Technology Developments on Thin iLGAD Sensors for Pixelated Timing Detectors

16th Trento Workshop on Advanced Silicon Radiation Detectors

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Instituto de Microelectrónica de Barcelona (IMB-CNM)

The RD50 iLGAD Project

Proof-of-concept and radiation tolerance assessment of thin pixelated Inverse Low Gain Avalanche Detectors (ILGAD)

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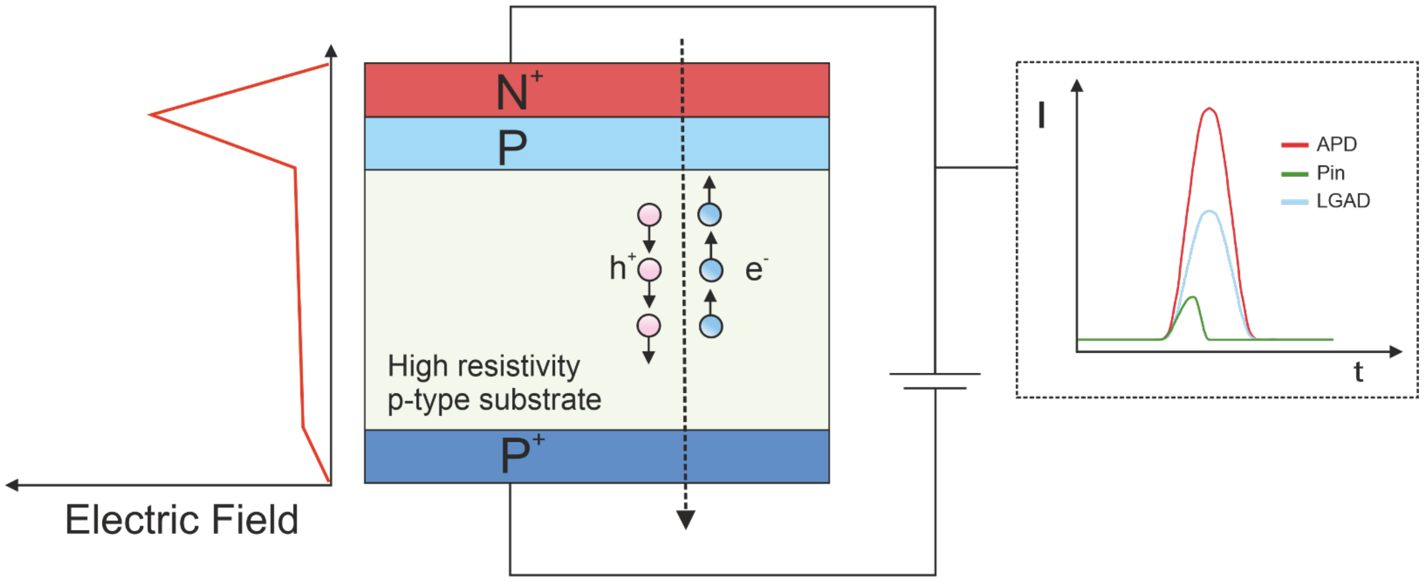
Outline of the Presentation

- Introduction: LGAD Technology
- Inverse LGAD as 4D Tracking Sensor
- First iLGAD Generation
- Inverse LGAD for Timing Applications
- Third iLGAD Generation (iLG3)
  - ➢ Trench iLGAD Concept
  - ➢ Fabrication Process
  - ➢ Mask Set Design
  - ➢ Work Plan
- Conclusion and future steps

Introduction: Low Gain Avalanche Detector (LGAD) Technology

- **LGAD** technology is based on the APD concept.
- Multiplication layer less doped to reach a **linear** and **moderate gain** (10-30) in a high operating voltage regime.
- **Low** signal to noise ratio **(S/N)**.
- **LGAD** is the baseline technology of the endcap MIP timing detector for the high-luminosity upgrade of the **ATLAS** and **CMS** experiments.



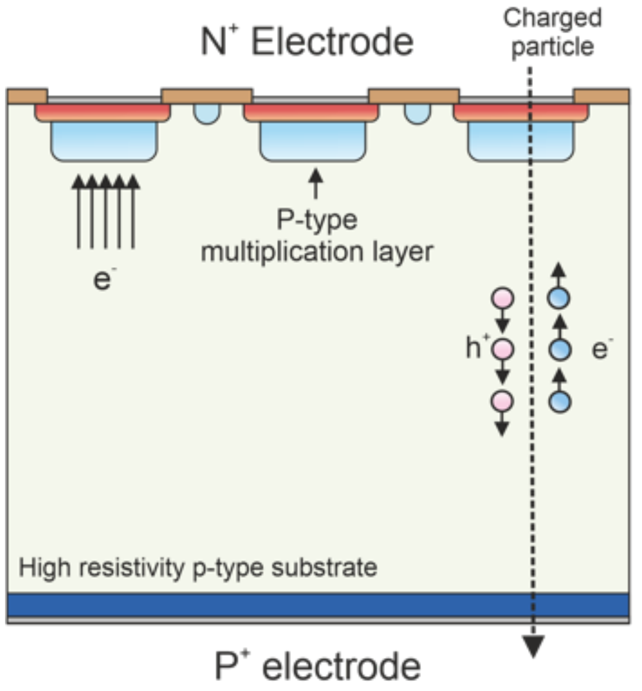
- Main challenges:
  - ➢ Radiation **tolerance to neutrons and protons.**
  - ➢ Technology **long-term reliability (Safe operating voltage).**
  - ➢ Large scale **manufacturing yield.**
  - ➢ Improve **fill-factor.** → **Motivation for the iLGAD**

Inverse LGAD as 4D Tracking Sensor

- Inverse Low Gain Avalanche Detector (iLGAD) is based on the LGAD technology.
- The main motivation for the iLGAD technology is increase the fill factor to a 100%.

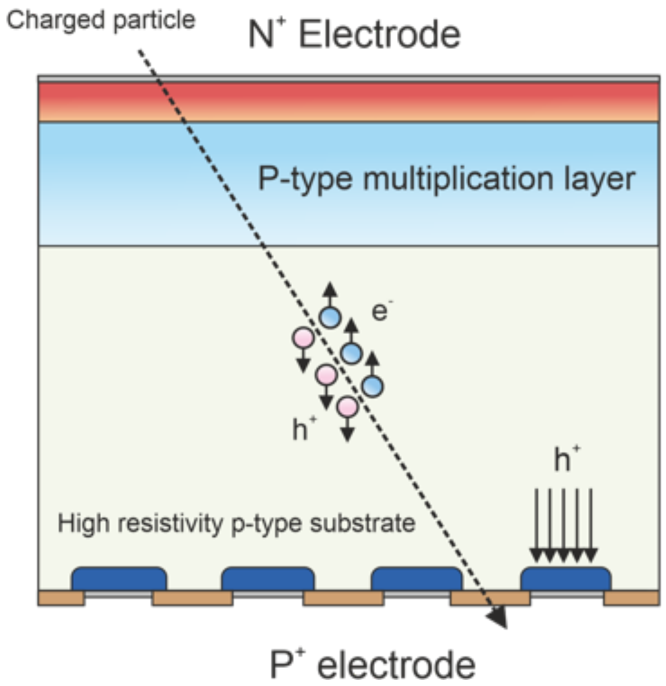
LGAD TECHNOLOGY

- Segmentation of the multiplication.
- Electron collection
- Single side process



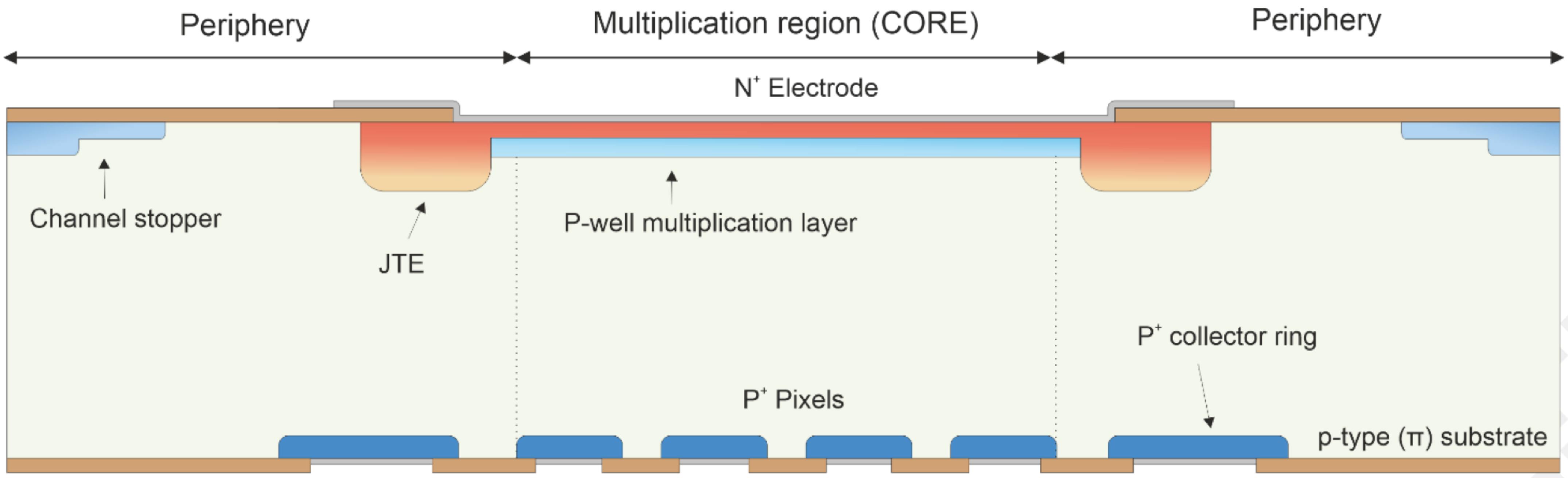
iLGAD TECHNOLOGY (iLG1)

- Multiplication extended over the electrode.
- Hole collection
- Complex double side process



iLGAD First Generation (iLG1)

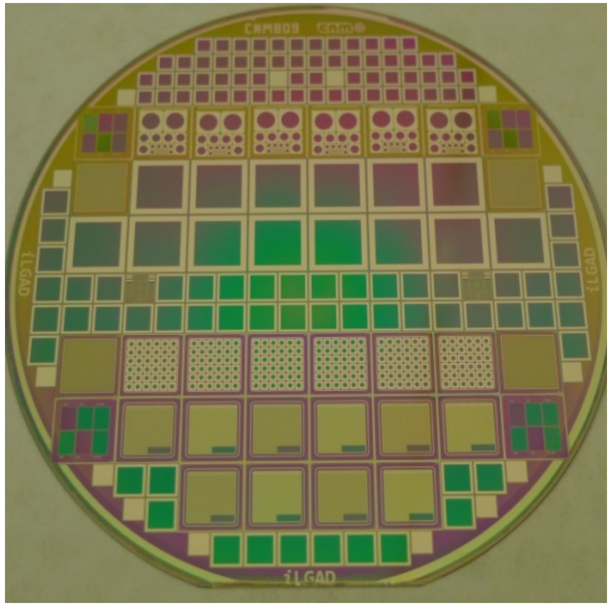
- Segmentation at the **ohmic contact**: strip and pixels.
- **Multiplication** extended over all the **CORE**.
- **P-type collector ring** at the ohmic side to extract leakage current.
- **JTE** to protect the n+/p curvature and **channel stopper** to avoid the depletion reaches the end of the detector.
- Readout is made by the strips/pixels: **holes collection**.



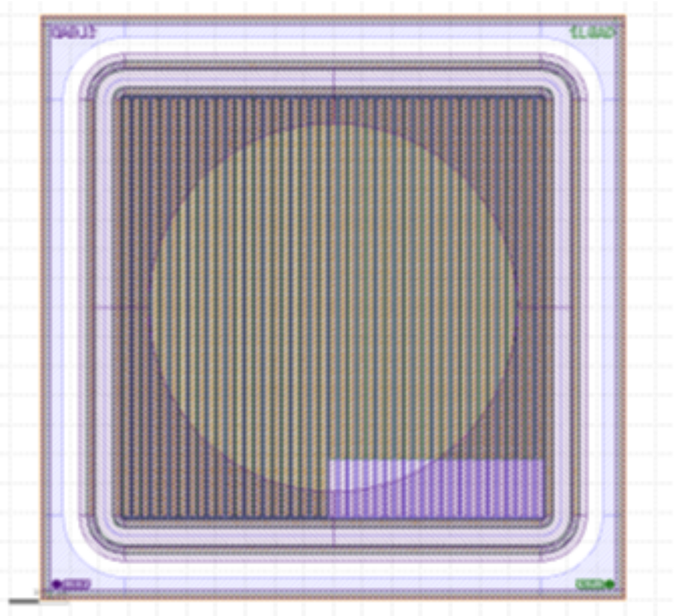
iLGAD First Generation (iLG1)

- 4-inch 285 µm p-type high resistivity wafers.
- More than 100 fabrication steps.
- 11 photolithographic steps: double side fabrication process.
- Pad-like, strip and pixelated detectors.

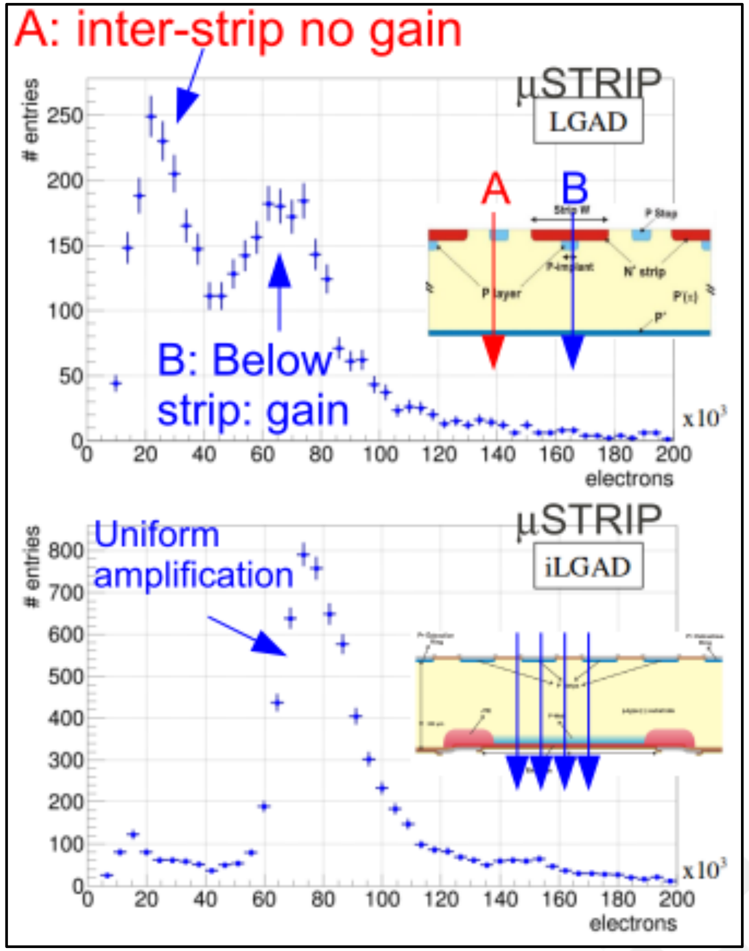
Mask design



µStrip iLGAD



Test Beam Characterization

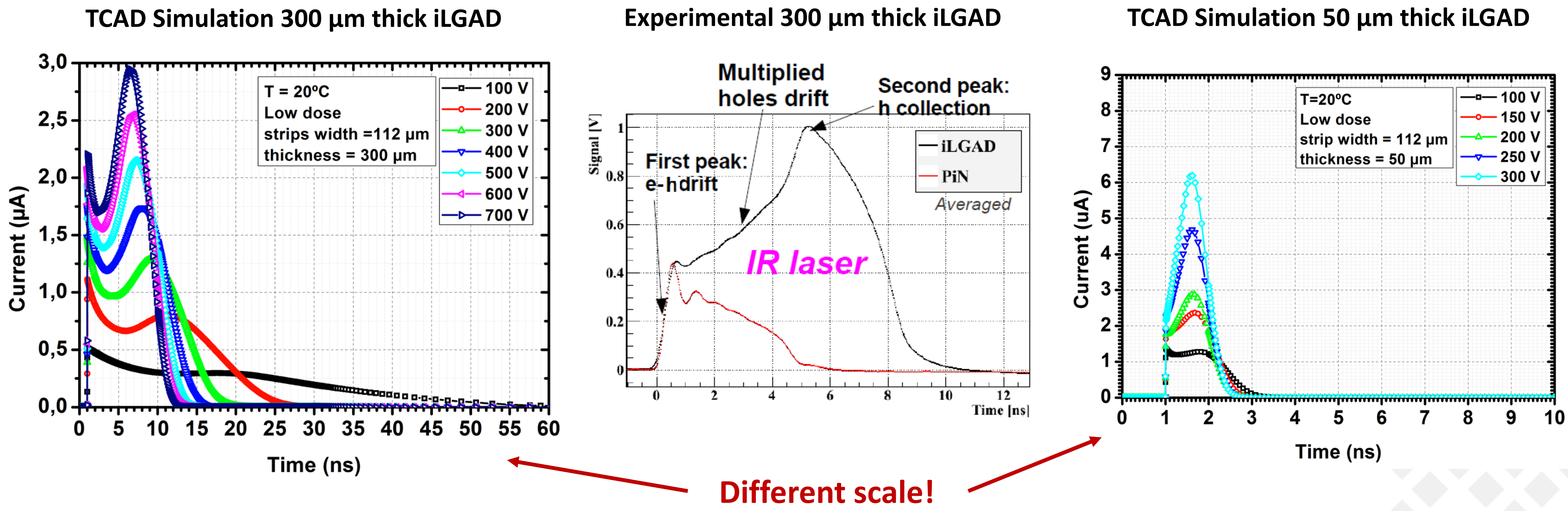


Currás, Esteban, et al. "Inverse Low Gain Avalanche Detectors (iLGADs) for precise tracking and timing applications." *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 958 (2020): 162545.

iLGAD for Timing Applications

In order to use iLGADs for timing applications:

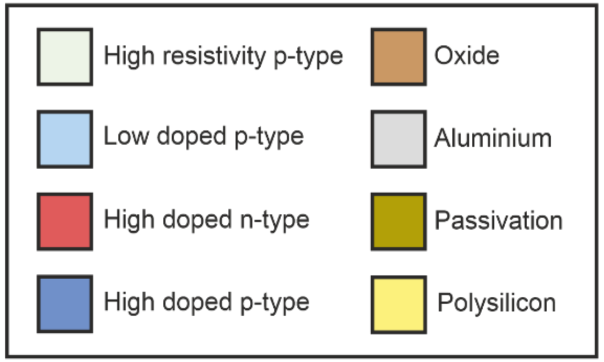
- **Reduce** the **thickness** of the detector to **increase the electric field (at same voltage)** in order that **hole drift velocity** reaches saturation.

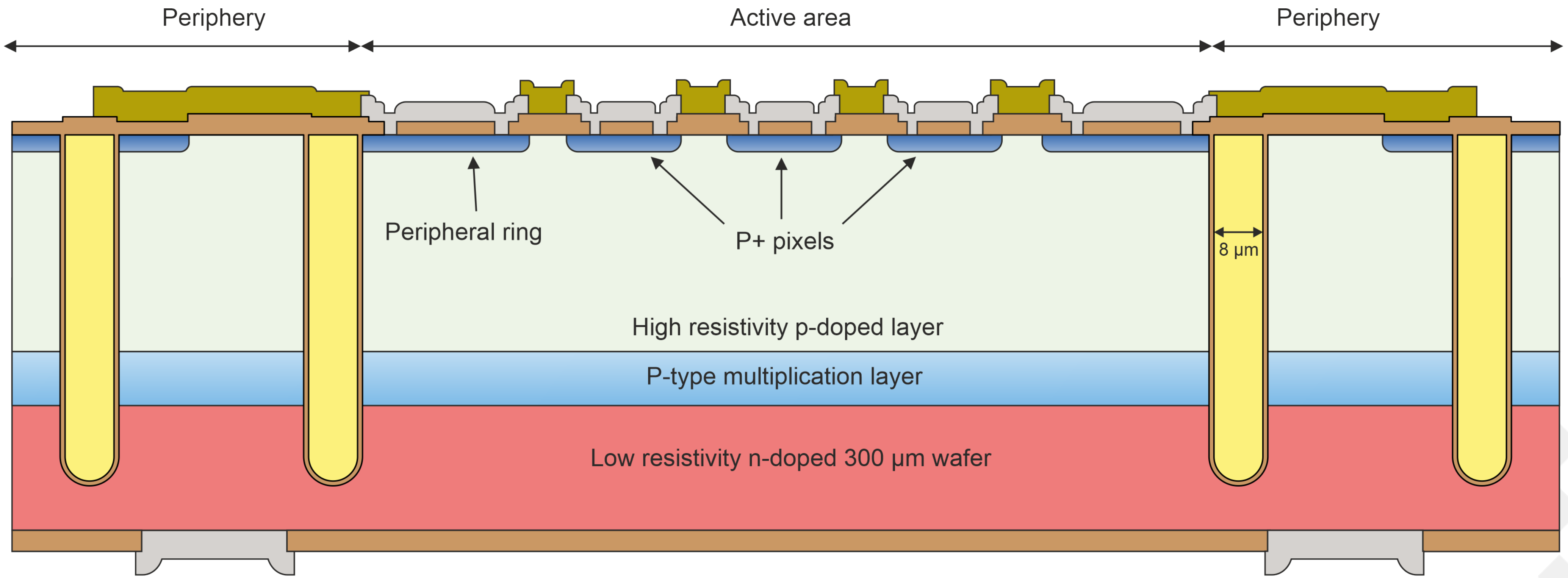


iLGAD Third Generation (iLG3): Trench iLGAD Concept

In the iLG3 we are going to use trenches to isolate the active area.

- ✓ **Multiplication region** is fully **isolated**.
- ✓ **Simpler single-side** and **50% less** fabrication steps.
- ✓ Devices are able to sustain **higher voltages.**
- ✓ **Slim-edge technology.**
- ✓ Optimization of the **multiplication layer is independent of charge collection and cross-talk at the electrodes.**

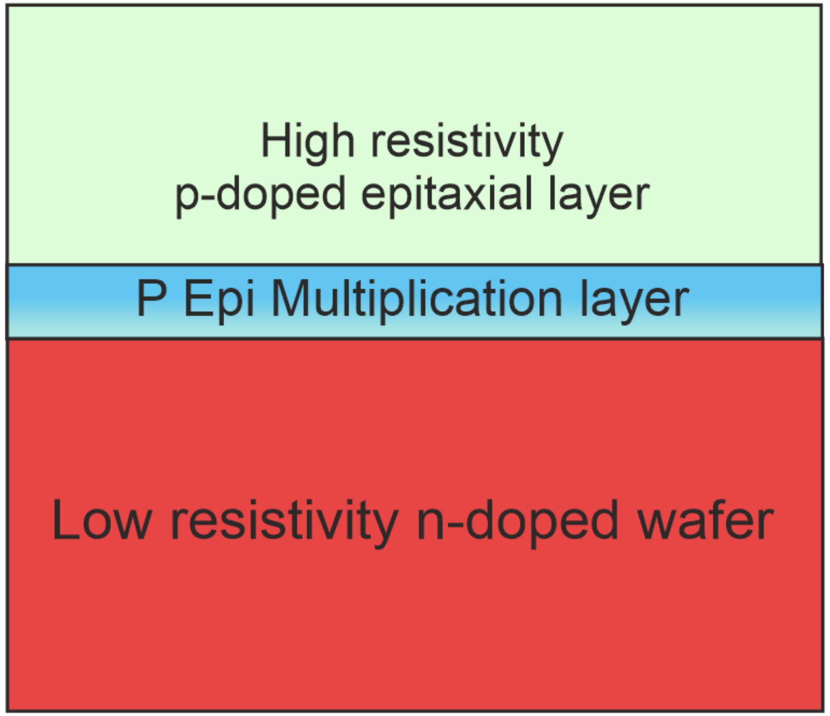




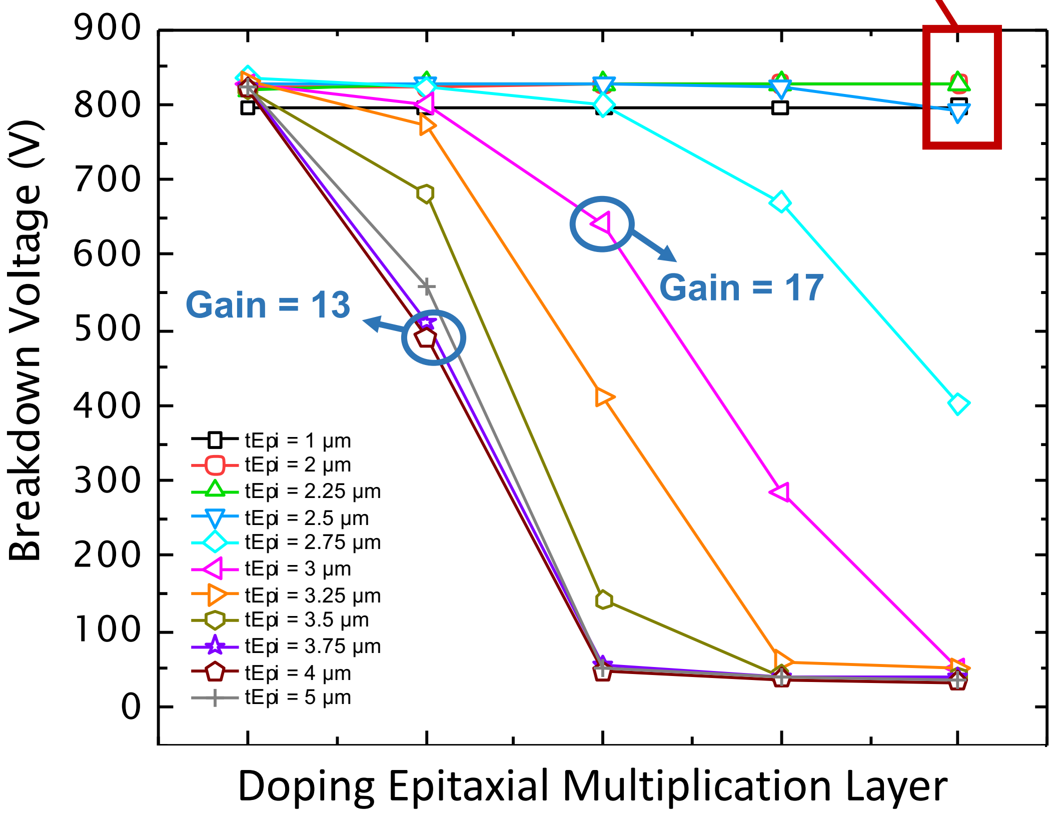
iLGAD Third Generation (iLG3): Fabrication Process

We are planning to carry out this fabrication with two different approaches:

1. **Epitaxial wafer + epitaxial multiplication**
2. Si-Si wafers + implanted multiplication



No gain layer due to diffusion of n-doped wafer to the epitaxial p-doped



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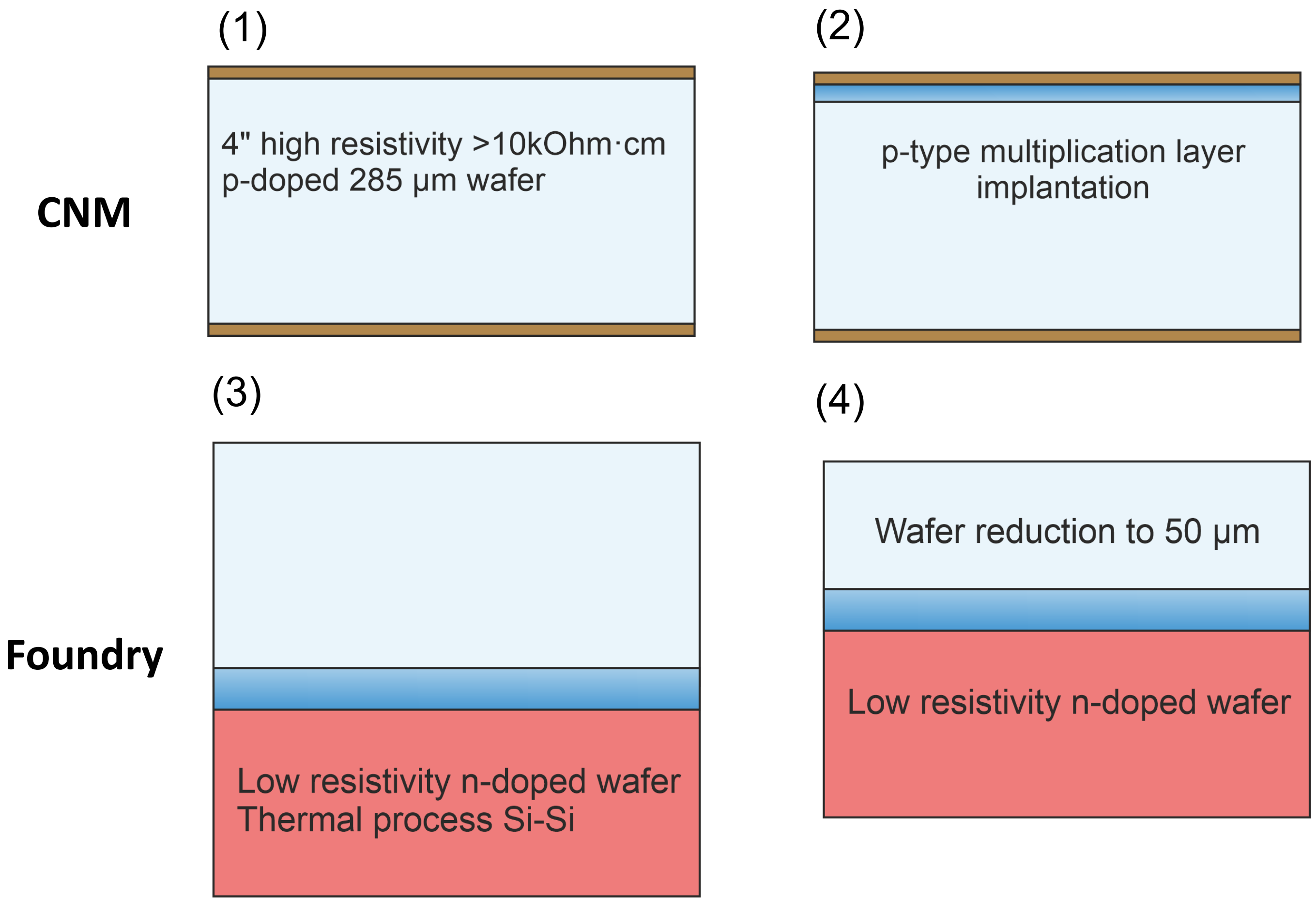
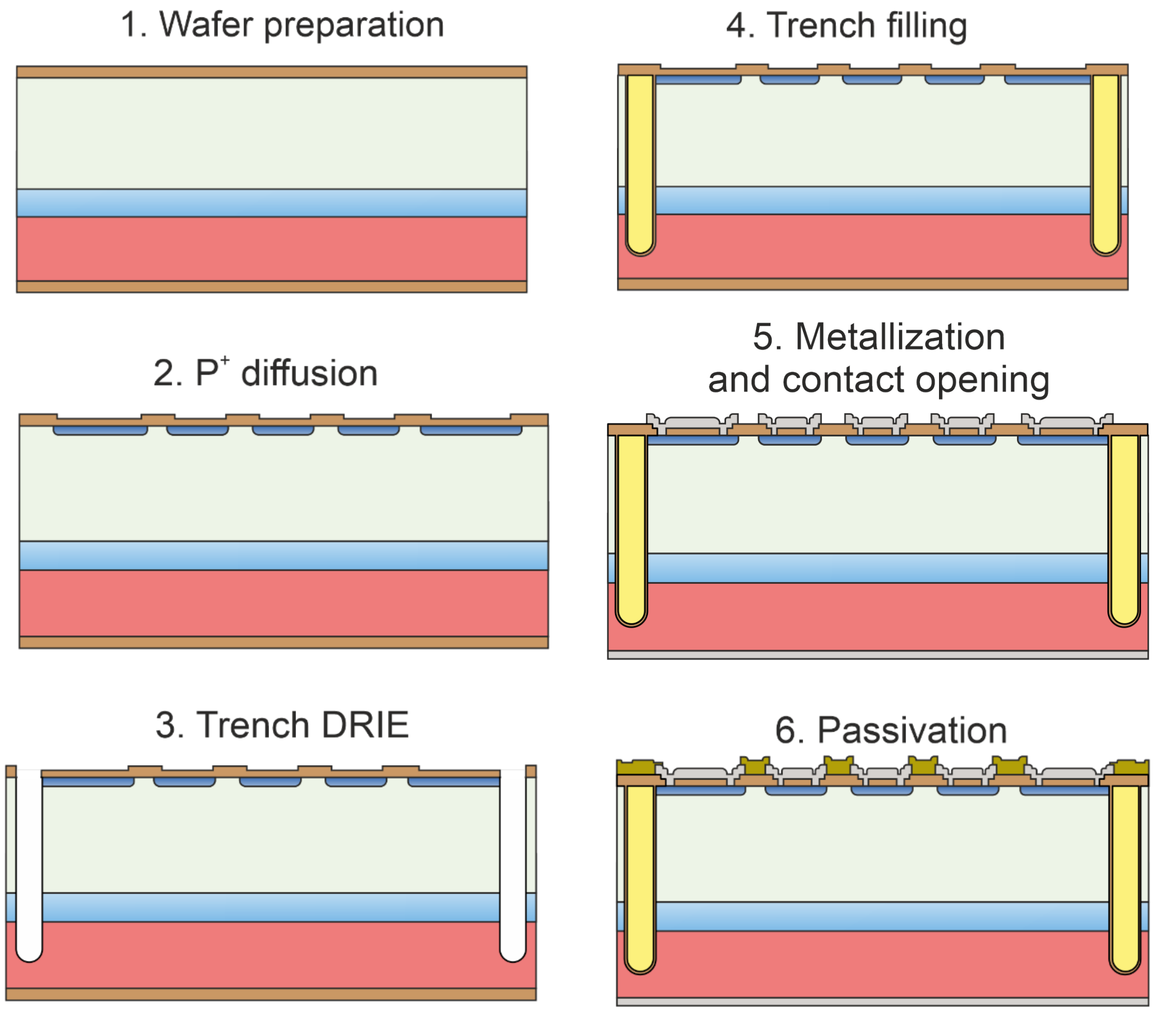


Dose/energy multiplication layer is adapted to the Si-Si thermal process

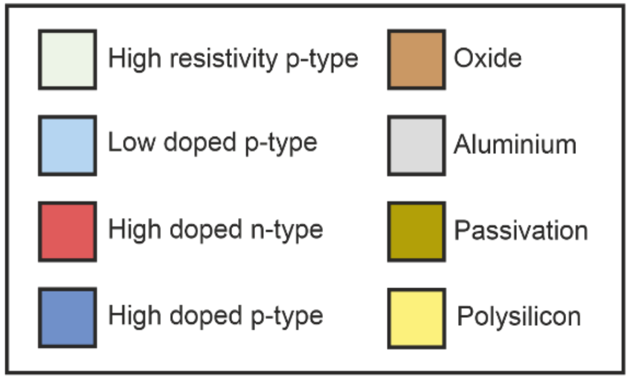
After (4), the profile is the same as standard LGAD runs. This is the starting point for the fabrication.

iLGAD Third Generation (iLG3): Fabrication Process

Trench iLGAD Fabrication Process



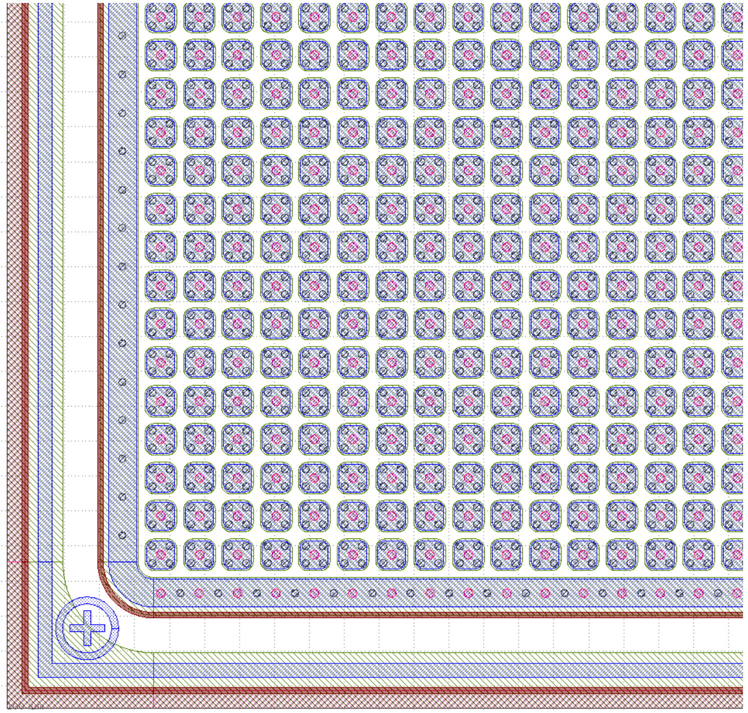
7 Photolithographic steps
~50 fabrication steps
Single-side process



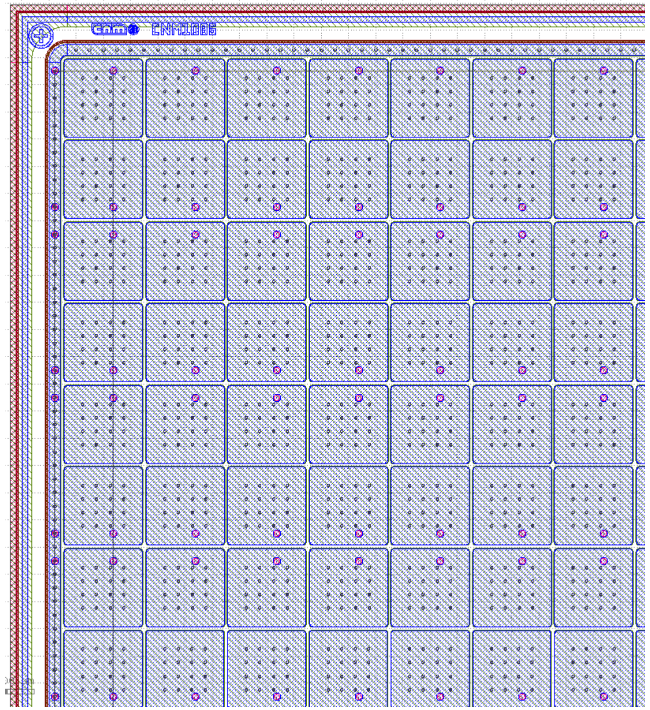
iLGAD Third Generation (iLG3): Mask Design

1. **Timepix3**: 55x55 pitch, 256x256 pixels
2. **TDCpix**: 300x300 pitch, 40x45 pixels
3. **UZH-PSI**: 100x100 pitch, 30x30 pixels
4. **iStrip:** 100x100 pitch, 75 strips

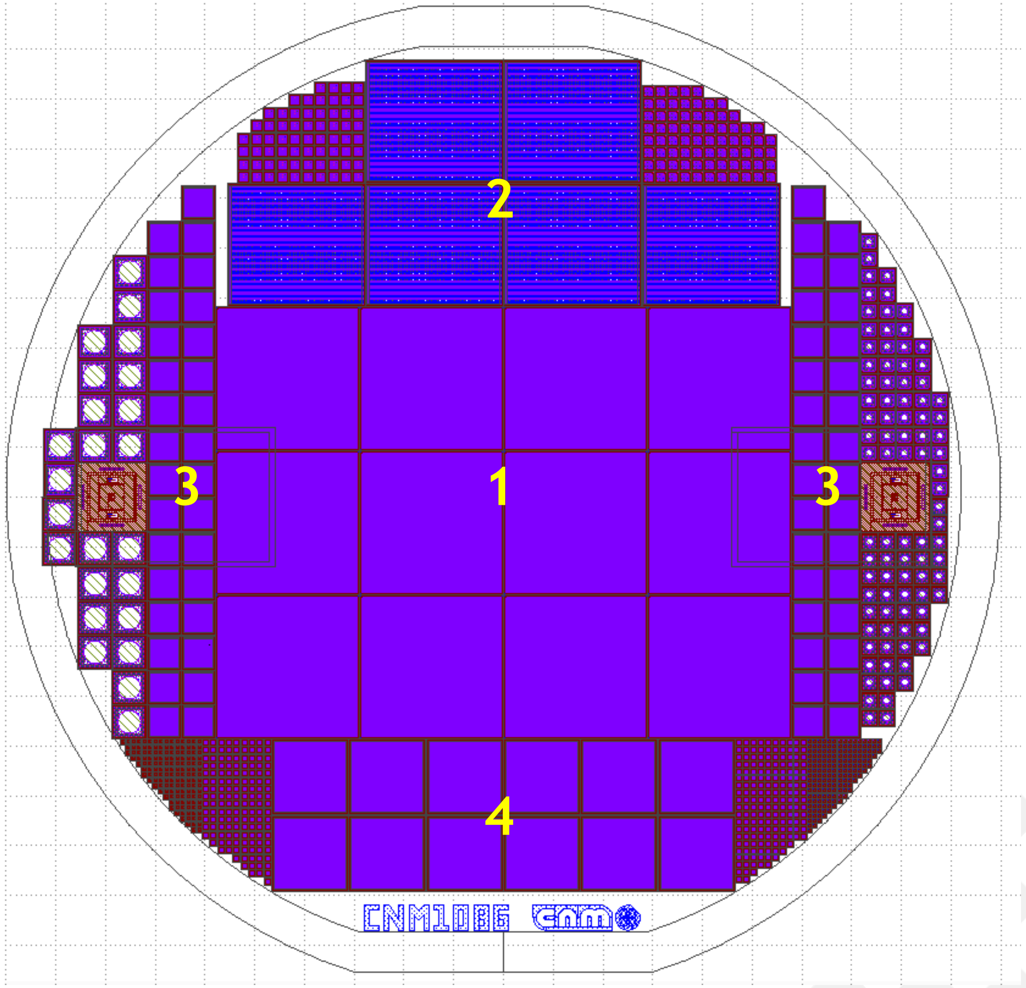
Timepix3



TDCpix



Wafer Layout



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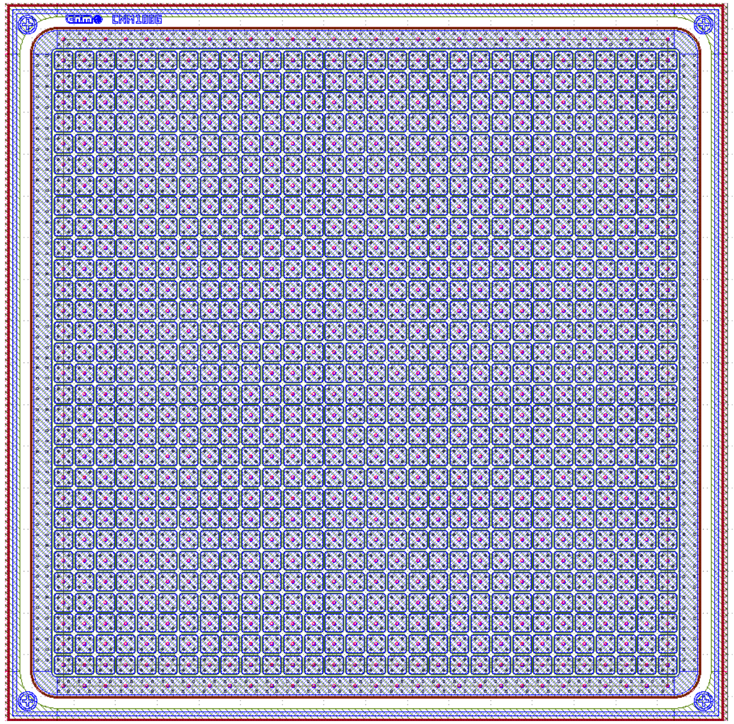
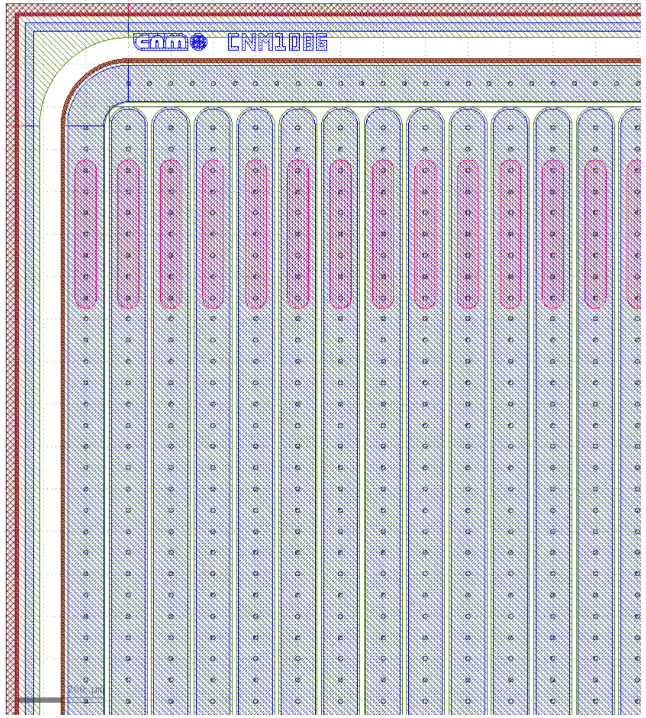
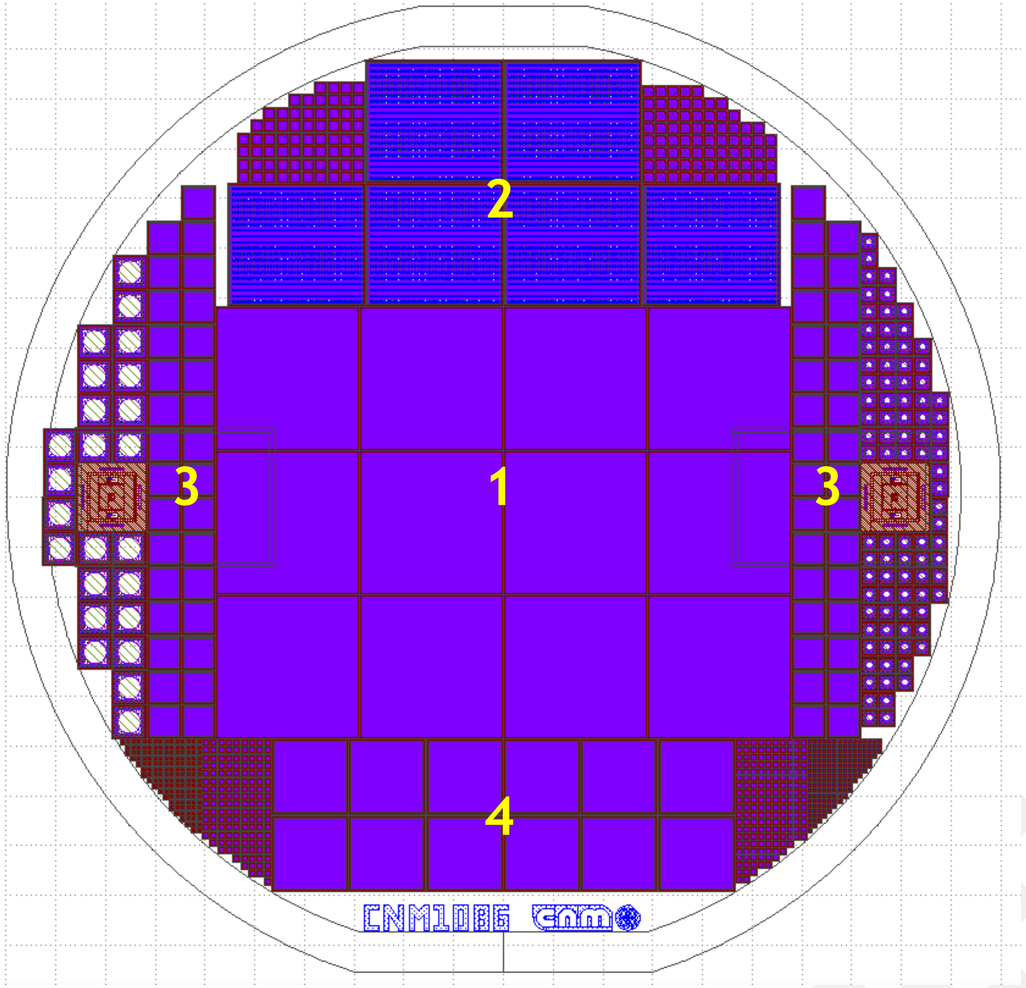
UZH-PSI



iStrip



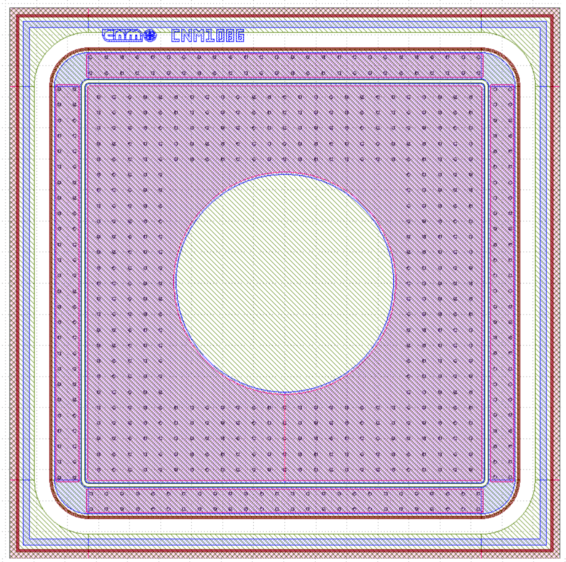
Wafer Layout

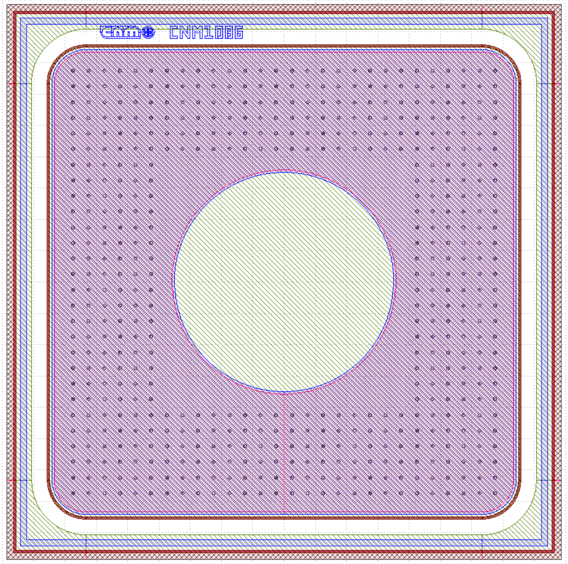


iLGAD Third Generation (iLG3): Mask Design

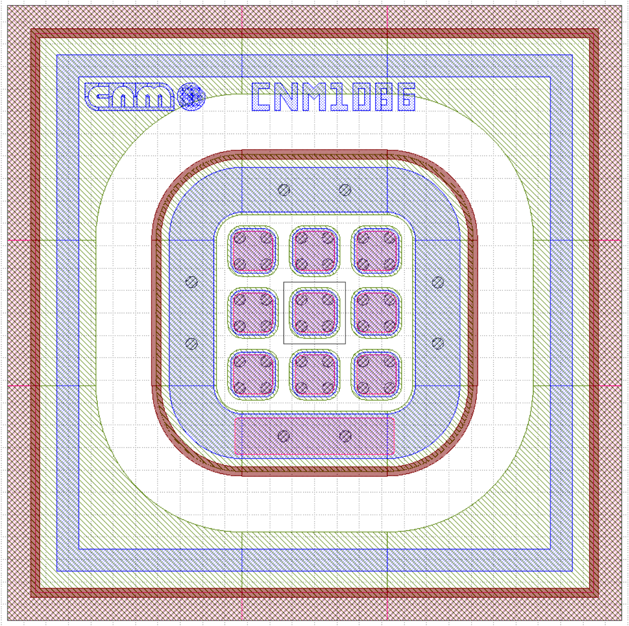
- LGAD Pad Detectors (3x3 mm^2,1.3x1.3 mm^2)
- 3x3 Test Structures
- MOS Structures
- Technological Test Structures

Pad Trench LGAD

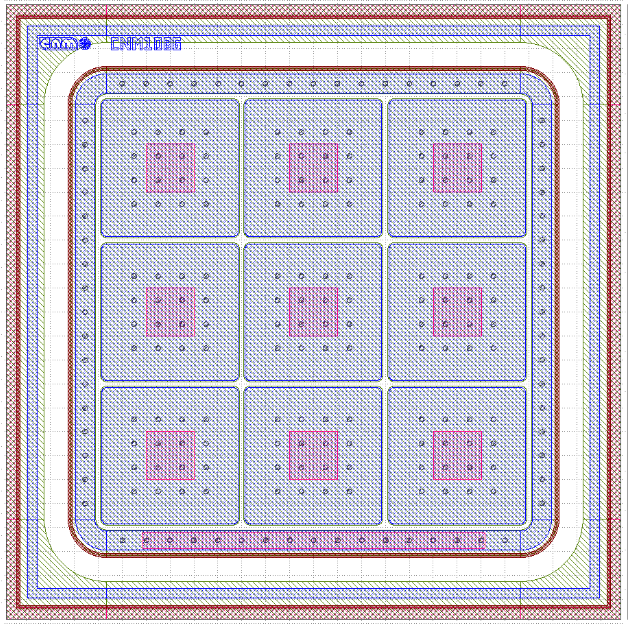




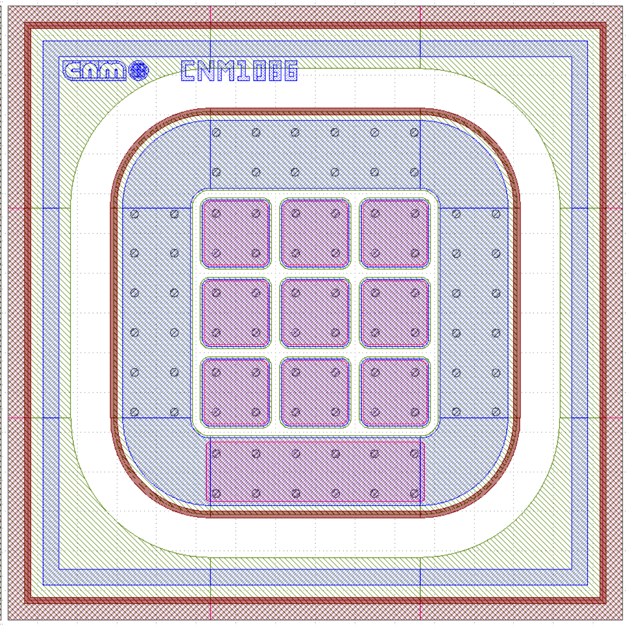
3x3 TiLGAD



3x3 Timepix3



3x3 TDCpix



3x3 UZH-PSI

iLGAD Third Generation (iLG3): Work Plan

- Epitaxial and Si-Si Wafers are purchased and delivered
- Technological simulations are ready
- The process technology steps are ready
- We are designing the mask set
- Work Planning:
    - Mask Design
        - End of February 2021
    - Mask Fabrication
        - Mid-March 2021
    - Fabrication
        - Some clean room processes will not available until mid-April 2021
        - Fabrication will start at the end of April 2021
        - Fabrication will be completed by the end of September 2021

Conclusions and Future Work

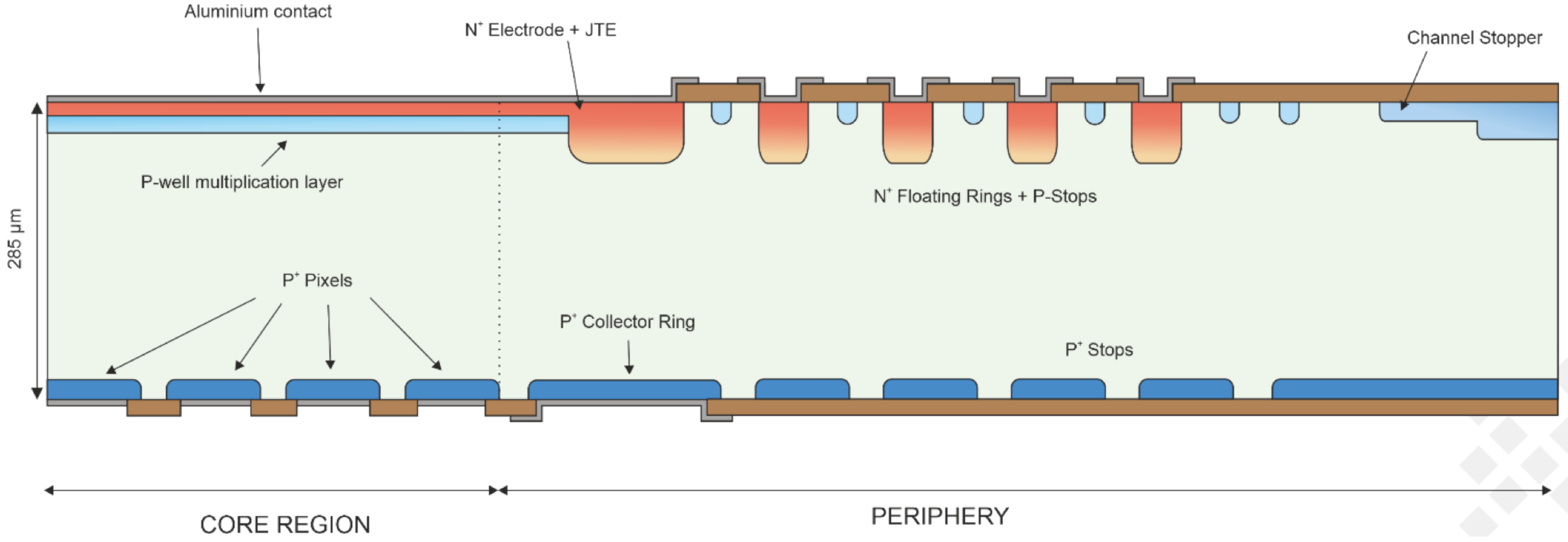
- Inverse LGAD concept has been considered as 4D tracking sensor.
- First iLGAD generation (iLG1) has been successfully fabricated and show promising results.
- Third iLGAD generation (iLG3) has been described. We expect to use these sensors for timing applications.
- TCAD simulations has been performed to obtain a suitable periphery to sustain high voltages and reducing the fabrication time.
- Fabrication is going to be done with two different types of wafers: epitaxial and Si-Si wafers.
- Currently, we are designing the mask set.
- The run will start by end of April 2021.
- By end of 2021, we will have the run fully characterized and samples will be distributed.

Thank you for your attention!

BACK UP SLIDES

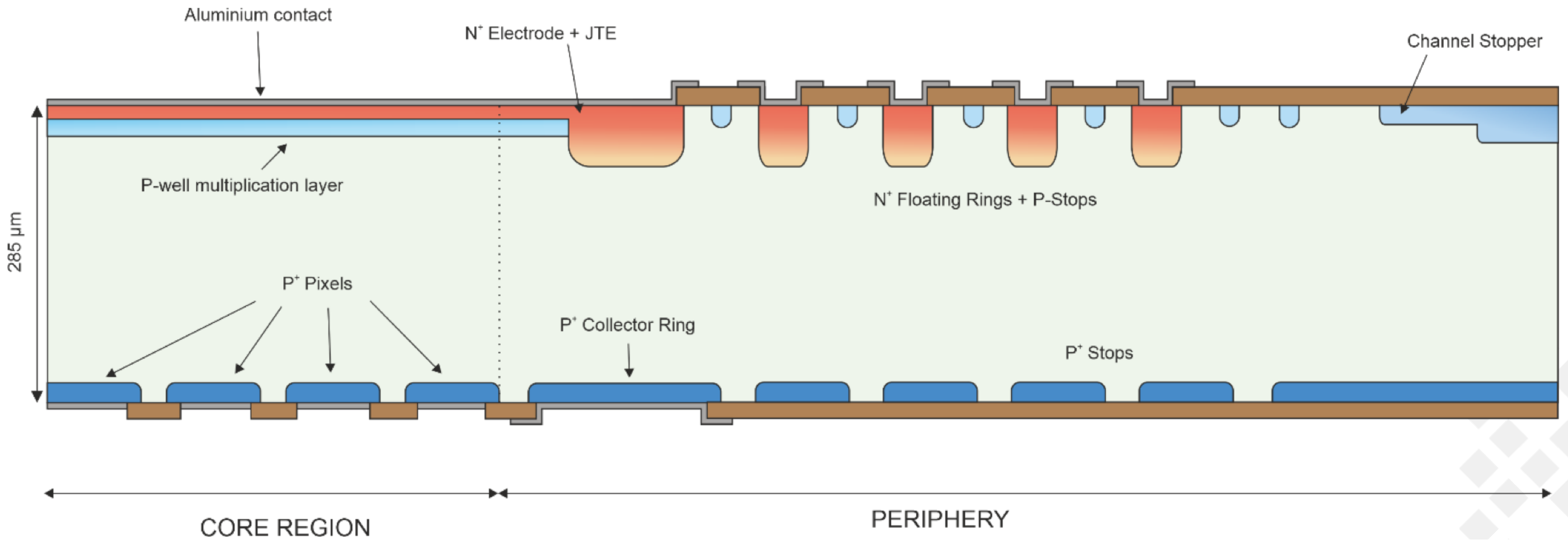
iLGAD Second Generation (iLG2)

- Segmentation at the **ohmic contact**: strip and pixels.
- **Multiplication** extended over all the **CORE**.
- **P-type collector ring** at the ohmic side to extract leakage current.
- **JTE** to protect the n+/p curvature and **channel stopper** to avoid the depletion reaches the end of the detector.
- Readout is made by the strips/pixels: **holes collection**.

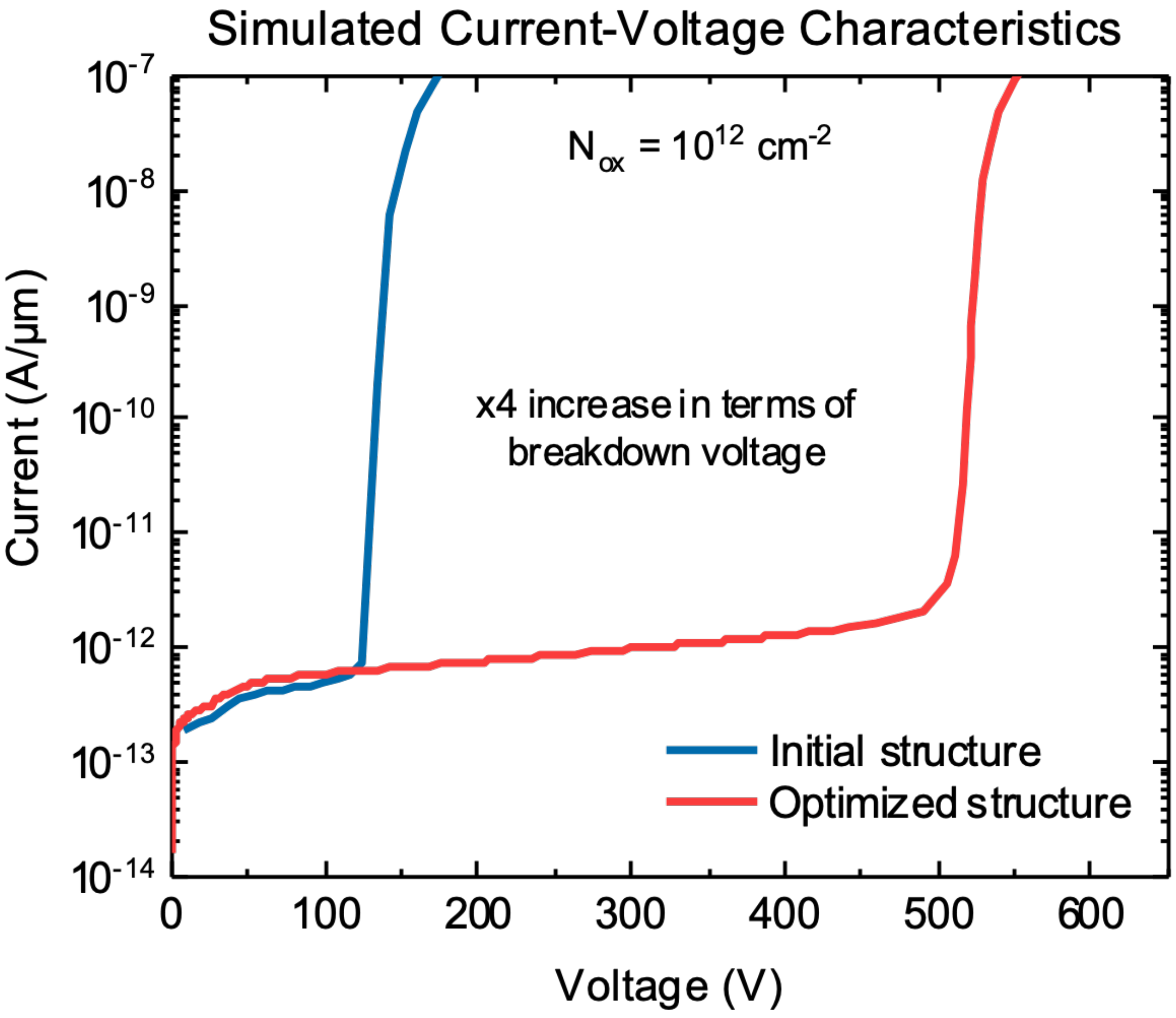


iLGAD Second Generation (iLG2)

- **Multi-Ring structure** at both multiplication and ohmic side.
- Periphery optimized for **synchrotron irradiations**.
- Rings at the ohmic side avoid high **electric fields peaks** due to **a high oxide charge density** created at the $Si\text{-}SiO_2$ interface by the X-Ray irradiation.



iLGAD Second Generation (iLG2)

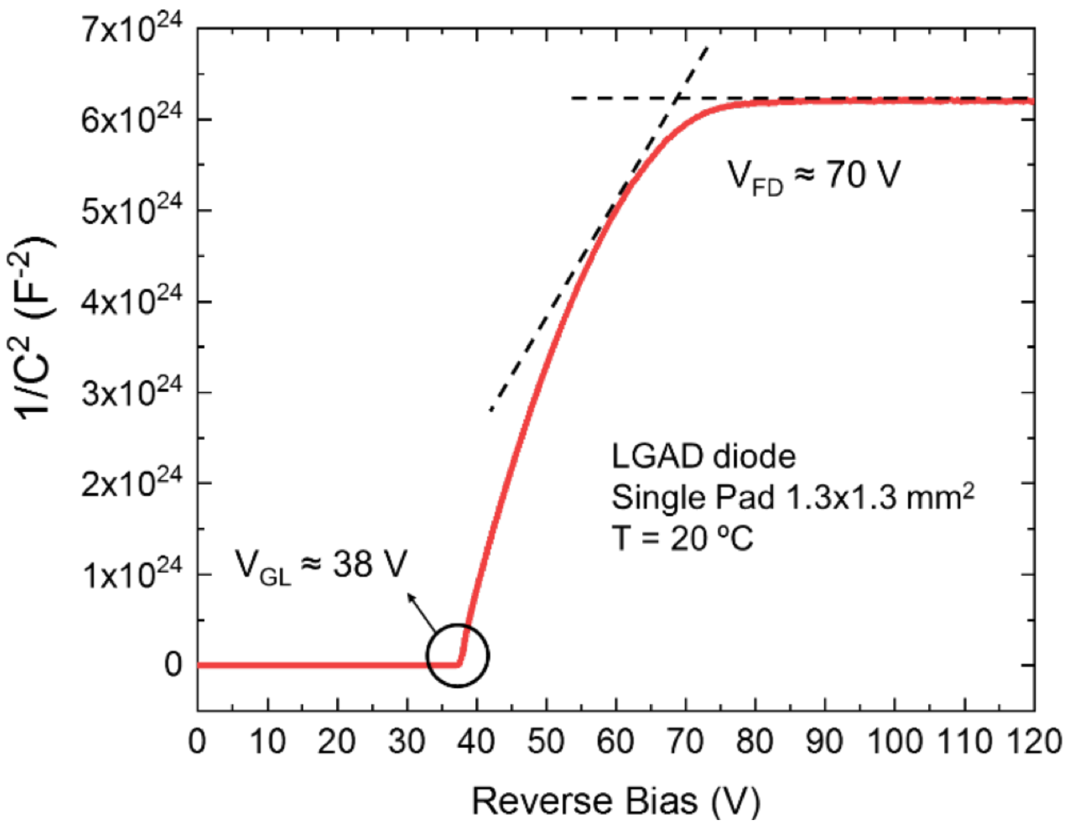


TCAD Simulations show a better performance in terms of breakdown for the iLG2 compared to the iLG1 with a high oxide charge density at the Si-SiO2 interface

iLGAD Second Generation (iLG2)

Electrical Characterization Unirradiated samples

C-V Measurement



I-V Measurement