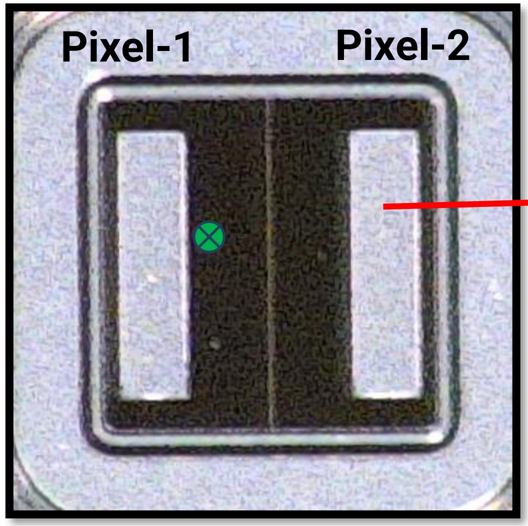


Connected to readout

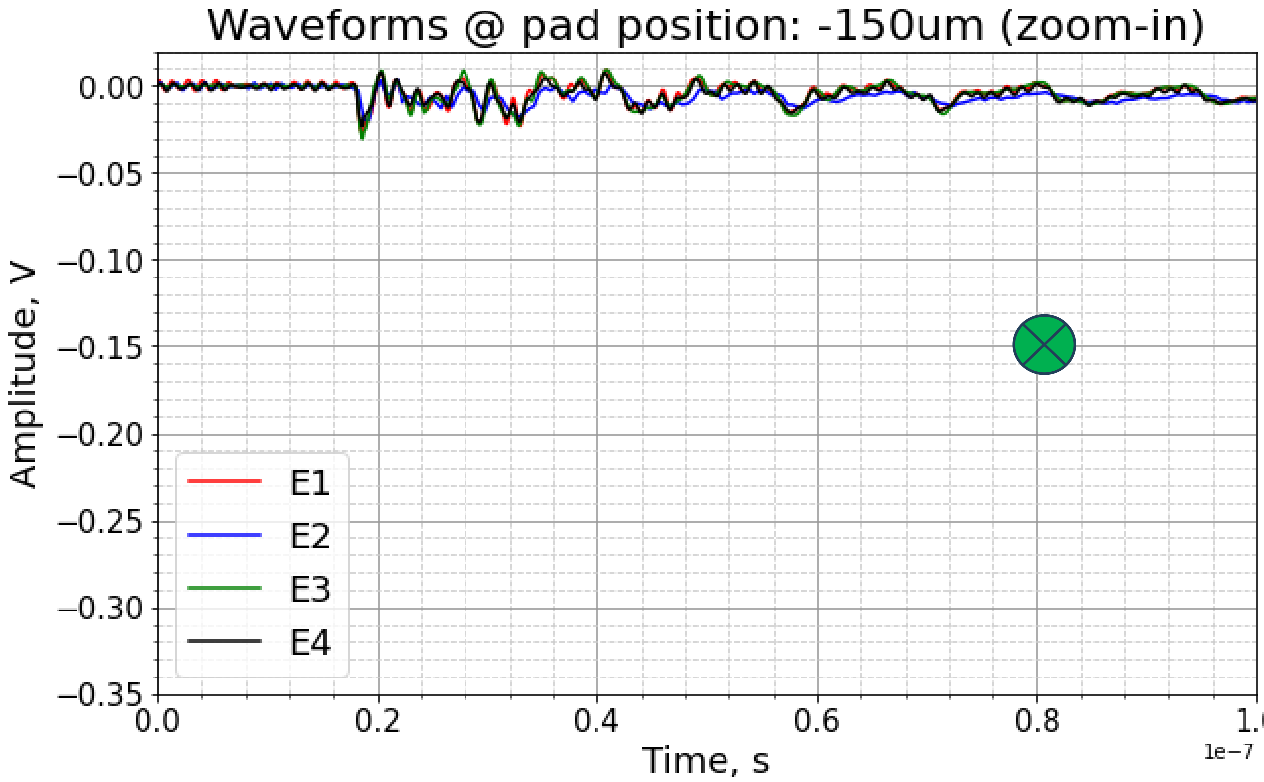


TCT: Pixel Isolation (IV)

- Laser is shot on **pixel-1**, which is not connected to readout.
- No Signal is observed for any device.
- Pixels are **isolated**! Trenches are **working**!

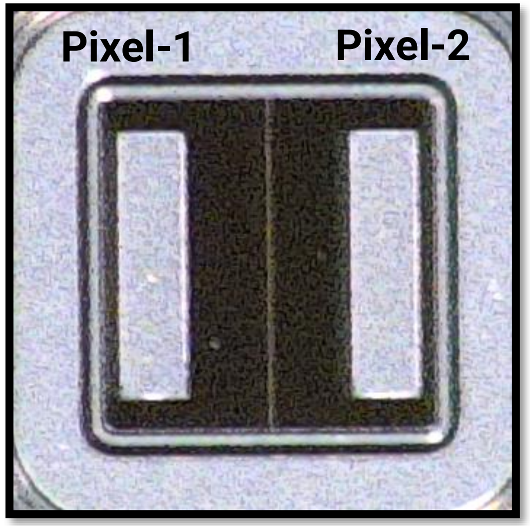


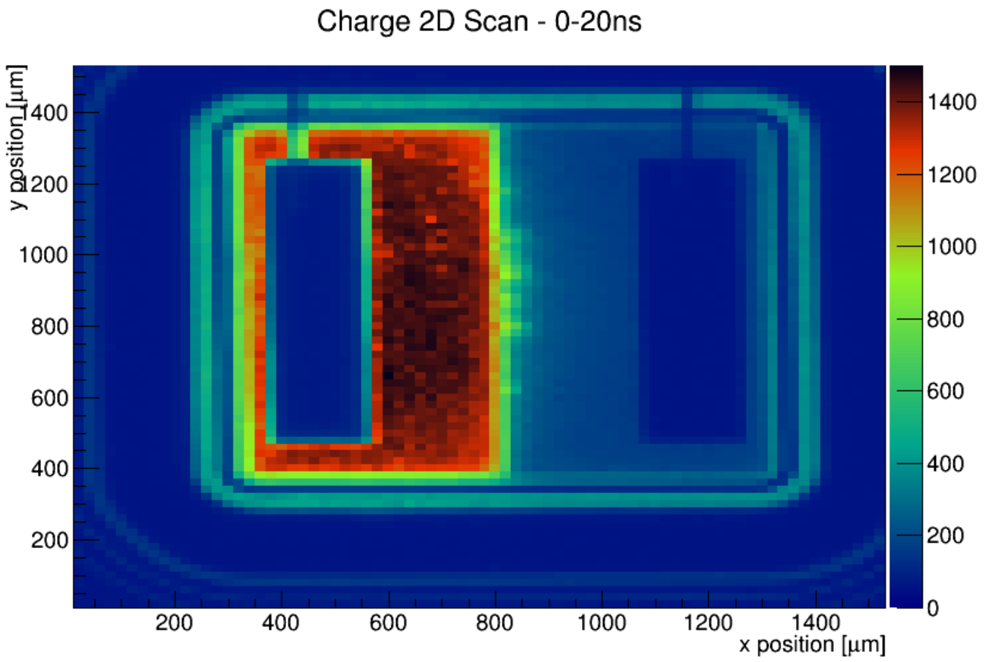
Connected to readout



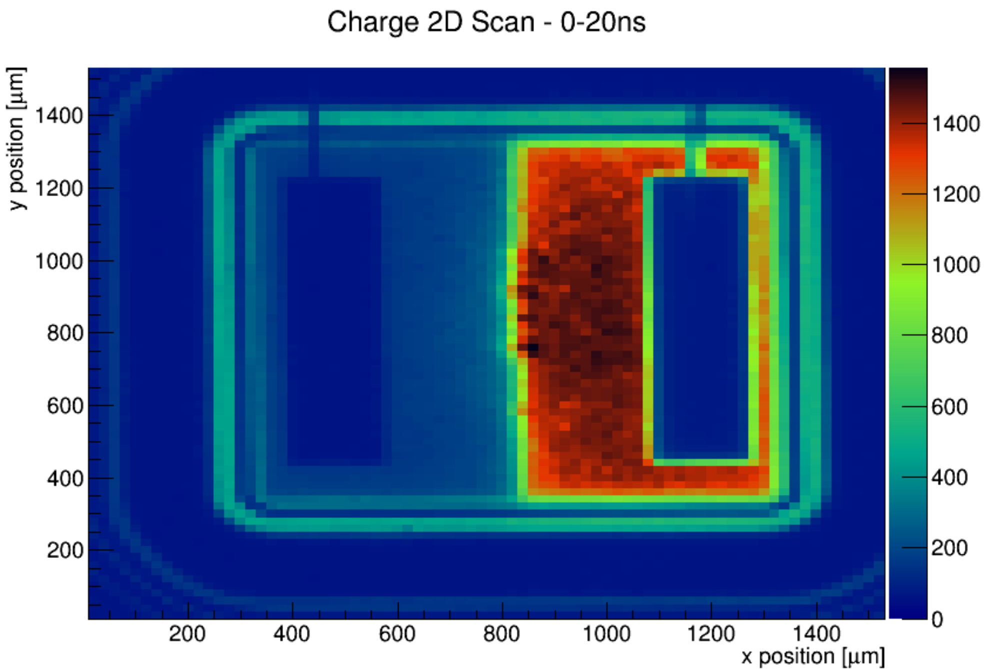
TCT: Pixel Isolation (2D Maps)

- One pixel connected to the readout
- Other pixel is only connected to bias voltage
- 2-dimensional (x-y) scans also depicts isolation between the pixels





Pixel-1 Connected to readout



Pixel-2 Connected to readout

TCT: Inter-Pixel Distance

- Measuring the "no-gain region" also referred to as inter-pixel distance (IPD).
- 1-dimensional scans along the x-position, and plot charge vs position for both pixels.
- Distance between the two pixels where normalized charge reaches 50% of its value.

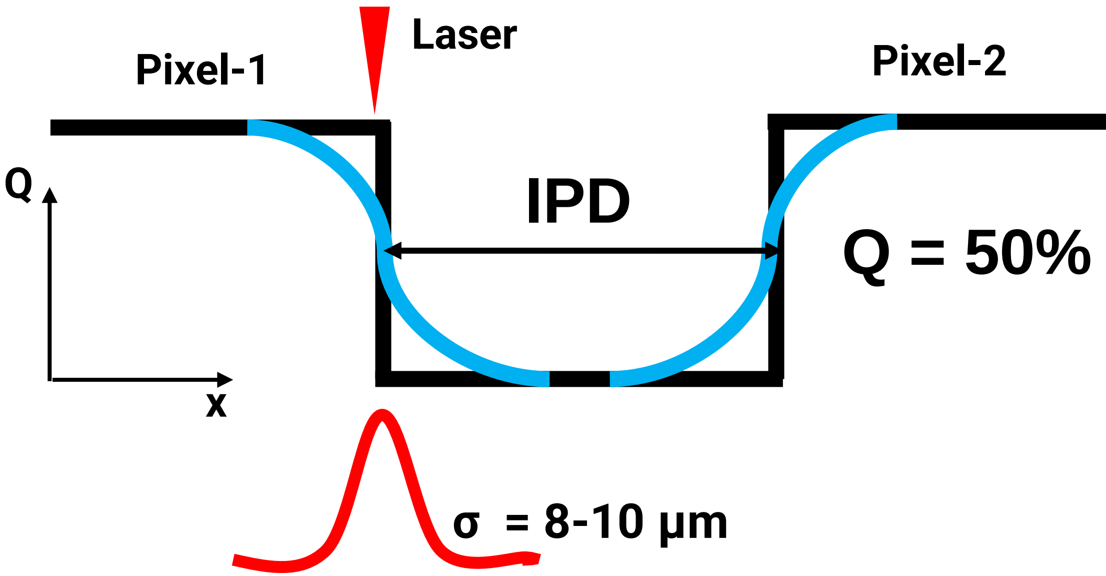


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Fig: Schematics of IPD calculation

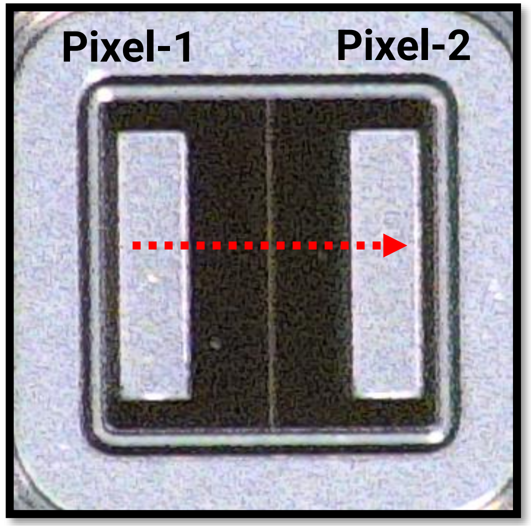

Fig: 1-dimensional scan in the x-direction

TCT: Inter-Pixel Distance (II)

- Measuring the "no-gain region" also referred to as inter-pixel distance (IPD).
- 1-dimensional scans along the x-position, and plot charge vs position for both pixels.
- Distance between the two pixels where normalized charge reaches **50%** of its value.
- Fit the s-curve on the charge obtained from each pixel, given by: $$f(x) = c_1 * [1 \pm \mathrm{erf}(\frac{x - c_2}{c_3})] + c_4$$
- IPD is given by:

$$IPD = x_{RP\,(Q=0.5)} - x_{LP(Q=0.5)}$$

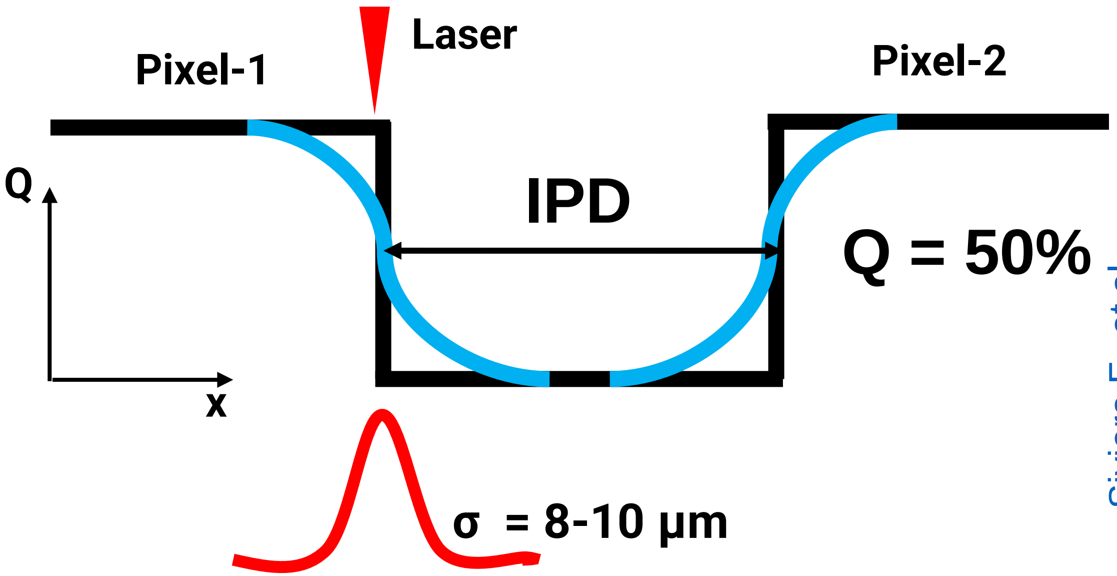

Fig: Schematics of IPD calculation

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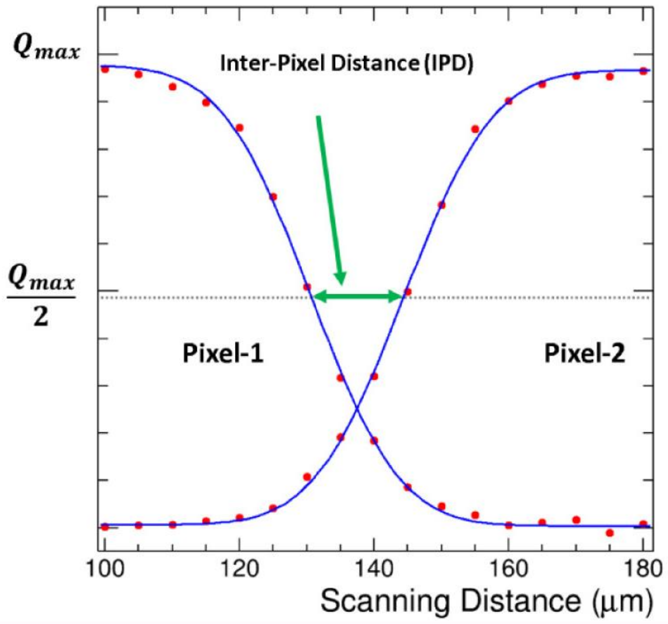
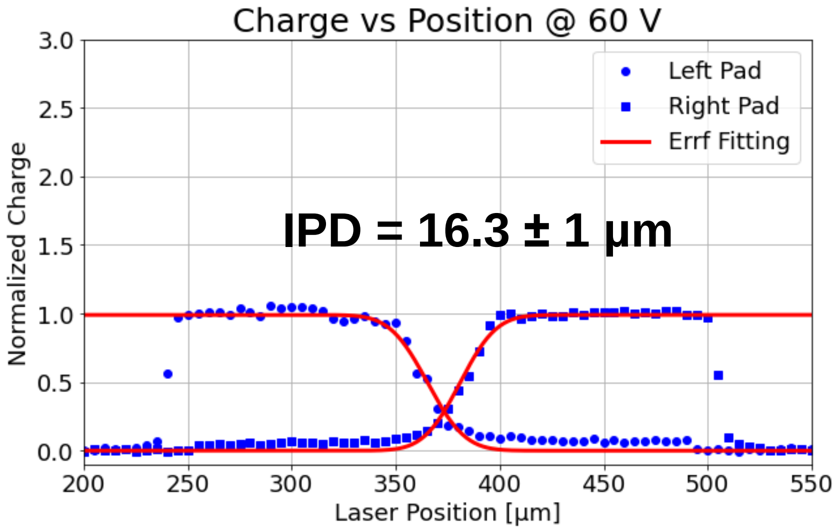
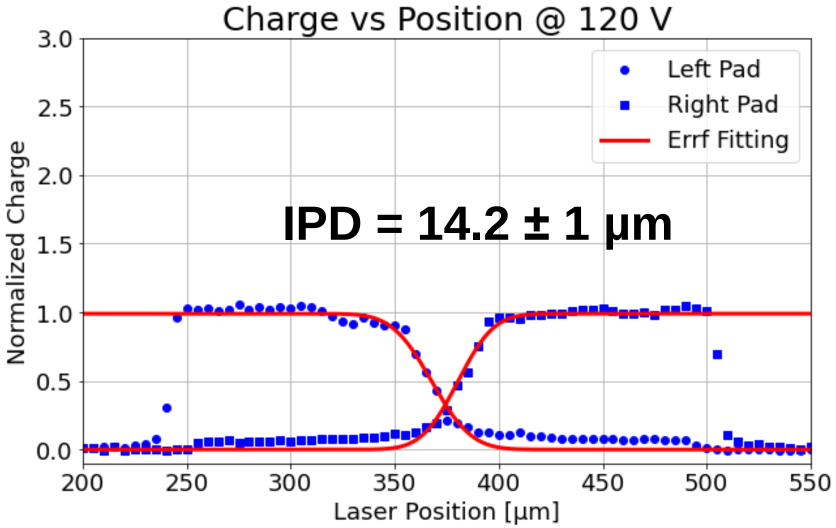
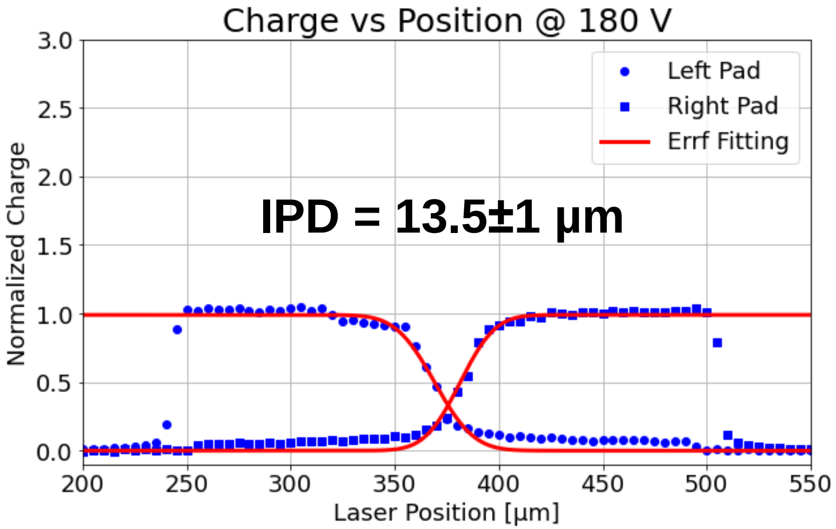


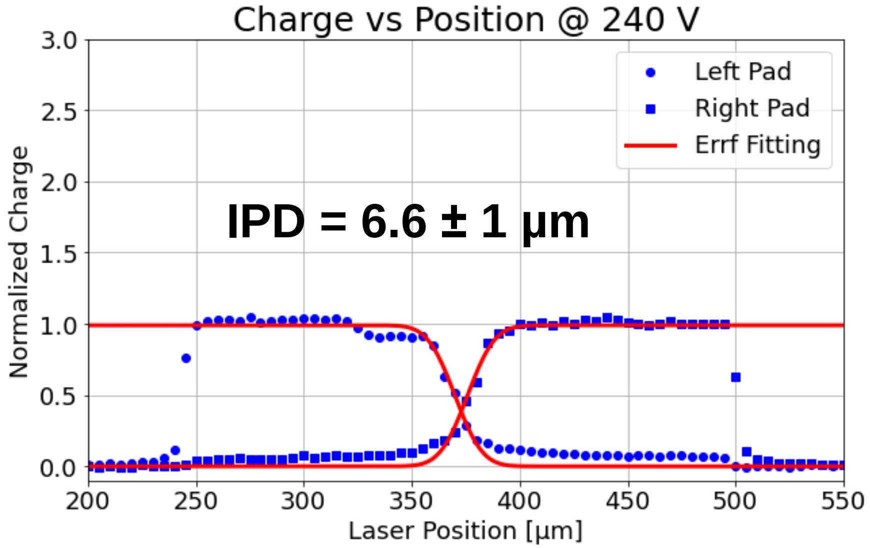
A. Bisht, et. Al.

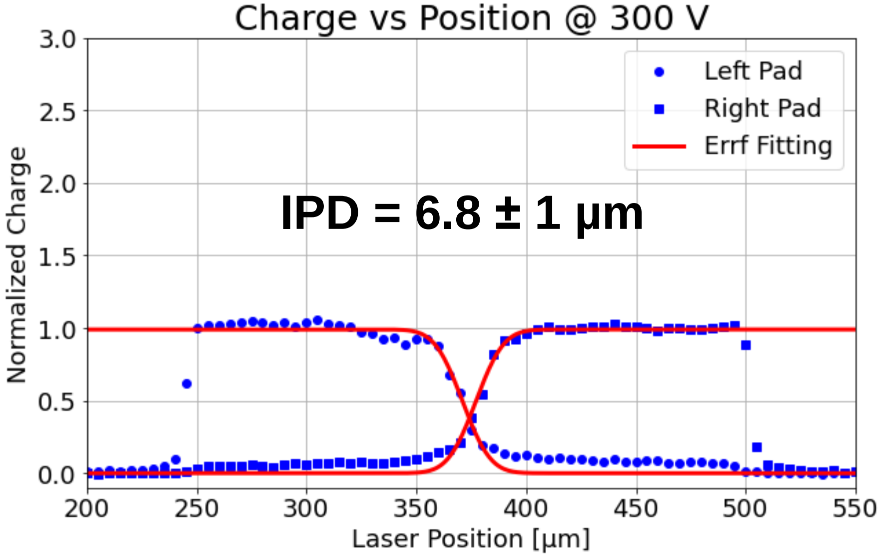
TCT: Inter-Pixel Distance (III)







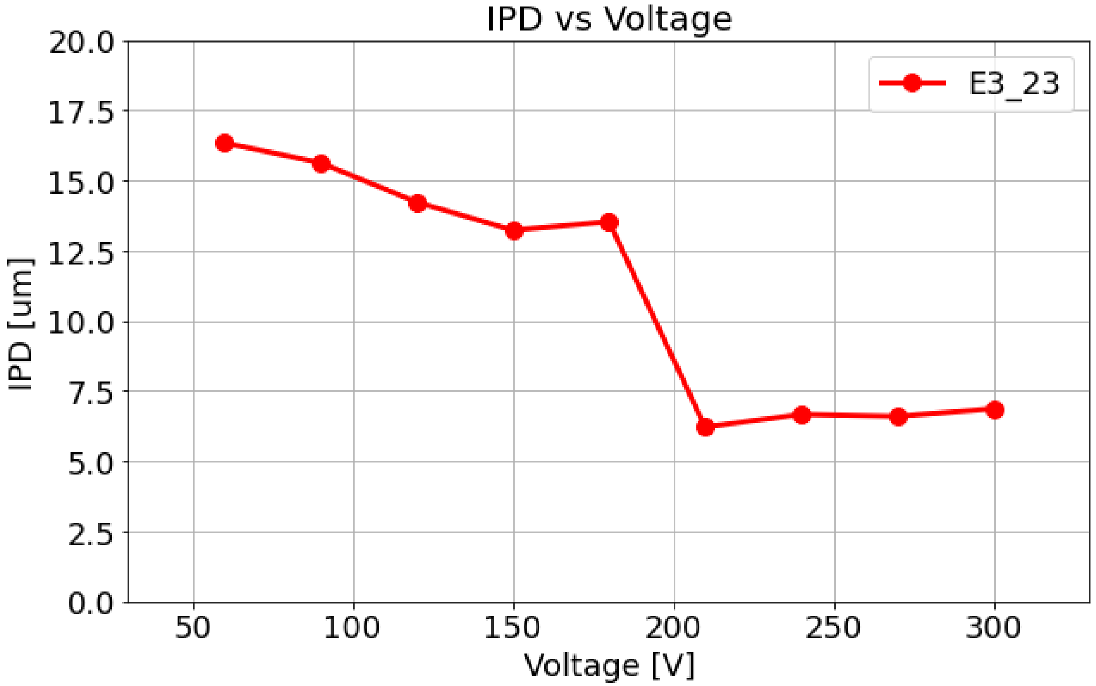


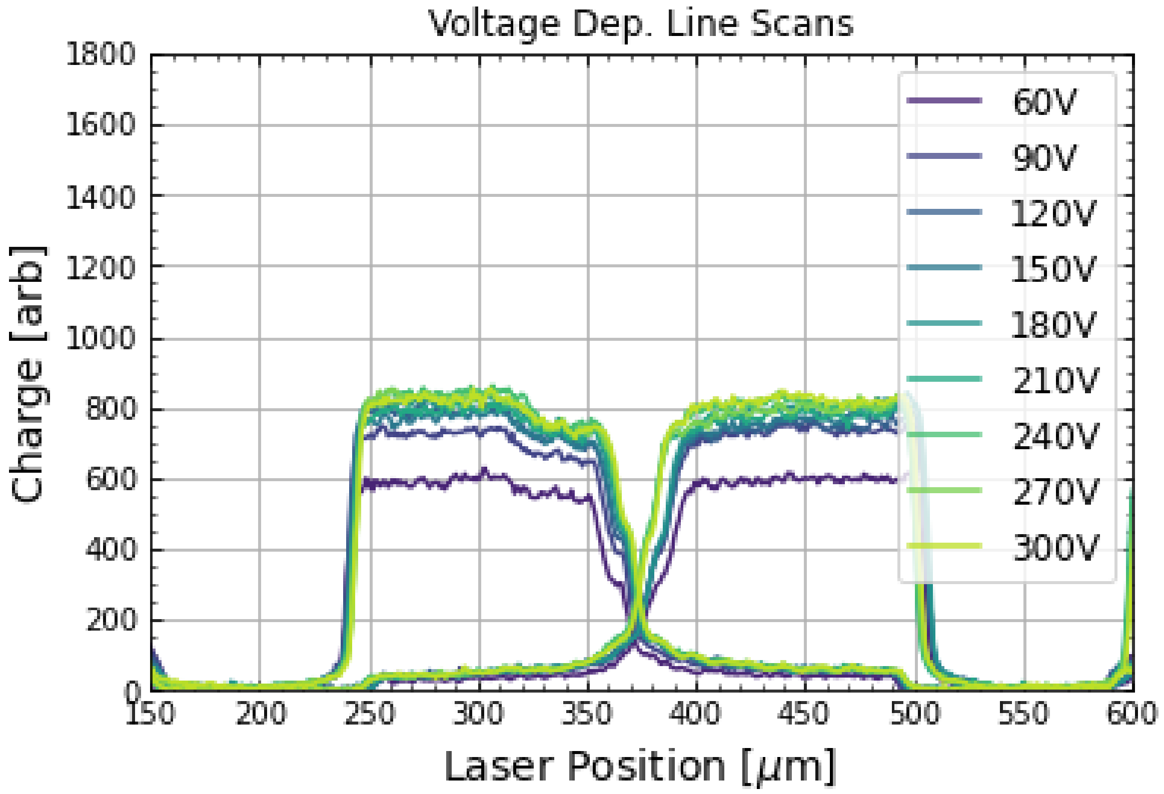


These values correspond to the **"Effective inter-pixel distance"**

TCT: Inter-Pixel Distance (IV)

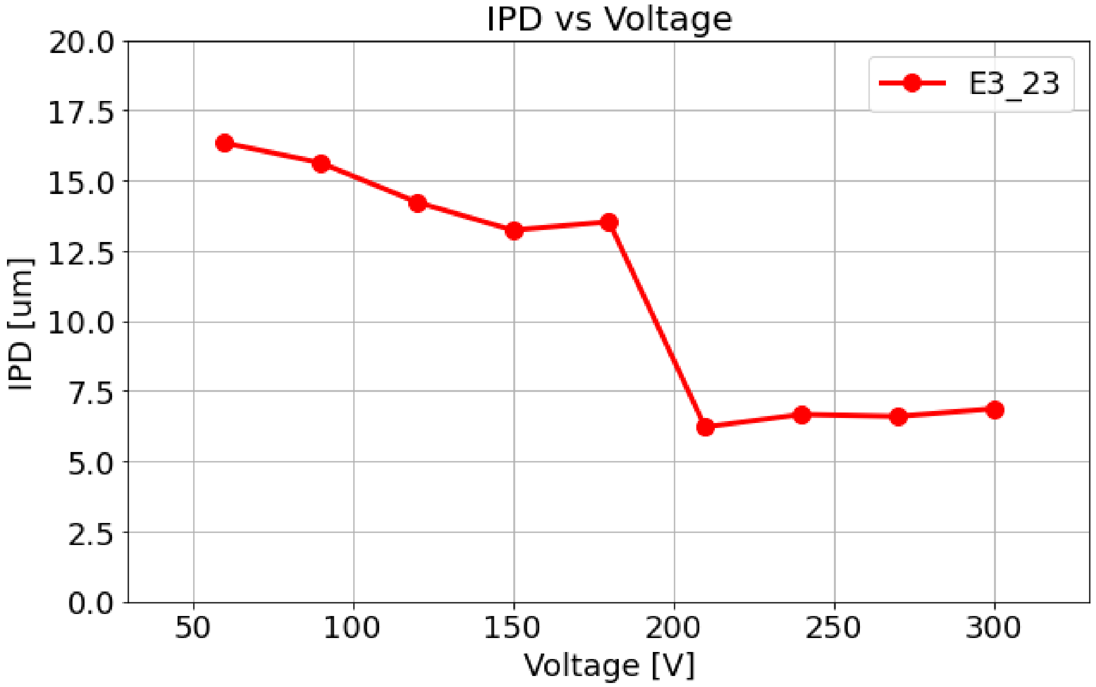
Interpixel distance decreases as voltage increases, as expected

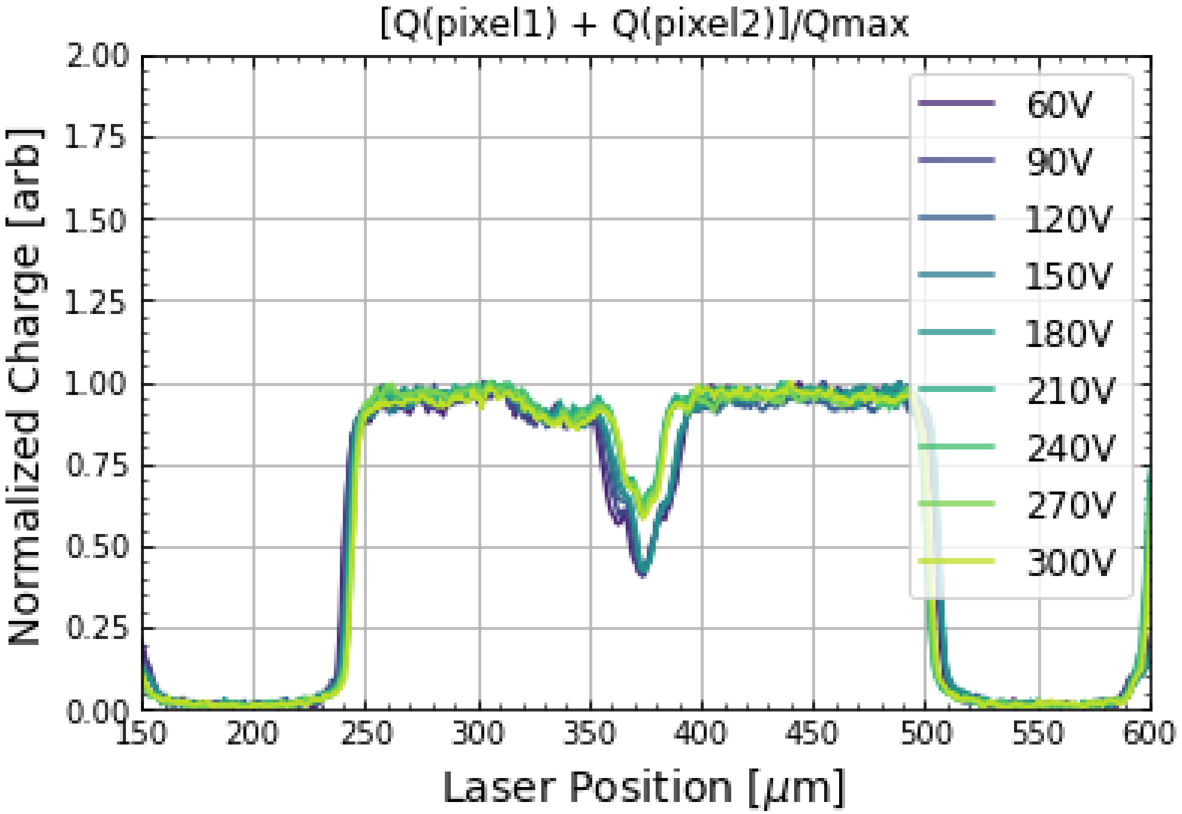




TCT: Inter-Pixel Distance (V)

Interpixel distance decreases as voltage increases, as expected

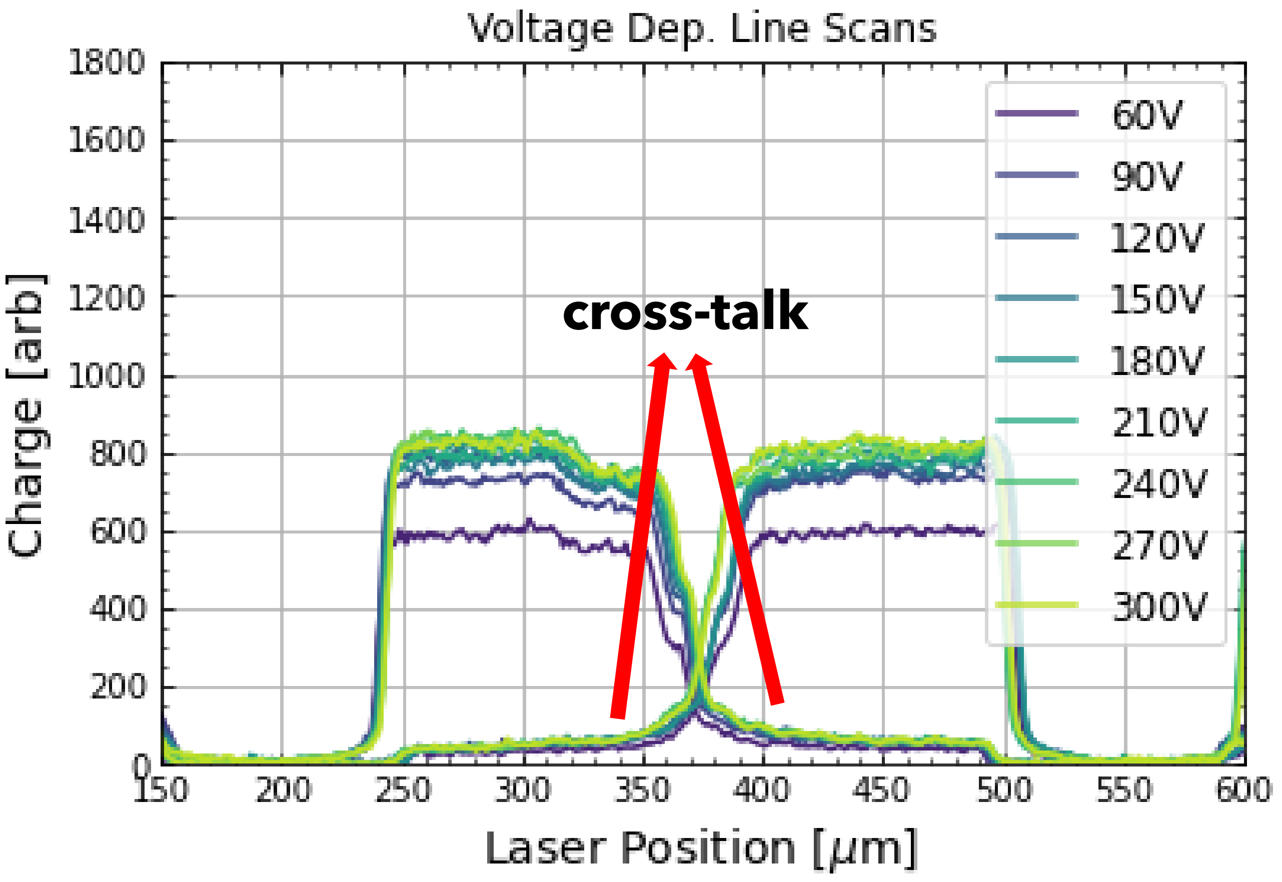




Fill factor is nearly 97%

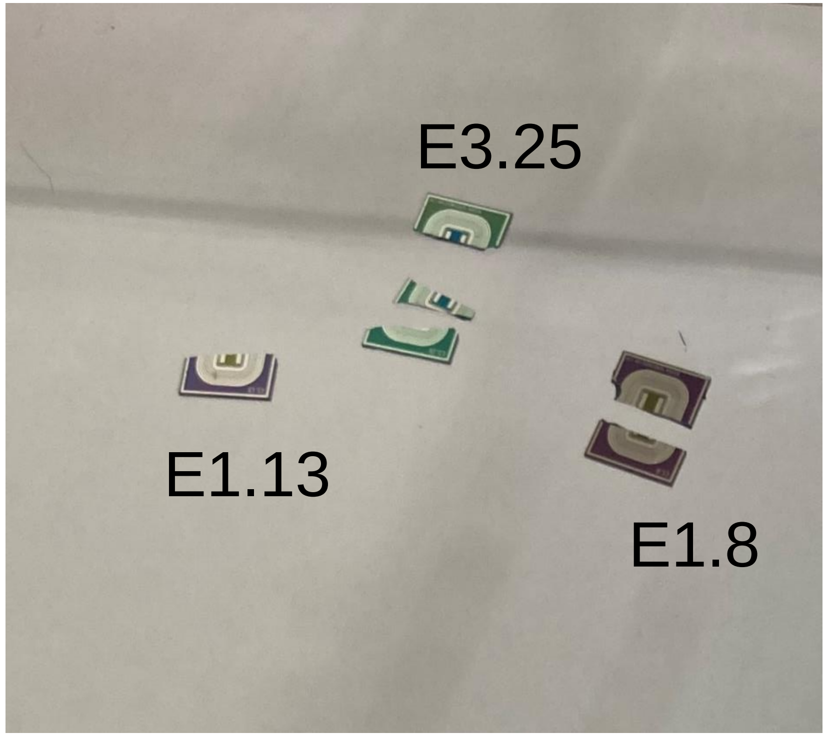
Discussion: Isolation

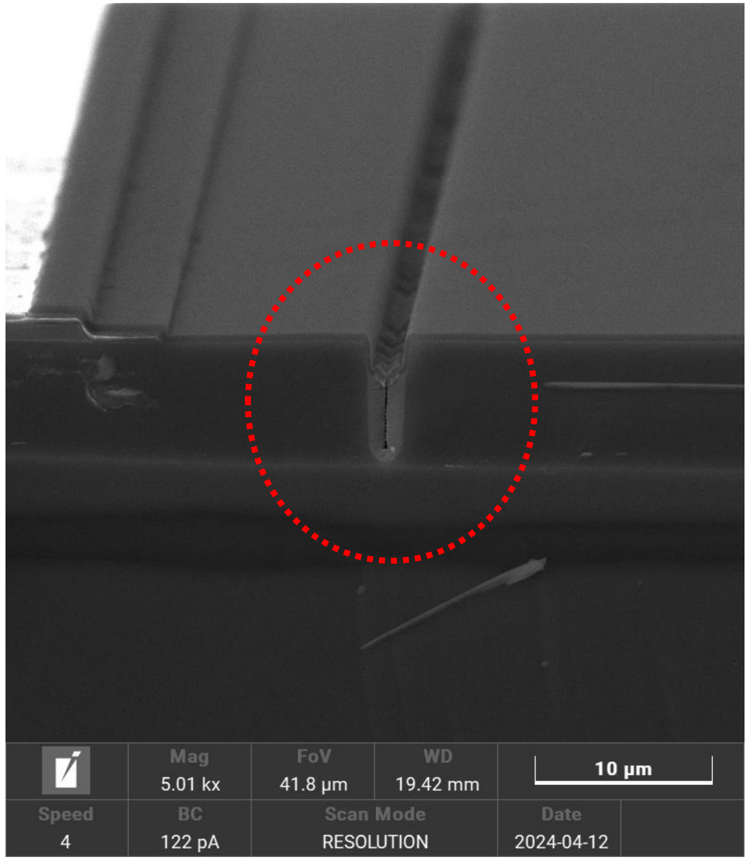
- There is still some charge collected from the pixel, when the laser is on adjacent pixel.
- Most probably due to the **cross-talk** between the pixels.
- Idea is to look inside the trenches



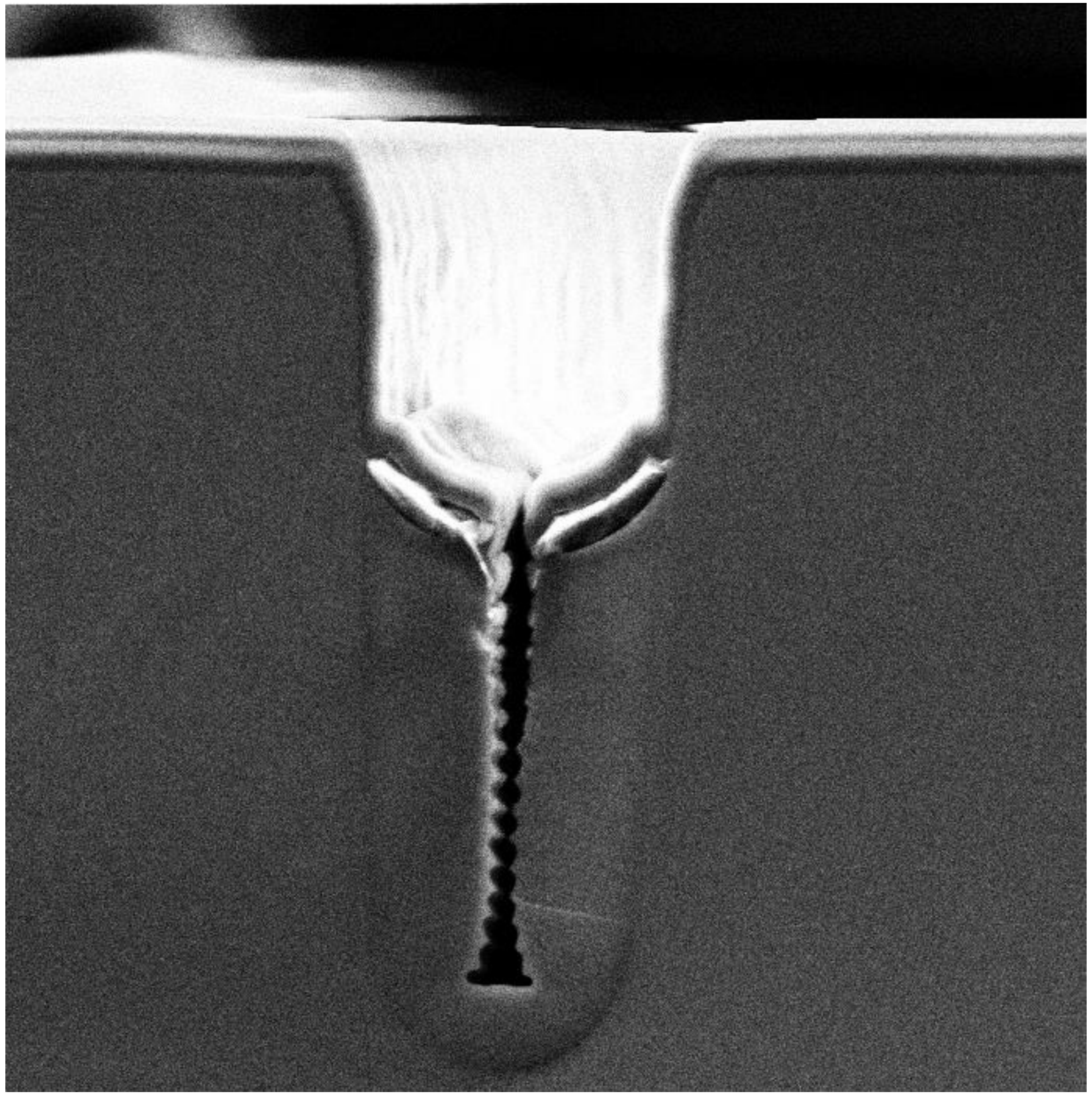
Discussion: SEM Images

- A couple of devices from a different part of the wafer were cleaved to investigate the trenches.





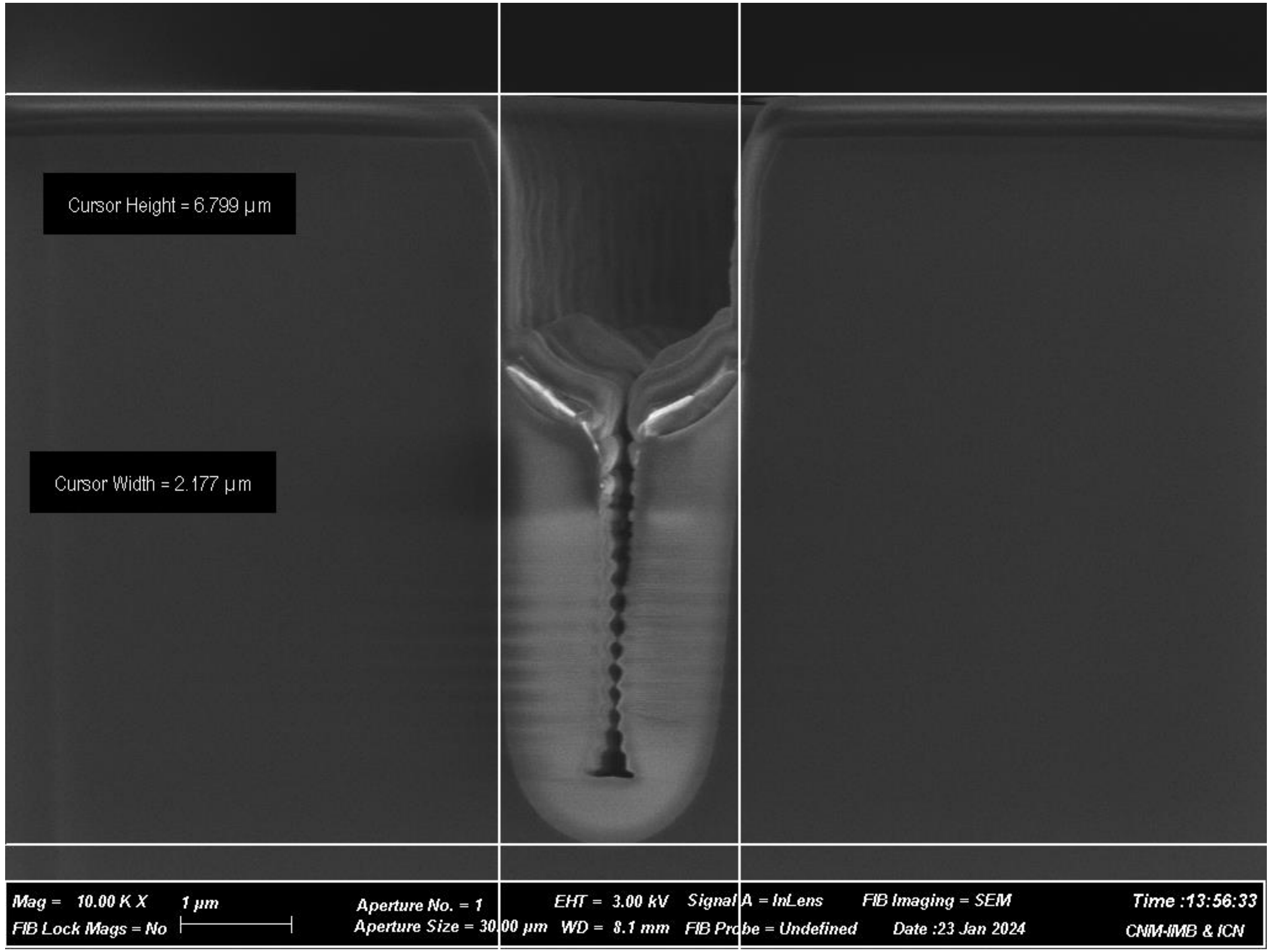
Discussion: SEM Images



Toast: to the Trench Isolated LGADs

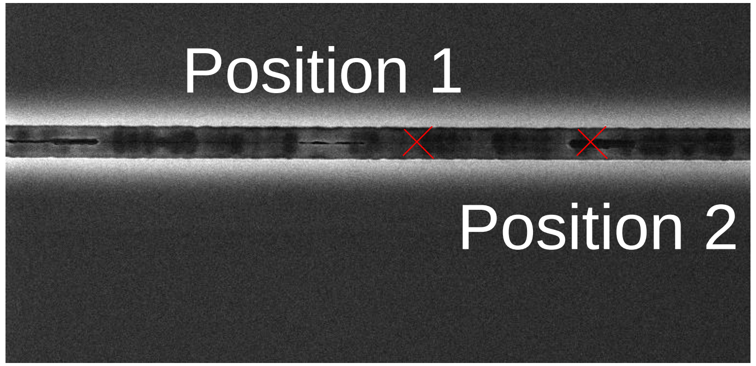
Discussion: SEM Images

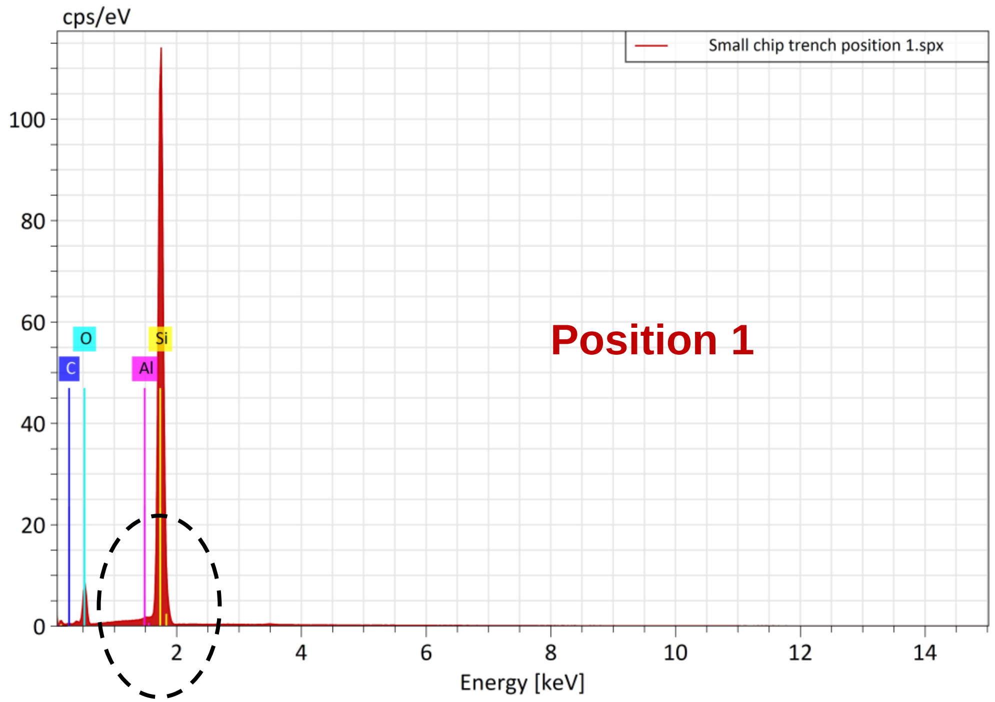
- Trenches are ~ 2μm wide and ~ 7μm deep.
- Trench filling with SiO_2 is not as expected
- SiO_2 is over-etched during the wafer processing leaving a part of trenches empty.
- Additionally, some metal debris is observed in the trenches which seems to be a reason for the cross-talk.

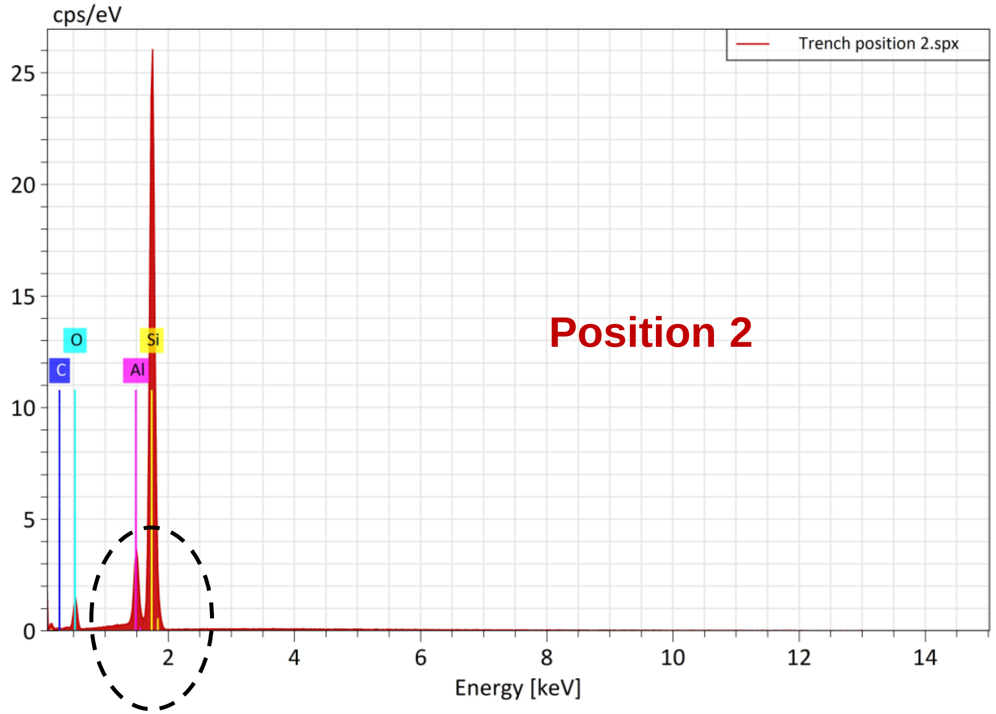


Discussion: Energy Dispersive X-Ray (EDX) Spectra

- Confirmation of some metal debris in the trenches which seems to be a reason for the cross-talk.
- Aluminium peak was observed at position 2 but not in position 1.



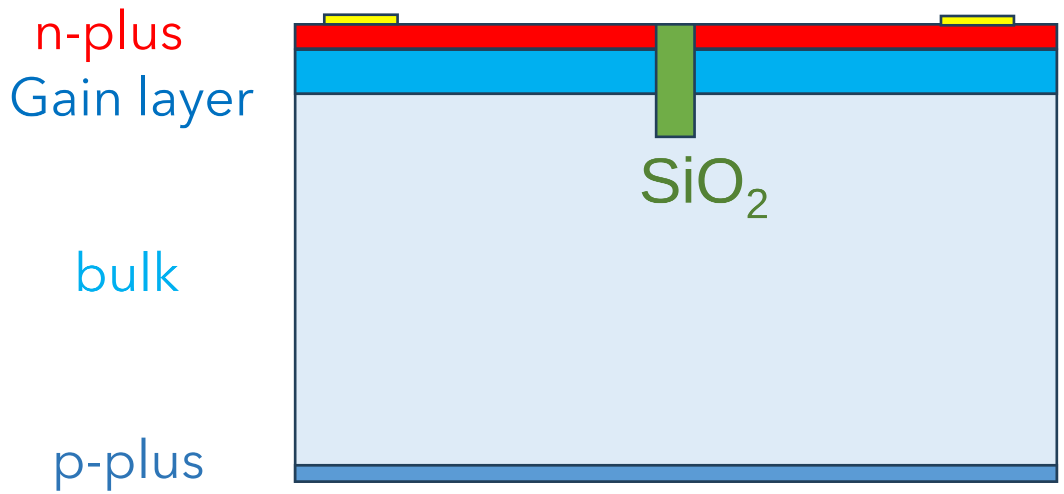




Measurements at SMC, Edinburgh

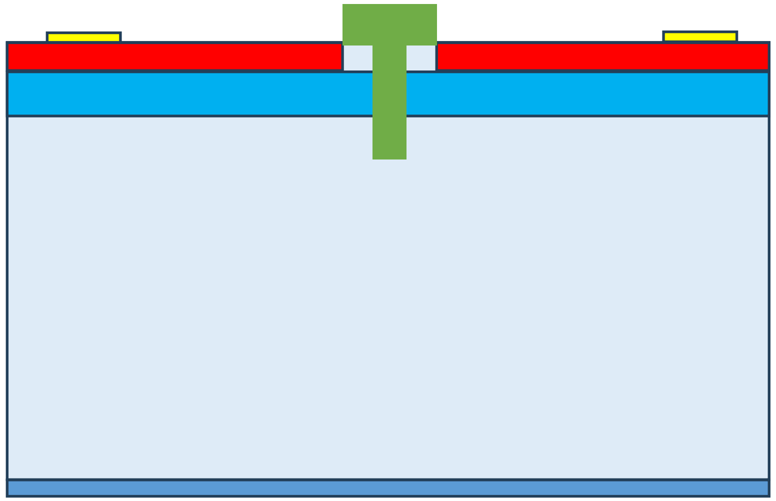
Discussion: Next Production

Gap = Distance between **trench** and **n-plus**



Current Device Model

(uniform n+ implant)



New Device Model

(gap between trench and n-plus is introduced)

- To avoid over-etching of SiO_2
- Smooth trench filling

Summary and Future Work

- Preliminary results from new run of Trench-Isolated LGADs with low-gain have been presented
  - We are delighted to say that the **pixels are isolated**, but a little cross-talk is observed.
- Inter-pixel distance calculations shows values significantly smaller than the standard LGAD segmentation
  - **IPD < 7μm** at voltages above 180V
  - Fill factor is nearly **97%**
- Some issues were observed with the filling of trenches
  - **New run is in progress to avoid cross-talk → better isolation**
- Next step is to characterise wafers with **higher gain.**
- Medipix arrays will be sent for under bump metal (UBM) → **flip chipping to Timepix3 & Timepix4**
- **Irradiation campaign** to study the effects on pixel isolation and IPD.
- Next production on thin **epitaxial wafers (50 μm)** for higher fill factor and improved timing resolution.

Acknowledegments

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