Technological Developments on iLGAD Detectors for Tracking and Timing Applications

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IFCA

Centro Nacional de Microelectrónica CSIC

Outline

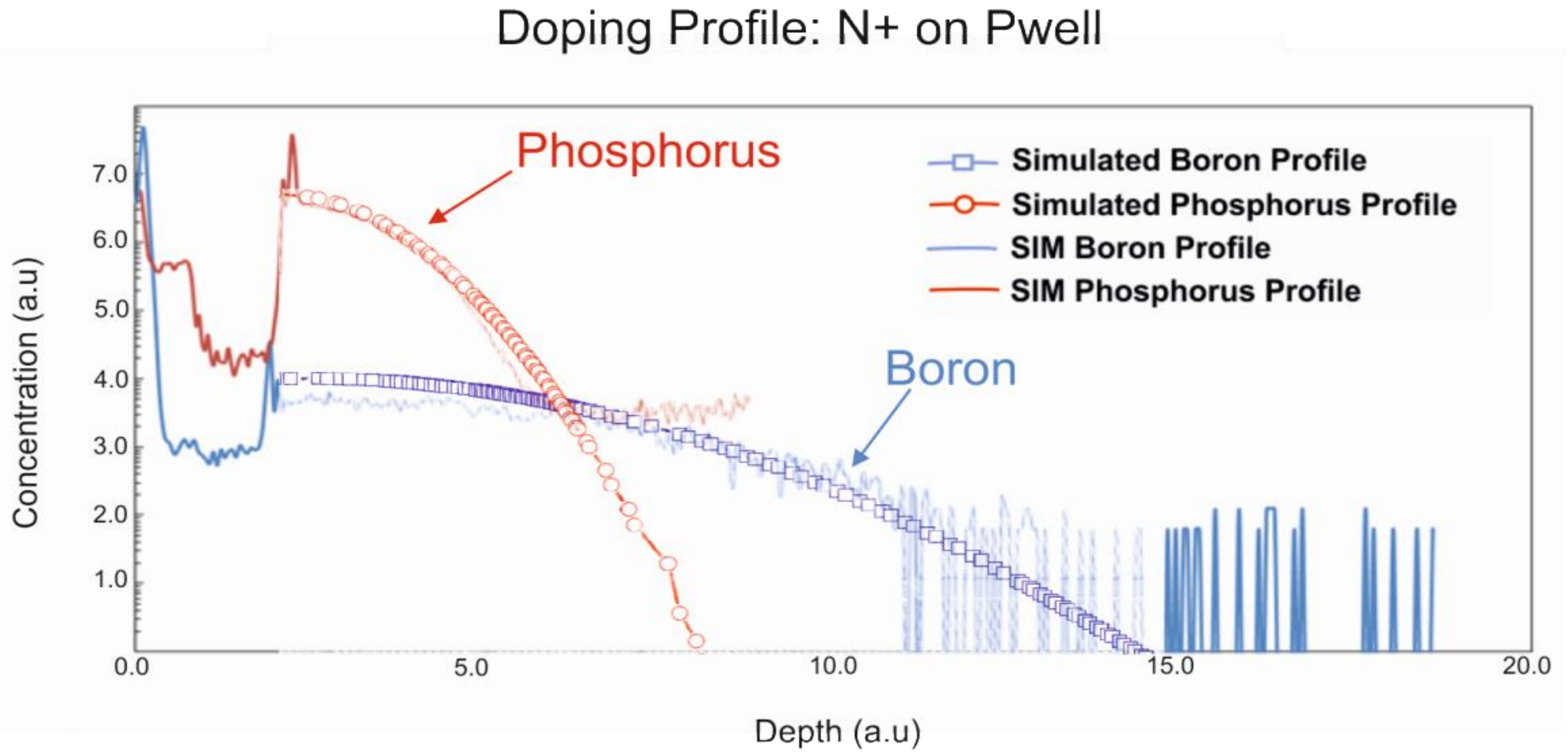
- Motivation
- Optimized Simulation
- iLGAD Structure
- iLGAD 2D Simulation
- Mask Set
- Technological Process
- First Measurements
- Conclusions

iLGAD Motivation

- Integrate a small gain (5-10) in a sensor while maintaining similar noise levels and avoiding readout front-end saturation & pile-up effects.
- Adjust the LGAD Simulation Model that reproduces the experimental data obtained from our devices.
- Take advantage of our well stablished LGAD technology process to fabricate position-sensitive detectors with a uniform electric field along the device.
- This kind of devices allows us to reduce the substrate thickness in order to develop a low-mass tracking systems with thinner microstrips sensors conserving the same SNR.
- iLGAD structures could be interesting for tracking and timing applications, as well as for primary interaction vertex or medical applications.

Optimization of LGAD Simulation

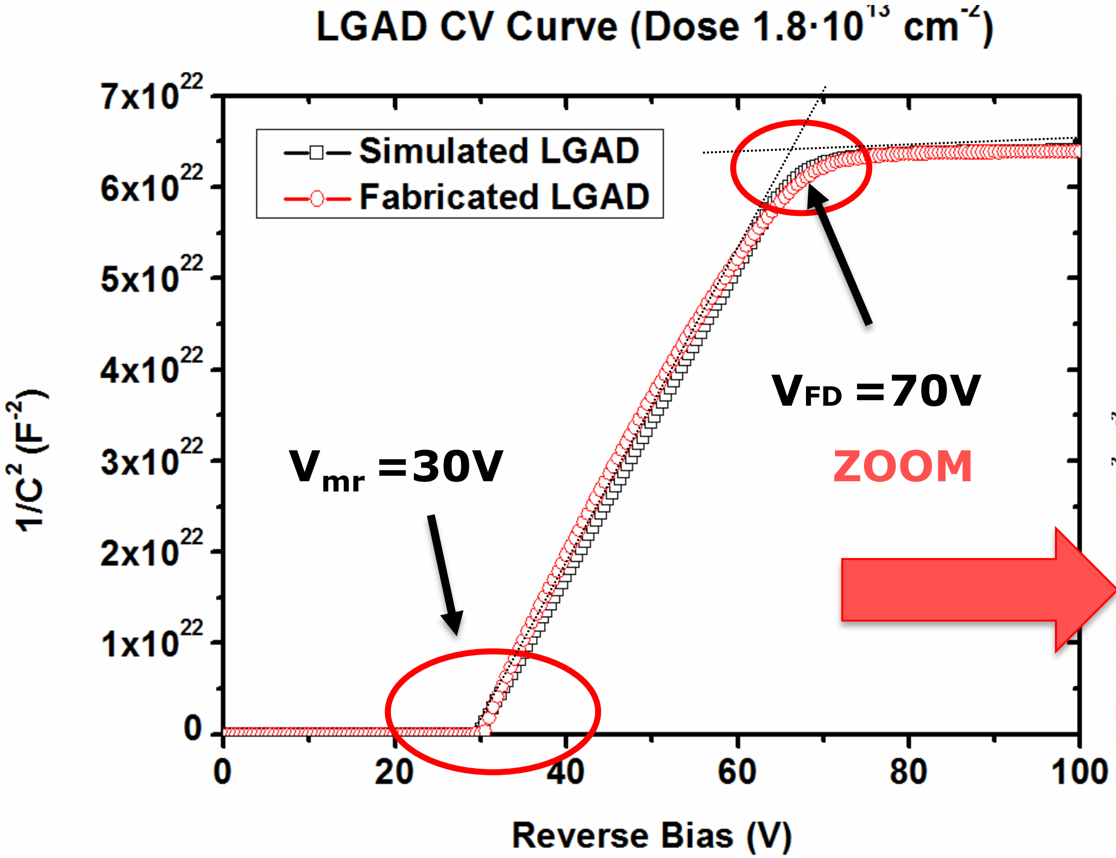
- **1ST Step:** we compare the Doping profile obtained by SiMs with the Doping Profile obtained in the Process Simulation. Our Process simulation overestimates the Phosphorus junction depth and the Boron peak. We have adjusted the models in order to reproduce the same profiles obtained by SiMs.



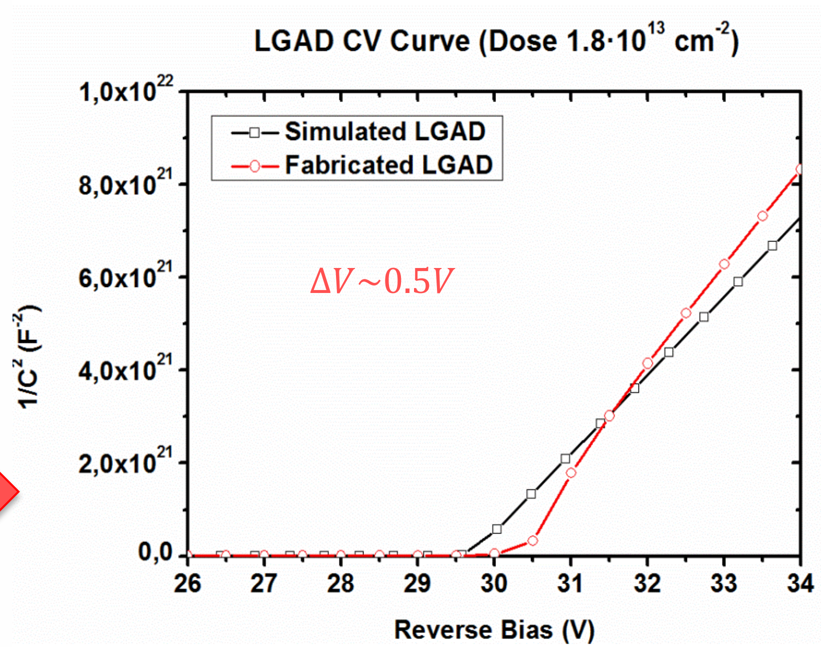
V.Gkougkousis, LGAD and irradiated doping Profiles, 27th RD50 Workshop, CERN, December 2015

Optimization of LGAD Electrical Simulation (TCAD Synopsys)

- **2nd Step:** The new Simulation Model is validated by C(V) simulation & experimental data (measured at the CNM Radiation Lab). Both of them have the same multiplication layer depletion Voltage @ 30V & the same full depletion Voltage @ 70V.

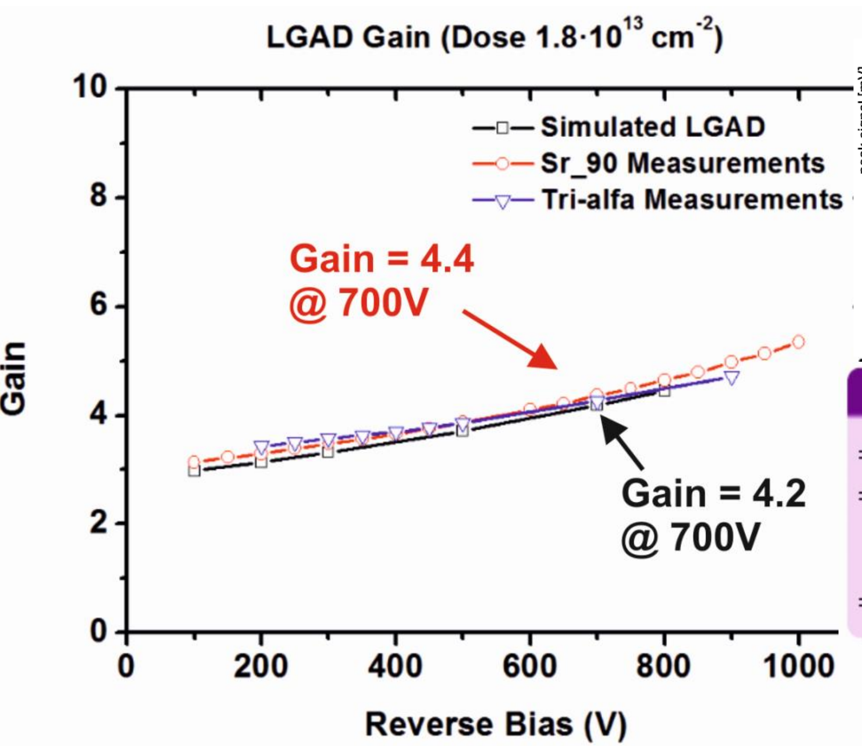


Foot Zoom

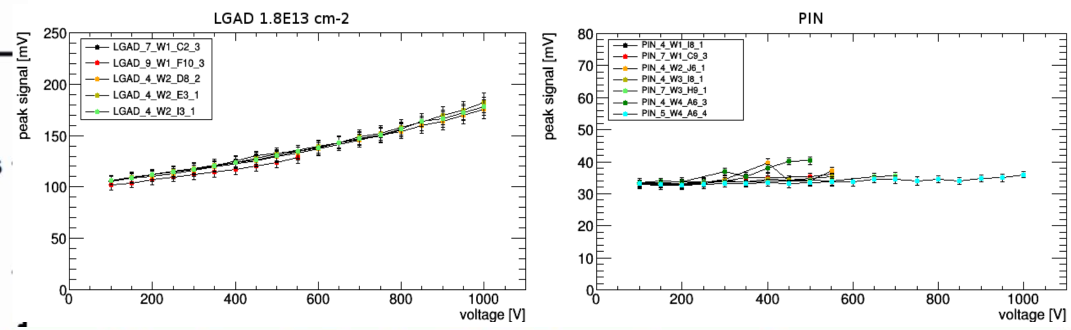


Optimization of LGAD Simulation

- **3rd Step:** We compare the Gain Simulation with the experimental Gain (measured at the CNM Radiation Lab with a tri-alfa source), as well as with the experimental MIP data (measured at CERN).



CERN Measurements:



Gain values obtained at 700 V for each type of measurement

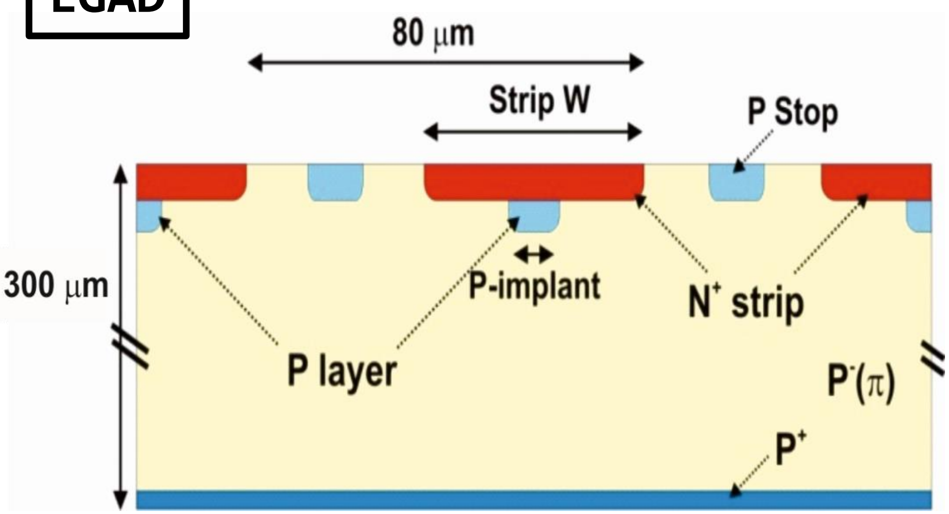
	TCT – IR back	TCT – Red back	TCT – Red front	Sr-90
1.8×10^{13} cm^{-2}	5.7	6.2	4.3	4.4
2.0×10^{13} cm^{-2}	W3 = 31.9 W4 = 25.7	21.4	W3 = 10.6 W4 = 12.9	11.7

Otero.S; Characterization of LGAD Sensors CNM Run7859, RD50 –December 2015

Segmentation. Two approaches

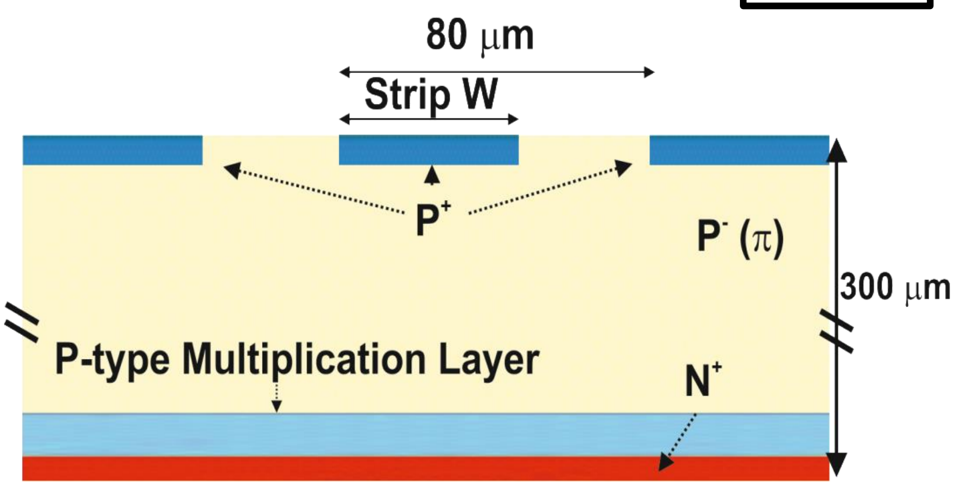
- **Single-side approach : N on P** microstrips with a P-type multiplication layer below the segmented N^+ implant.
- **Double-side approach: P on P** LGAD with pad-like multiplication structure in the back-side and ohmic read out strips, or pixels, in the front-side.
- The collecting current is dominated by holes instead of electrons.
- N on P vs P on P LGAD microStrips Comparison

LGAD



N on P MicroStrips

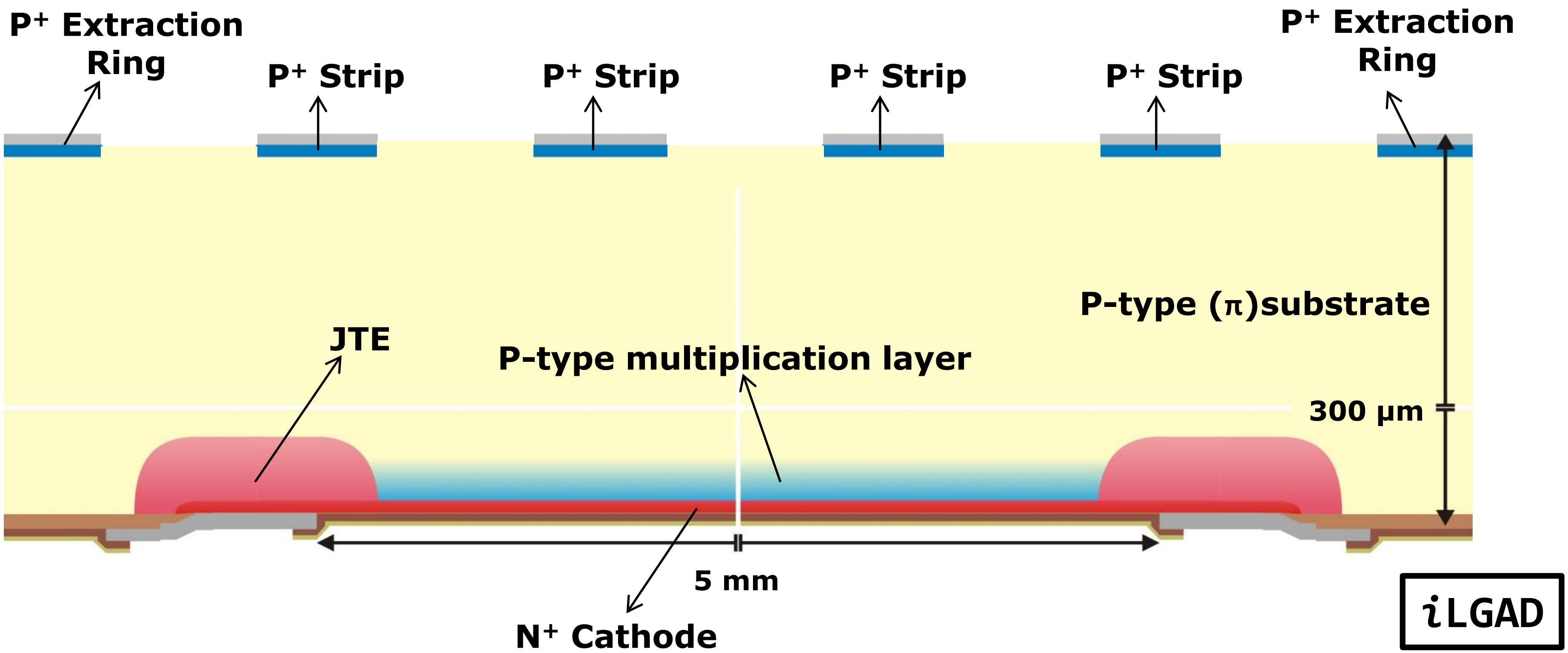
iLGAD



P on P MicroStrips

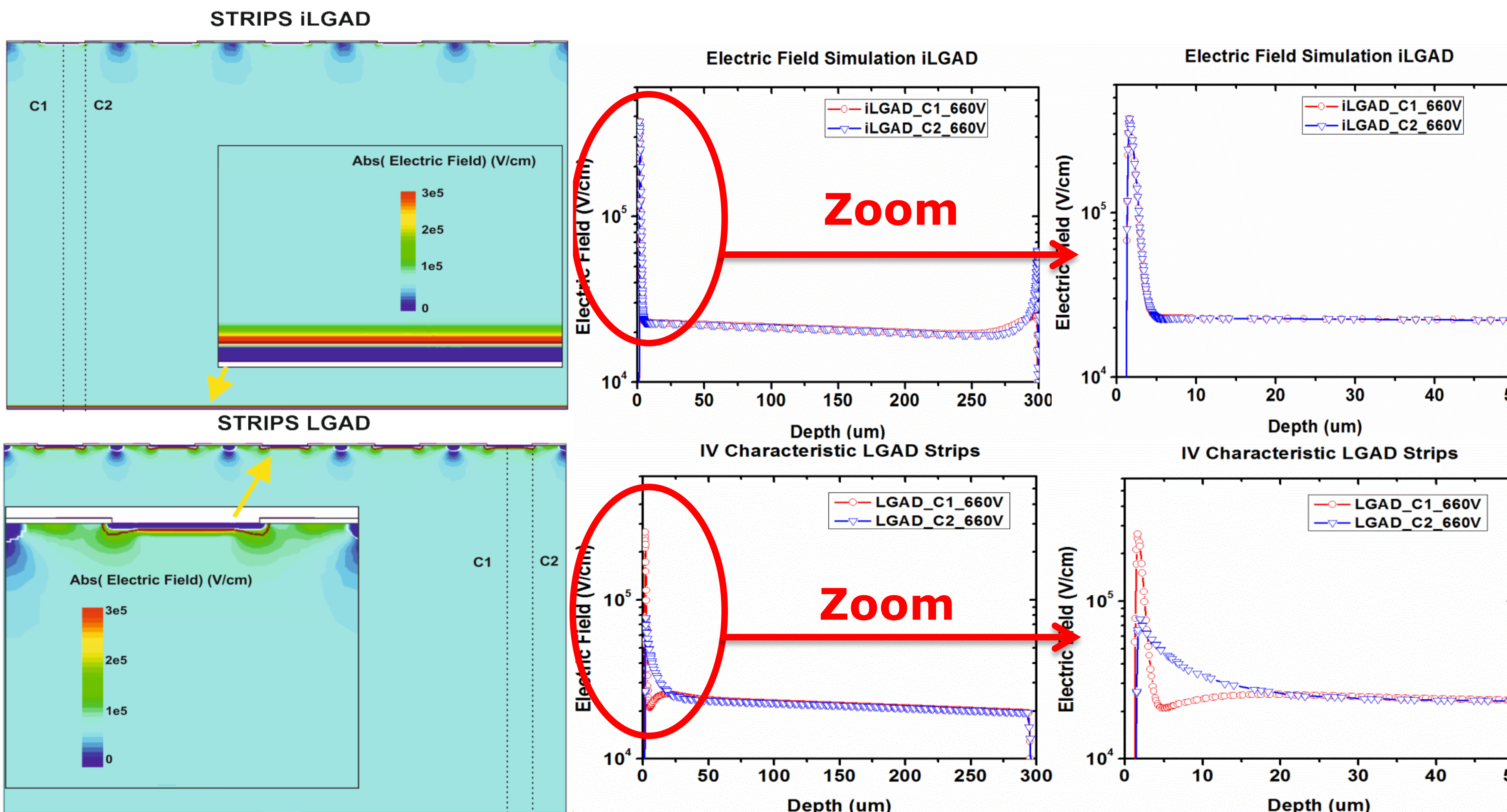
P on P Strip iLGAD: The "inverse" LGAD

- The confined **uniform electric field** that occurs in the core region of a LGAD activates the multiplication mechanism, and amplifies the signal value.
- **JTE** to ensure high voltage capability of the structure
- **P+ Extraction Ring** to collect the peripheral leakage current
- **First Batch** Including Pad, microStrip and pixel i**LGAD** layouts



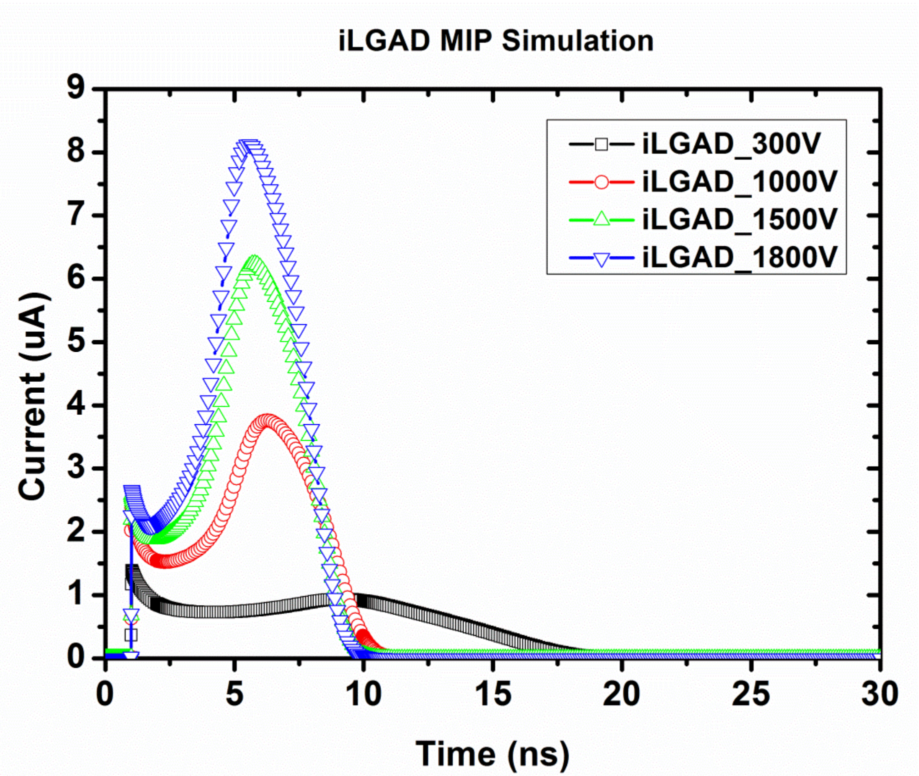
2D Simulation. Electrical Performance (300um thickness)

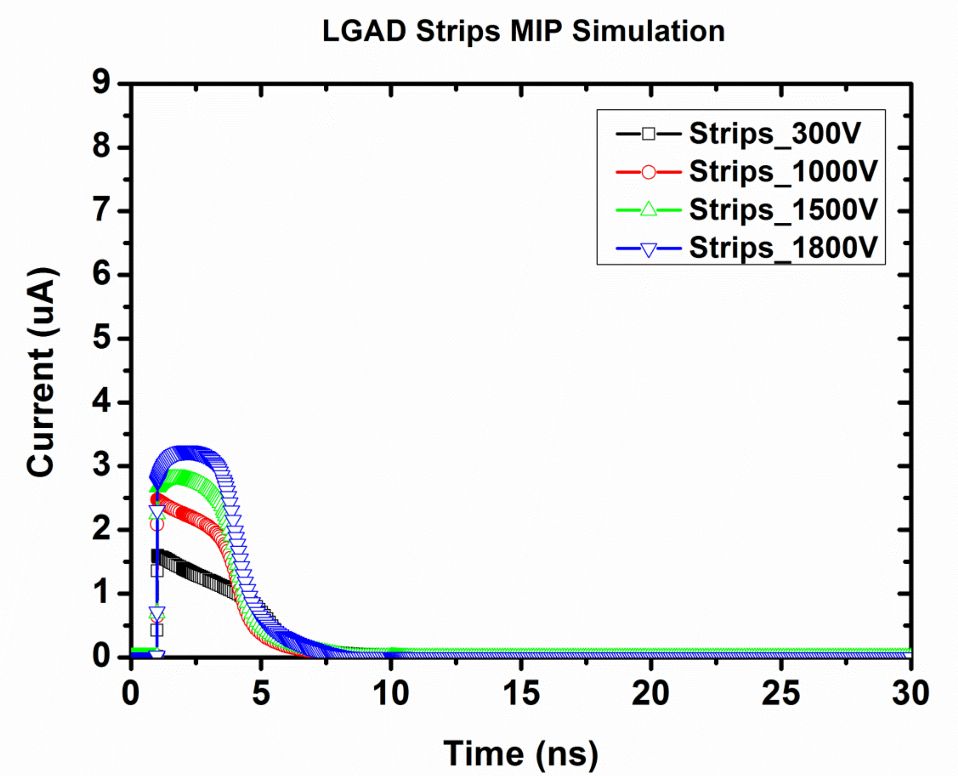
- Five microStrips. Electric Field Distribution. Maximum value @ P-N Junctions.
- More uniform electric field distribution for the iLGAD.



2D Simulation. MIP (300 um Thickness)

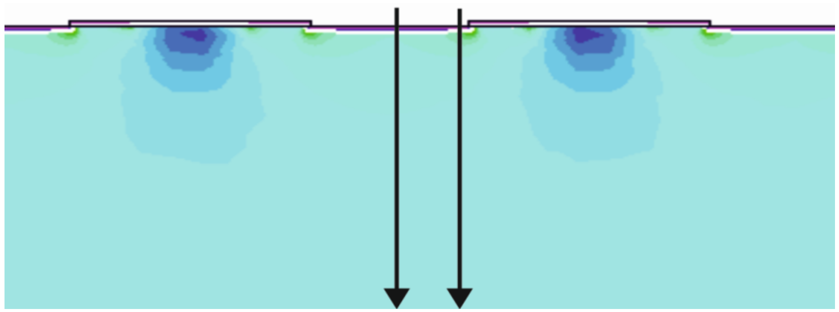
- **MIP** through the middle of the central strip
- Signal amplification increases with the voltage meanwhile Collection time decreases with the voltage
- iLGAD shows larger collection time than LGAD due to the fact that we are collecting holes.

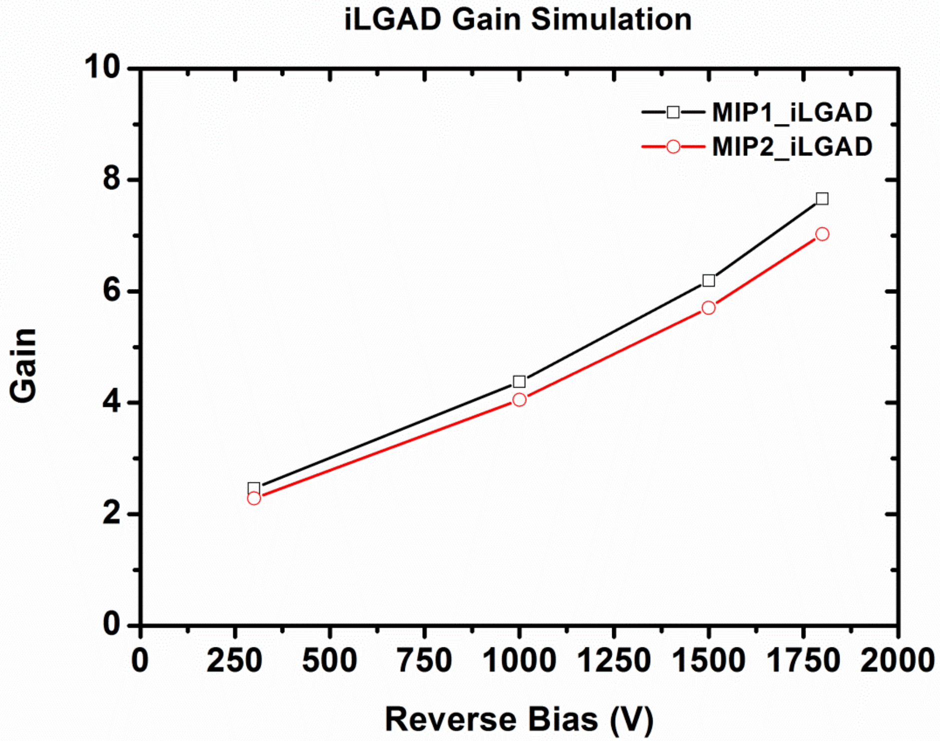


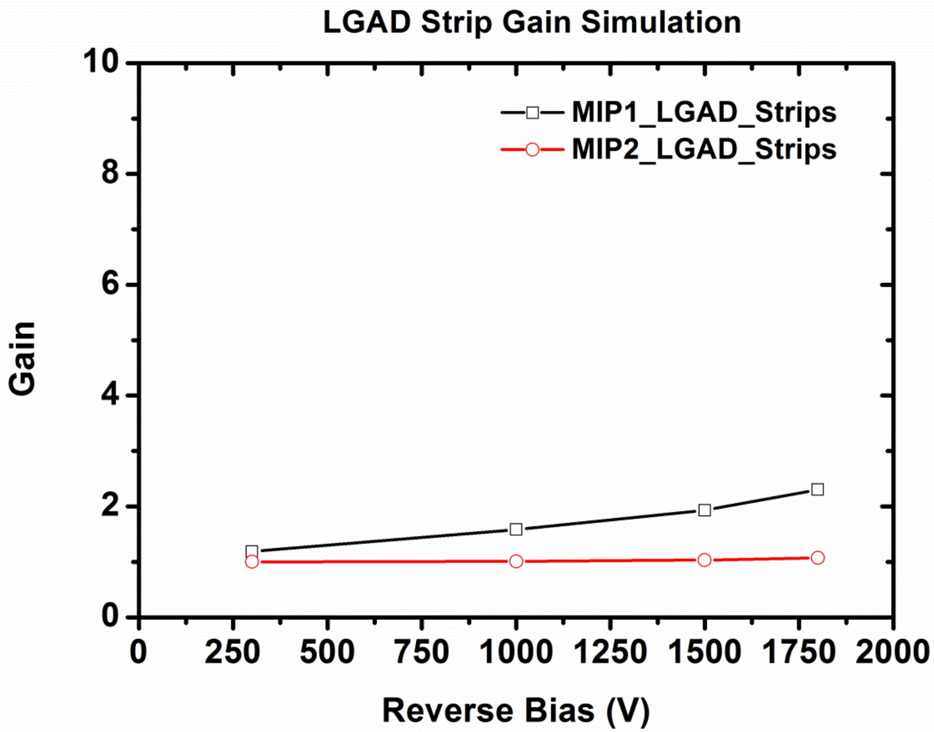


2D Simulation. MIP (300 um Thickness)

- **MIP** through the edge of the strip
- iLGAD exhibits multiplication wherever the MIP enters de structure

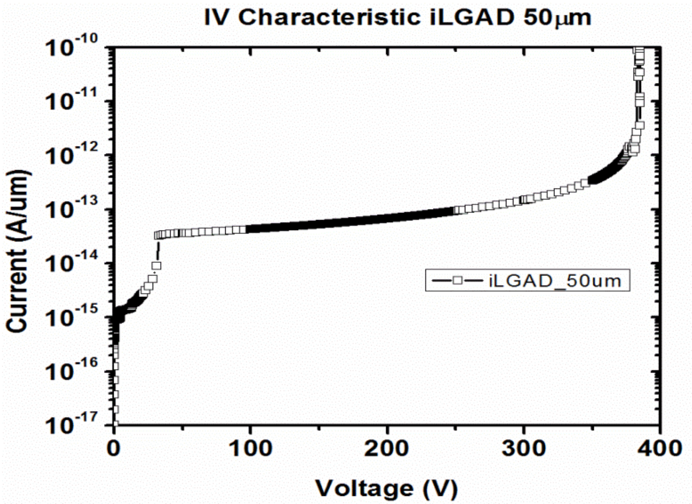


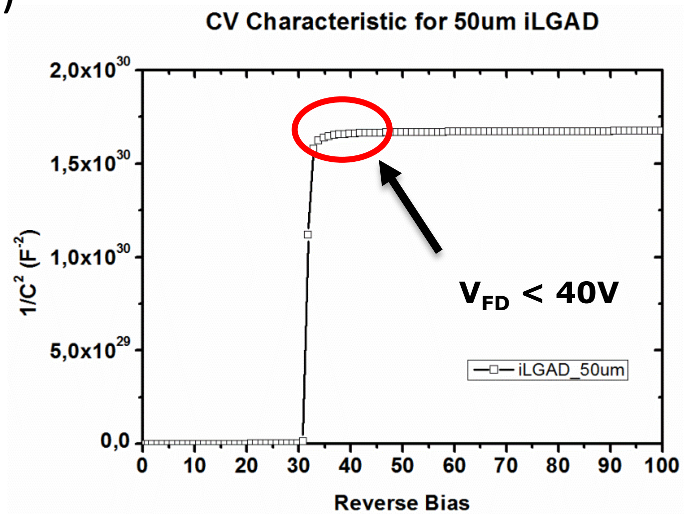


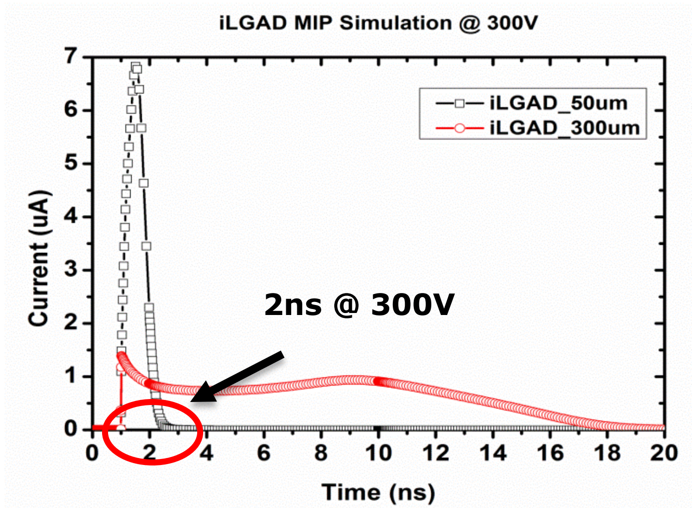


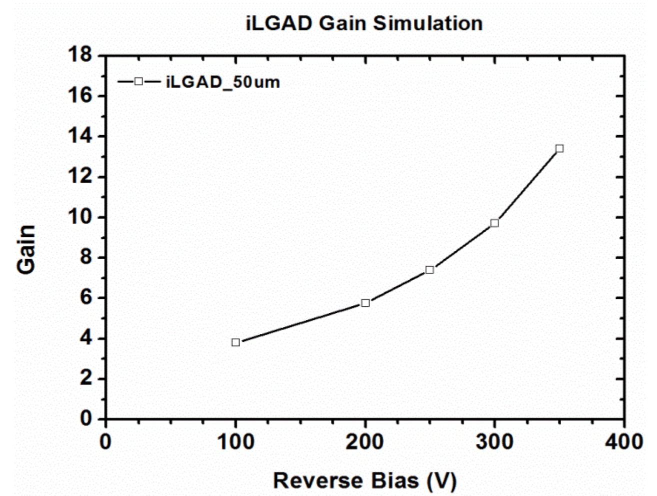
2D Simulation. iLGAD (50 um Thickness)

- Voltage capability = 380 V; Full-depletion voltage = 40 V
- Collection time decreases to 2 ns; Gain (4-13)





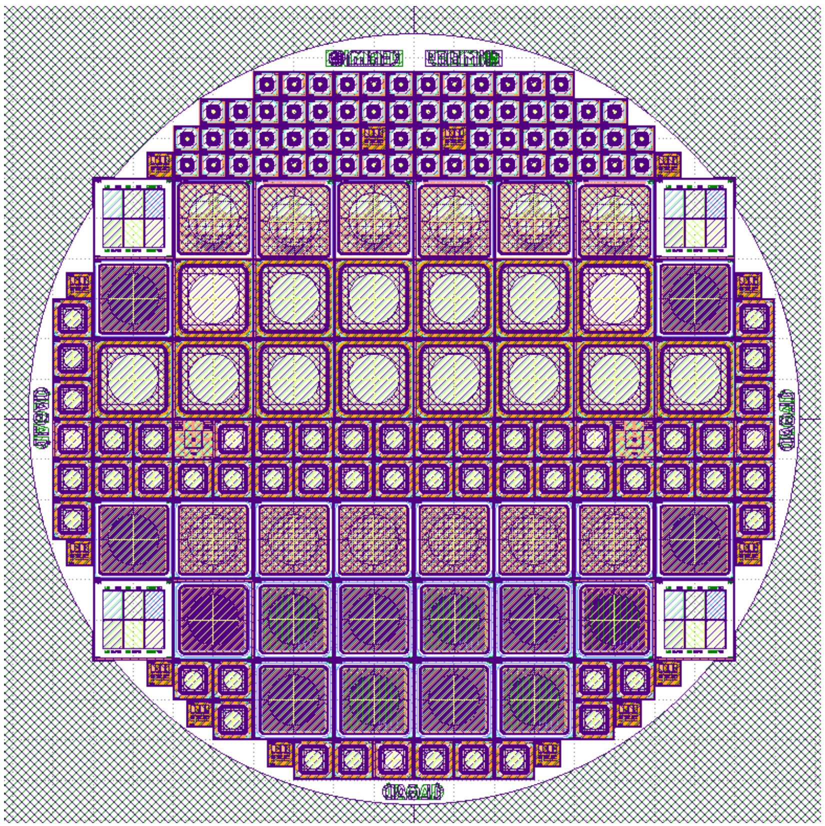




iLGAD. First Mask Set Description. Integrated Devices

iLGAD

- **176 Chips**
  - ✓ **44** (10 x 10 mm, total area)
  - ✓ **56** (5 x 5 mm, total area)
  - ✓ **76** (3.3 x 3.3 mm, total area)

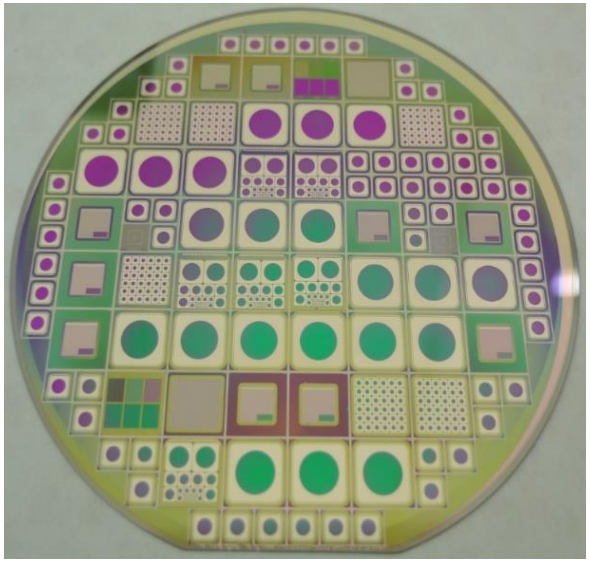


- **113** LGAD Pad Detectors
  - ✓ **12** (8 x 8 mm mult area)
  - ✓ **49** (3 x 3 mm mult area)
  - ✓ **52** (1 x 1 mm mult area)
- **17** PiN Detectors
  - ✓ **2** (8 x 8 mm active area)
  - ✓ **5** (3 x 3 mm active area)
  - ✓ **10** (1 x 1 mm active area)
- **8** iLGAD pStrips Detectors
  - ✓ **4** (45 Channels)
  - ✓ **4** (90 Channels)
- **2** PiN pStrips Detectors
  - ✓ **1** (45 Channels)
  - ✓ **1** (90 Channels)
- **6** Pixelated iLGAD Detector (6 x 6 pixels)
- **4** Pixelated iLGAD MediPix Detector (145 x 145 pixels)
- **6** iLGAD for Timing Applications
  - ✓ **3** (720 μm to cut line)
  - ✓ **3** (370 μm to cut line)
- **4** Specific Test Structure (SPR,SIMS,XPS)
- **16** CNM Test Structures (Microsection, CBR, Kelvin, Capacitors, Diodes)

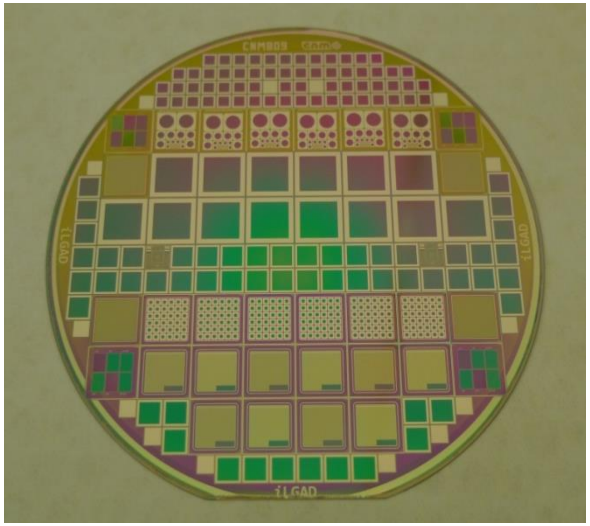
LGAD and iLGAD Fabrication Runs. At Glance

- **LGAD Run** Basic Information:
  - ✓ **Cnm761** Mask Set
  - ✓ **8** Mask Levels
  - ✓ **70** Technological Steps
  - ✓ **Single** Side Process
  - ✓ **Electron** Collection
- **iLGAD Run** Basic Information:
  - ✓ **Cnm809** Mask Set
  - ✓ **12** Mask Levels
  - ✓ **100** Technological Steps
  - ✓ **Double** Side Process
  - ✓ **Hole** Collection
- **Common** Information:
  - ✓ P-Stop to Improve Surface Isolation
  - ✓ Junction Termination Extension

LGAD

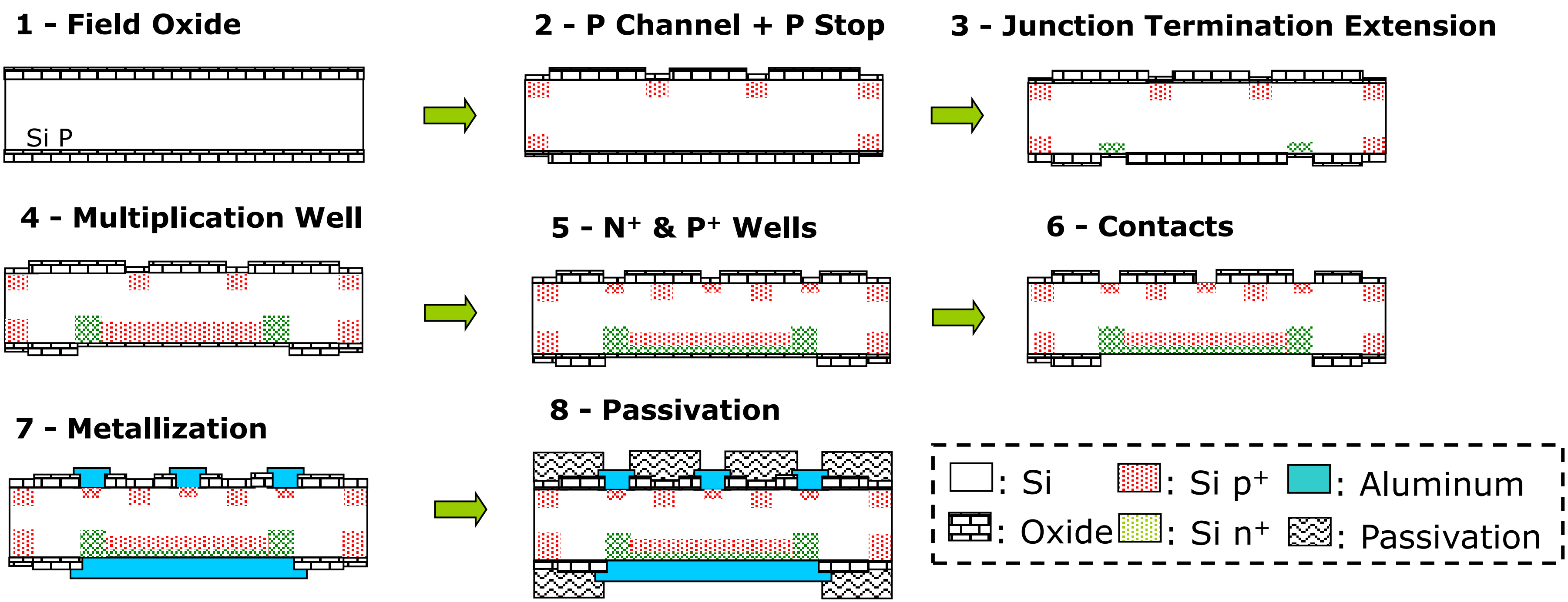


iLGAD



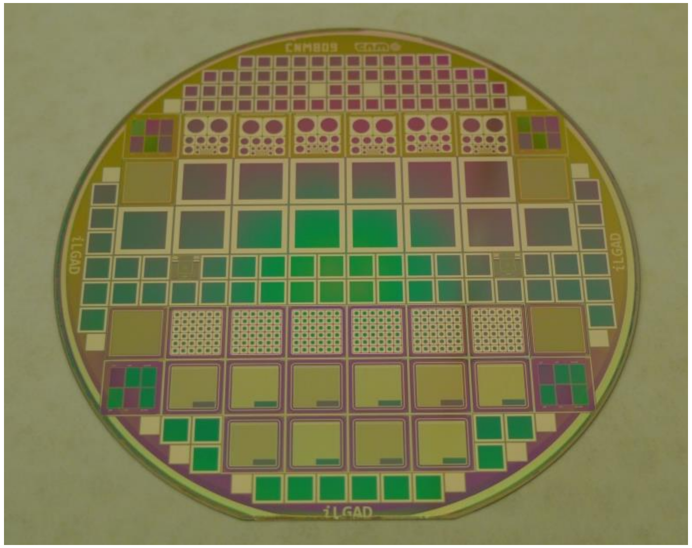
iLGAD. First Fabrication Process

- **Critical** Step
  - **Multiplication Layer** Formation
    - **Boron** Implantation 100 keV @ 1.8, 1.9 and 2.0E13 atoms/cm^2
    - Drive-in

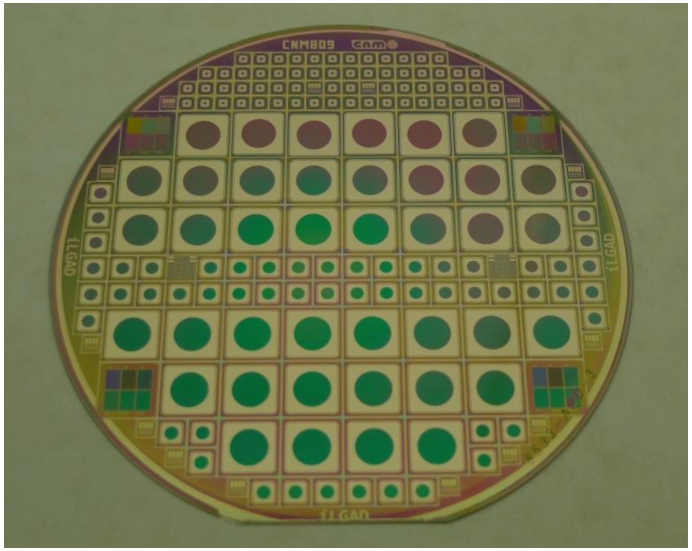


iLGAD. First Fabrication Process

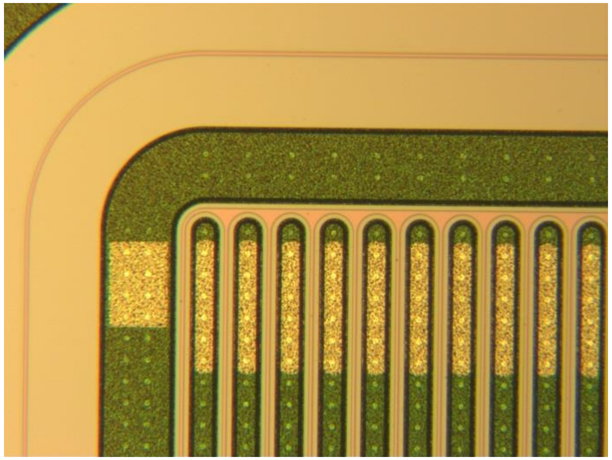
FRONT-SIDE



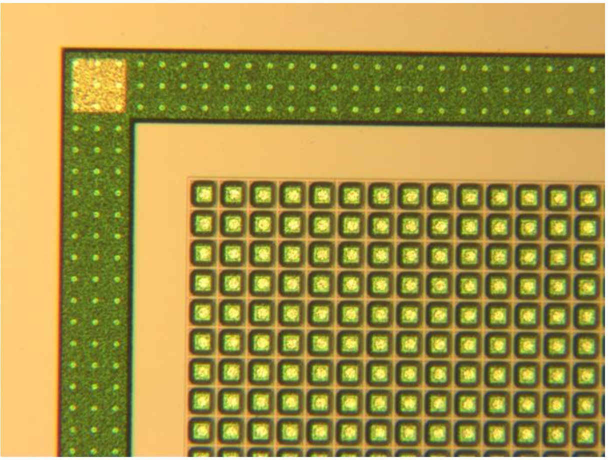
BACK-SIDE



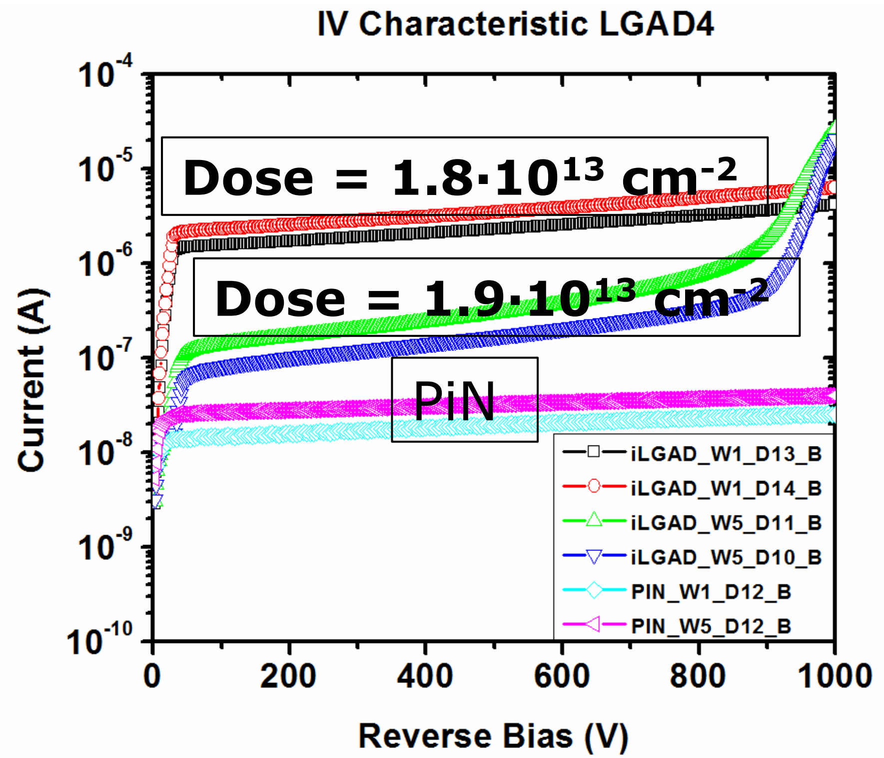
Microstrips

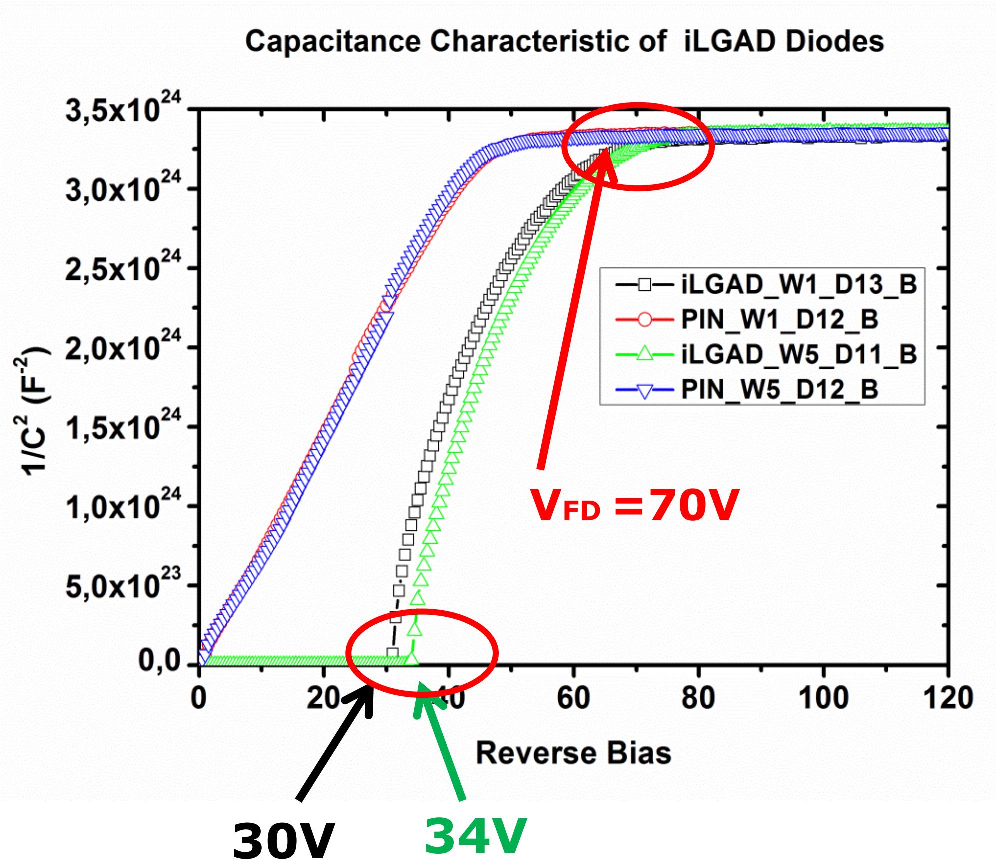


Pixel



iLGAD. First IV & CV Measurements

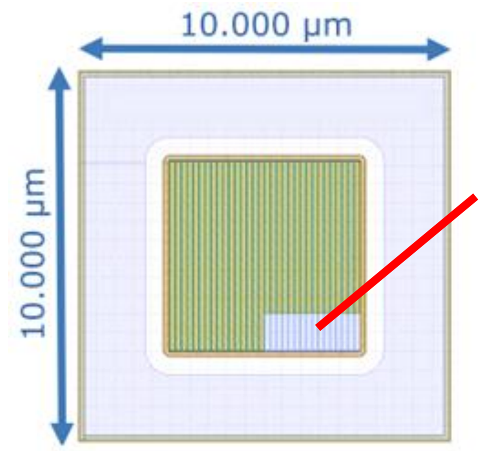


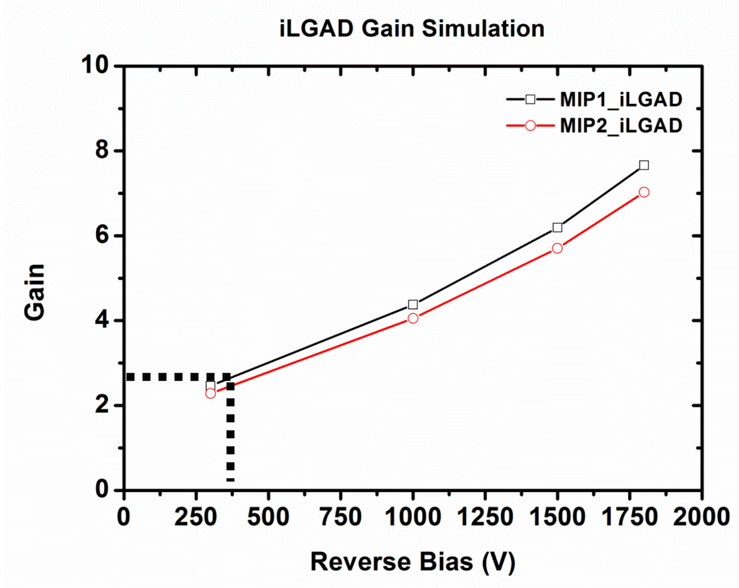


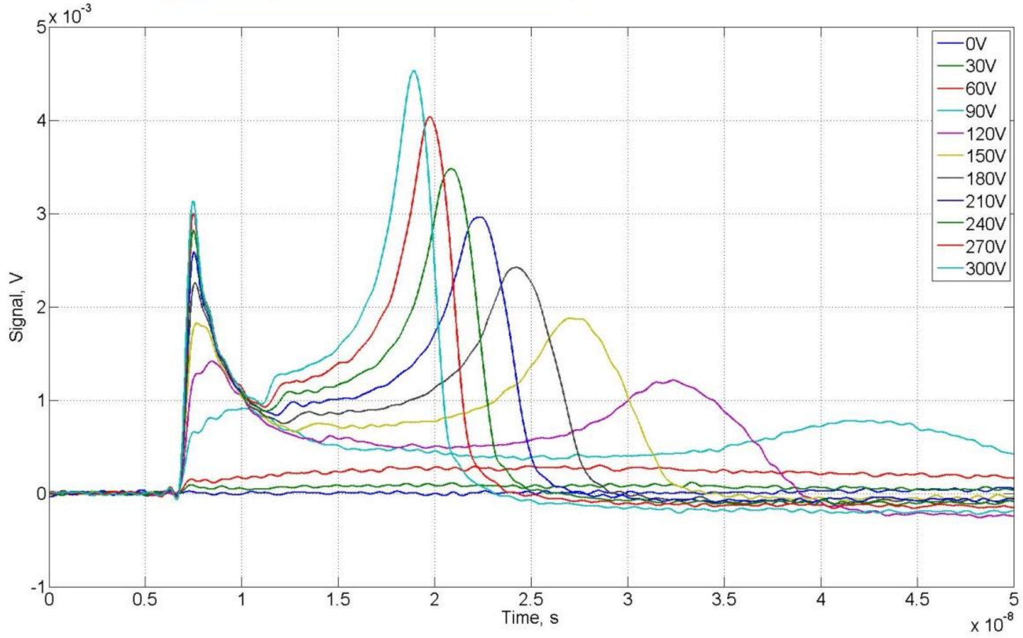
iLGAD. TCT Measurements at IFCA

- Sensors: W1-K037 (STR.45.160.8000.06.12)
- Láser: 670nm, Tune 35%
- Vbias: 0 to -300V, step:10V.
- Front-side incidence.

- **More information at Ivan Vila talk.**

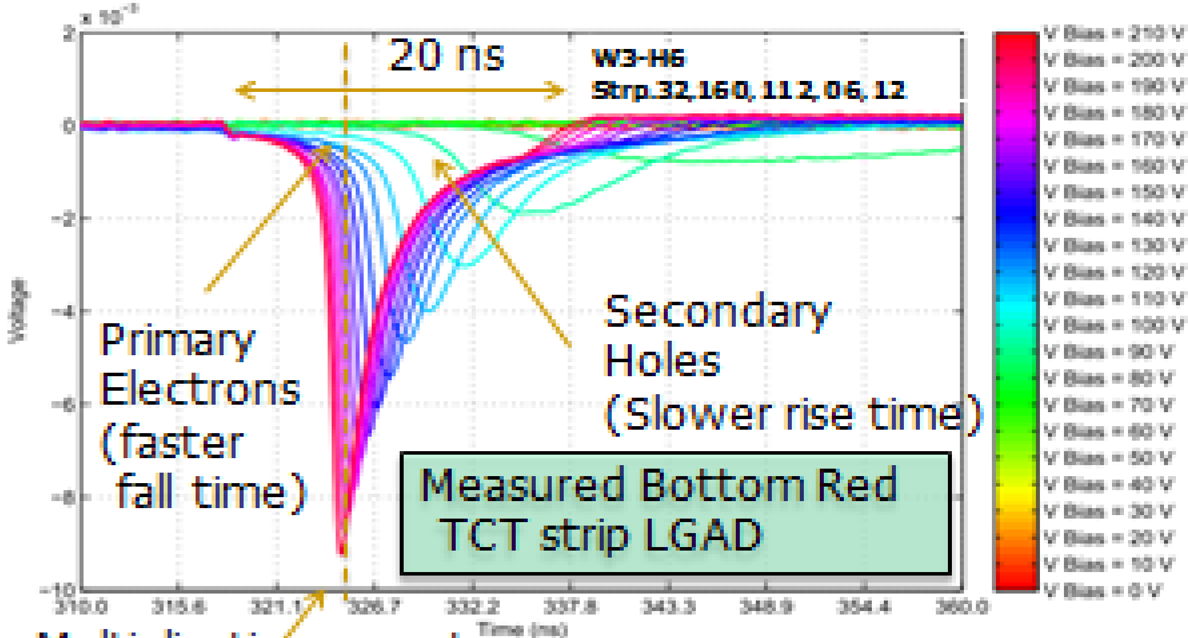


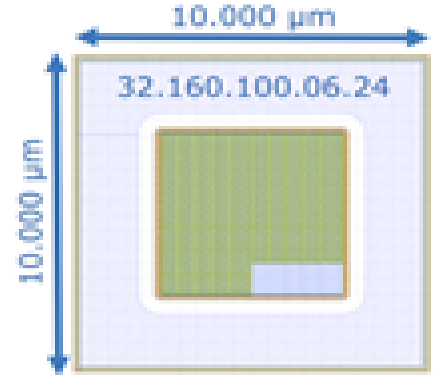


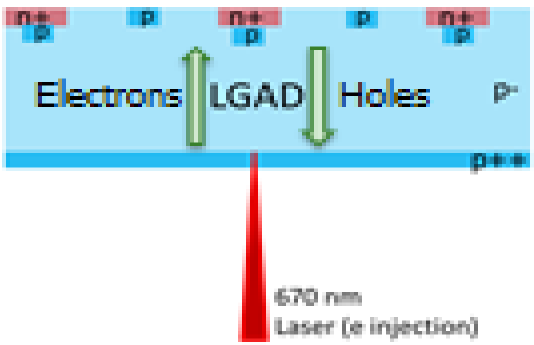


LGAD strip: back-side electron injection

- Signal gain observed:
  - Wider TCT pulses wrt to PIN
  - Charge increases vs HV
- Strip current waveform shows clear sequential electron and hole drift







*** More information at Ivan Vila talk.**

I. Vila, AIDA 2020 - WP7, 25th February 2016, Paris

Conclusions

- iLGAD designed, optimized and fabricated @ CNM

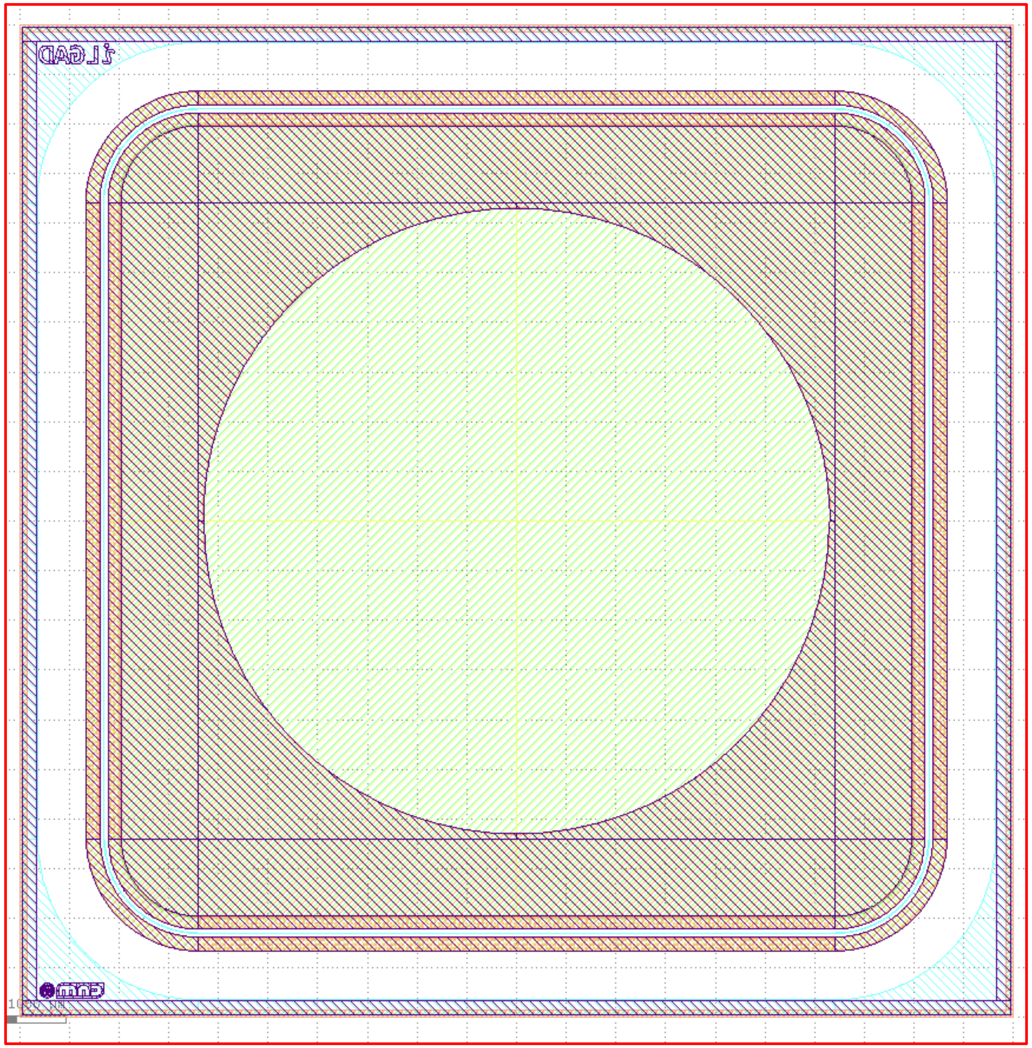
- iLGAD advantages
  - ✓ More uniform charge amplification
  - ✓ Based on a well stablished technology

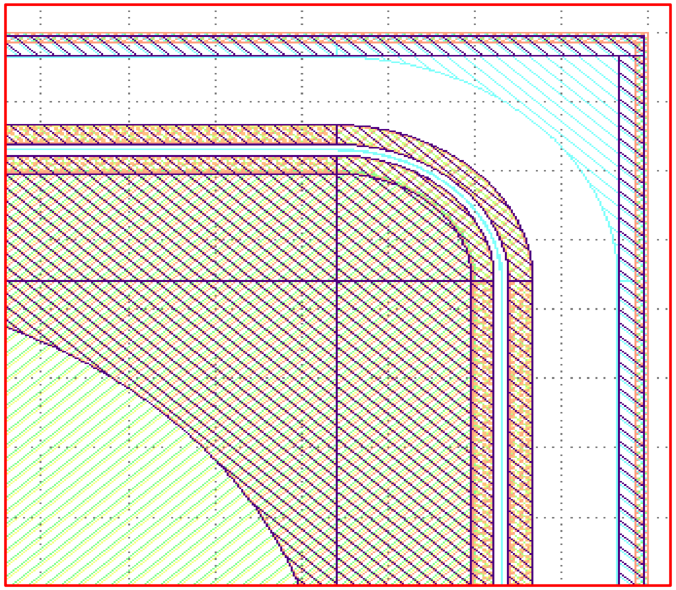
- iLGAD disadvantages
  - ✓ More complex processing (double-sided, 12 mask levels)
  - ✓ Collection current is dominated by Holes

- Future work
  - ✓ TCT Measurements at high voltages
  - ✓ Charge collection measurements
  - ✓ Timing measurements
  - ✓ Radiation Hardness
  - ✓ Simplification of the technological process

Thank you for your attention !!!!

iLGAD. First Mask Set Description. LGAD, PiN Pad





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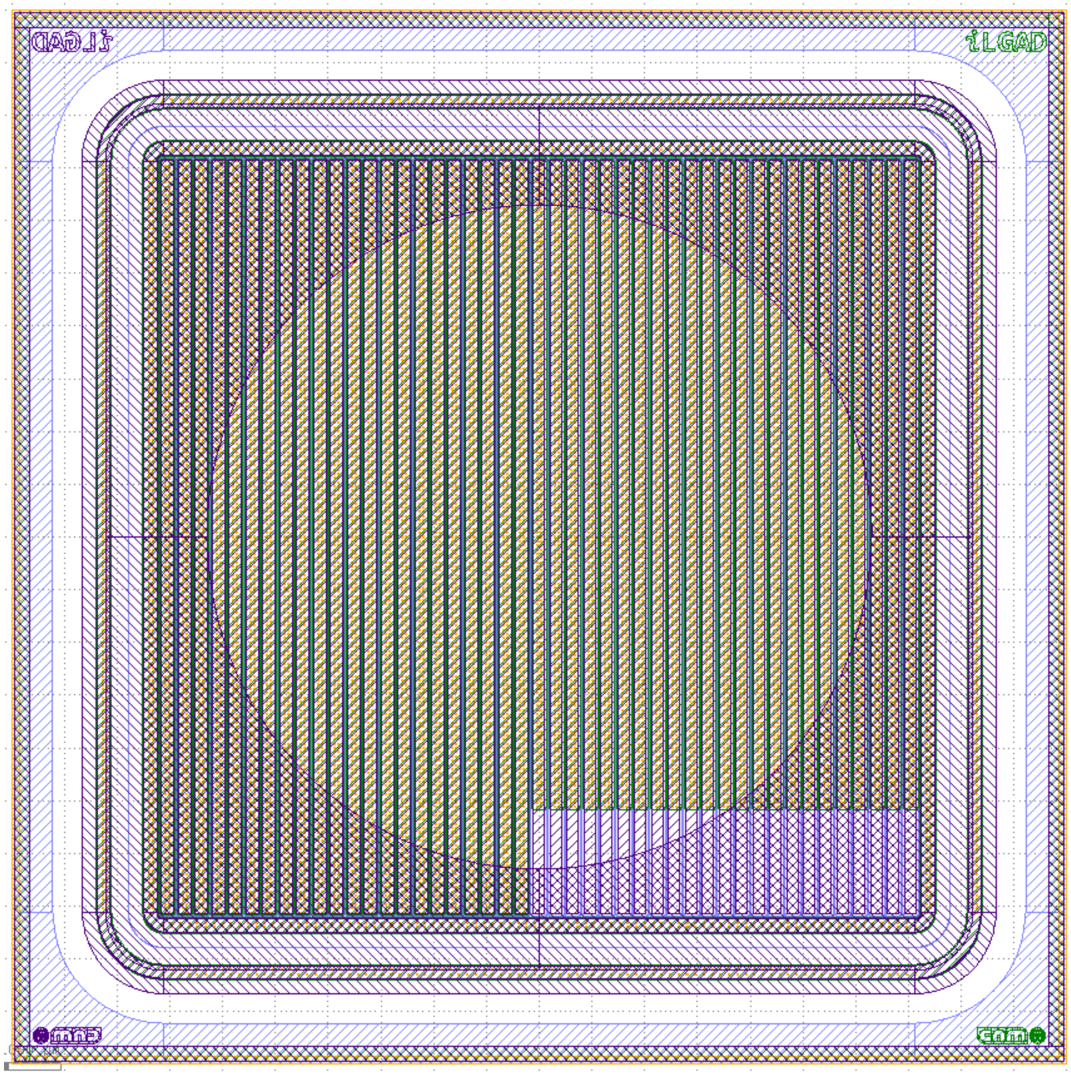
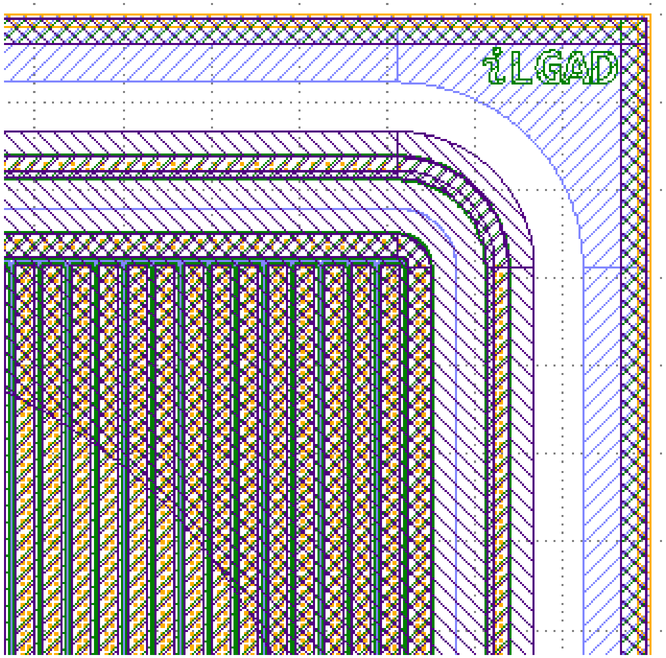
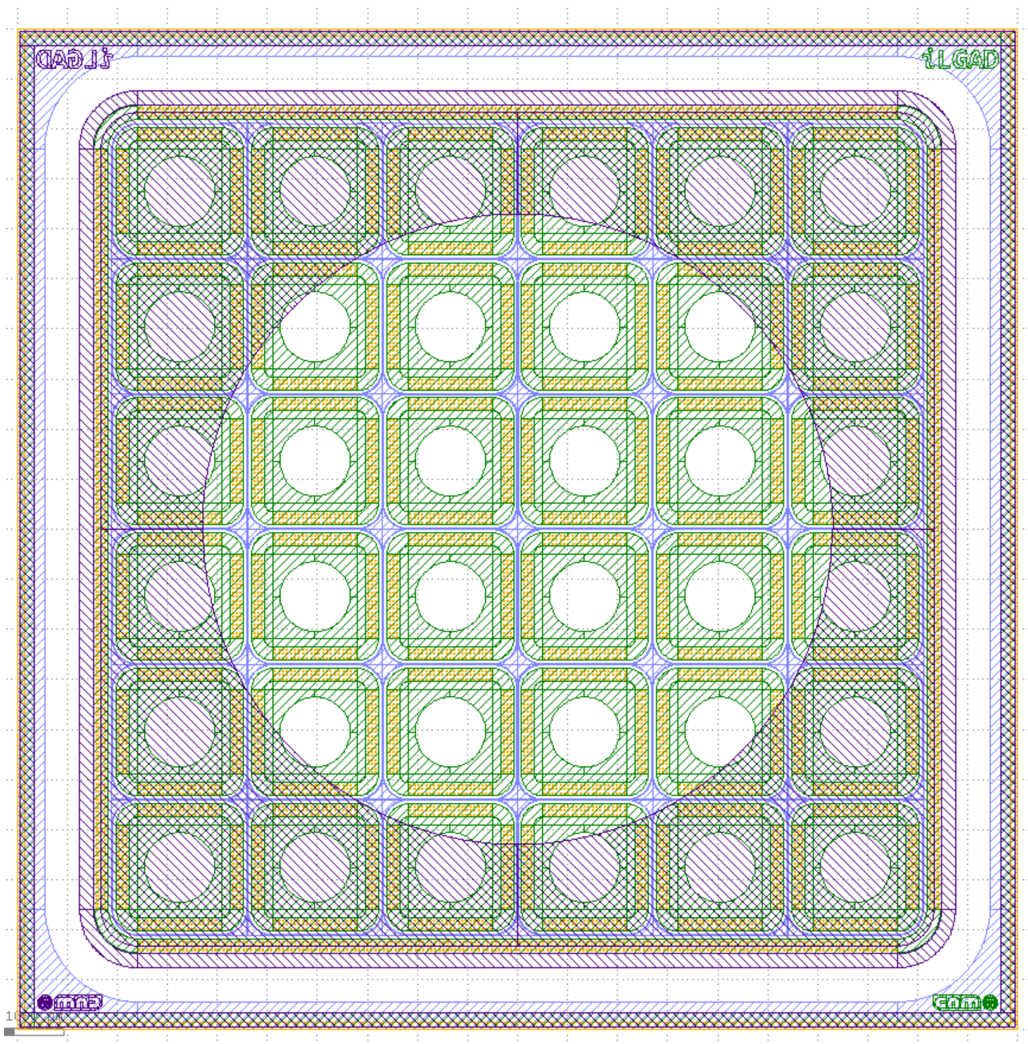
iLGAD. First Mask Set Description. iLGAD, PiN µStrips

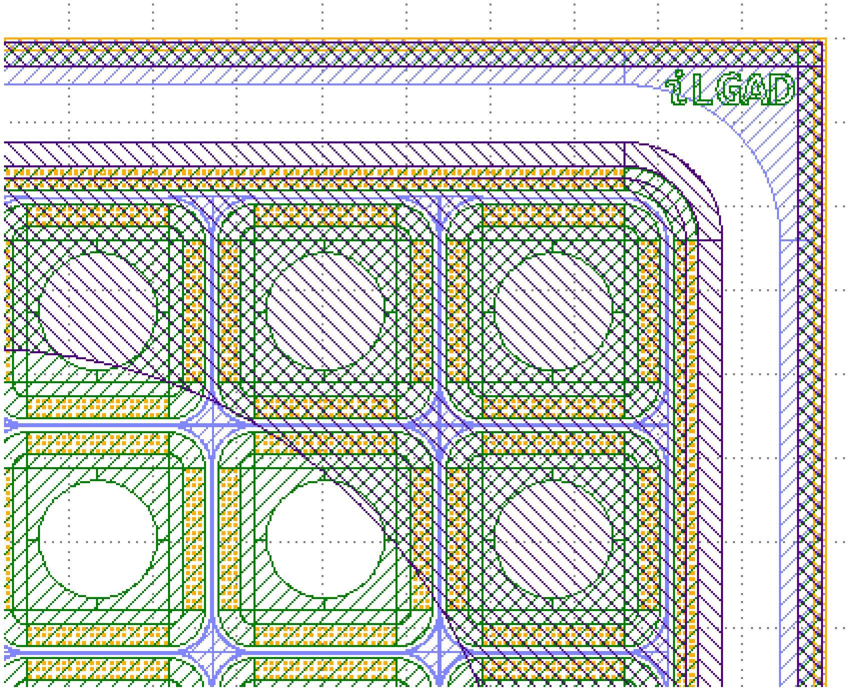




- 8 iLGAD pStrips Detectors
  - ✓ 4 (45 Channels)
  - ✓ 4 (90 Channels)
- 2 PiN pStrips Detectors
  - ✓ 1 (45 Channels)
  - ✓ 1 (90 Channels)

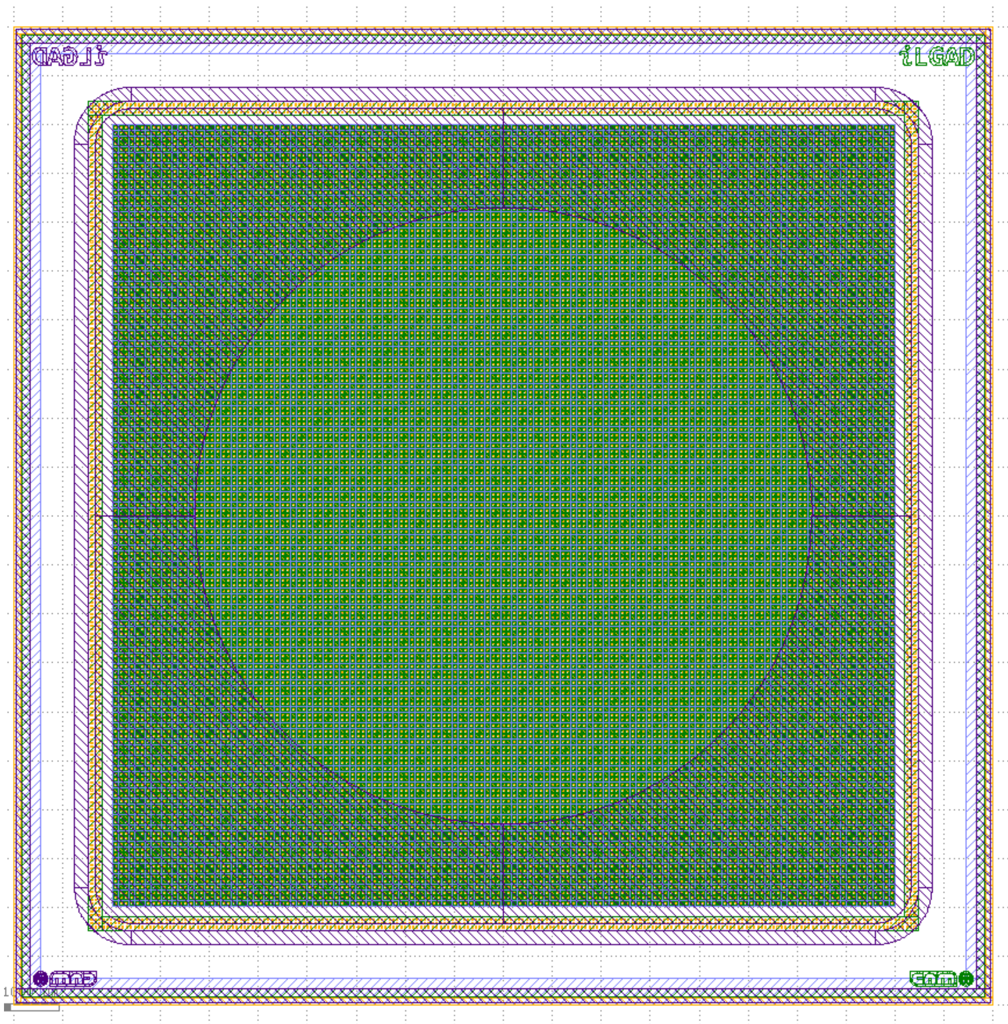
iLGAD. First Mask Set Description. iLGAD Pixels

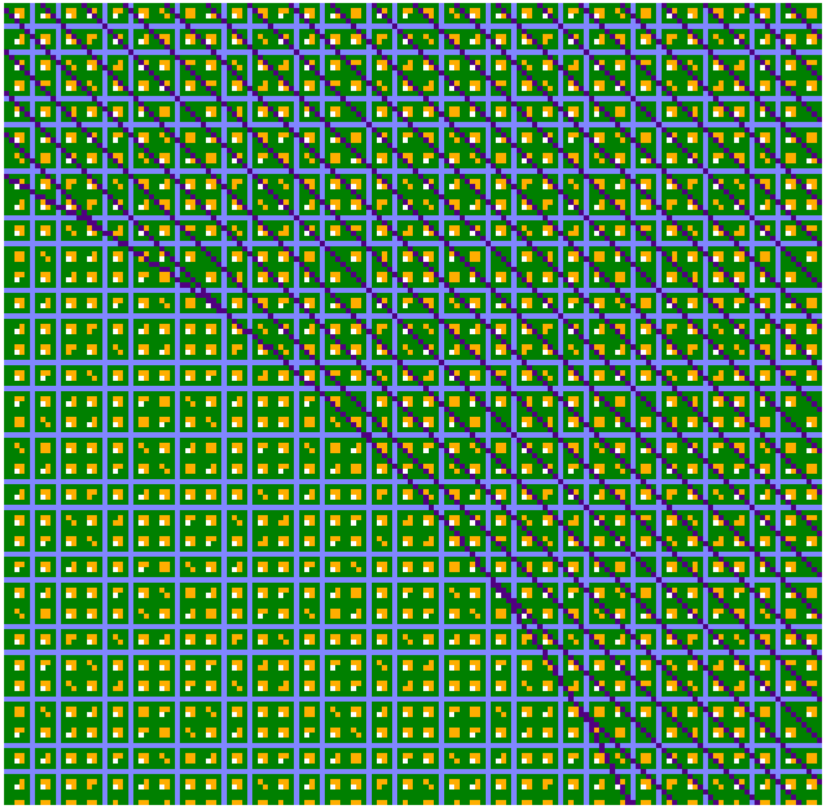




- 6 Pixelated iLGAD Detector (6 x 6 pixels)

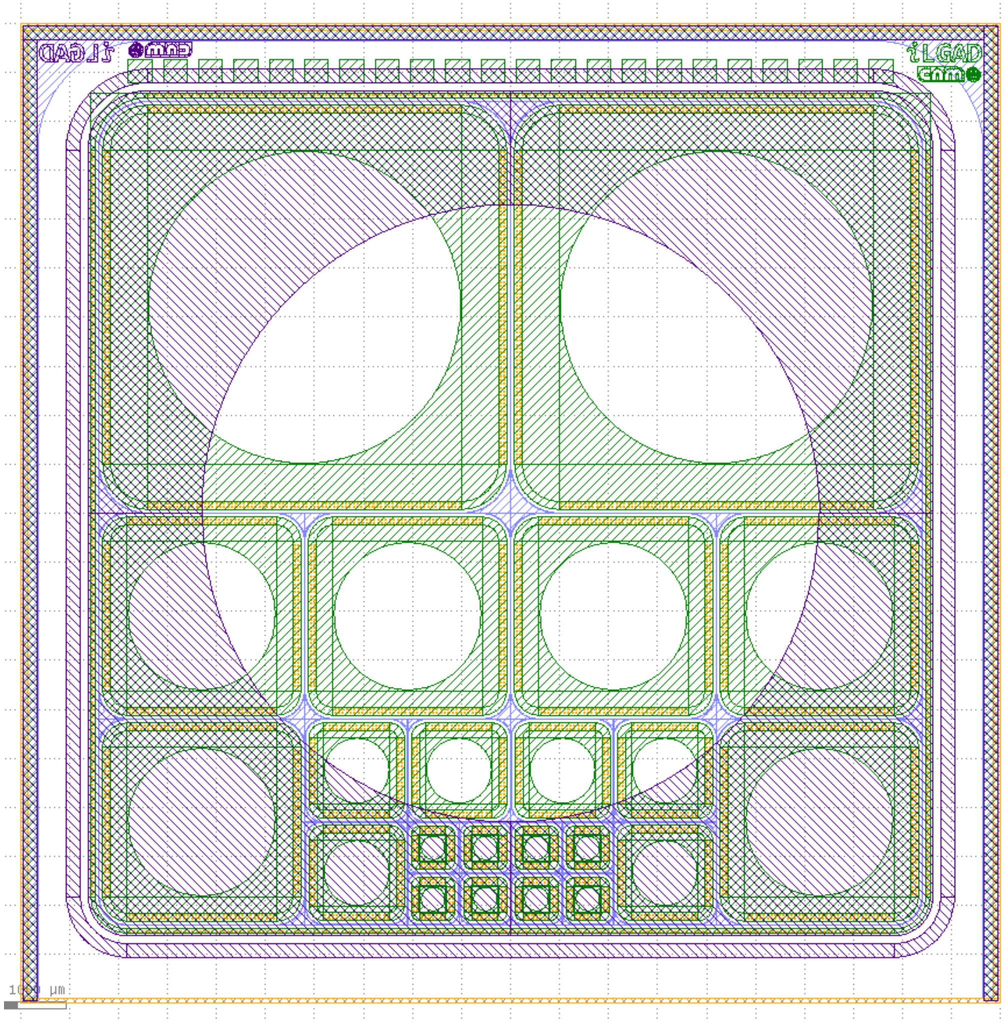
iLGAD. First Mask Set Description. iLGAD Pixels MediPix

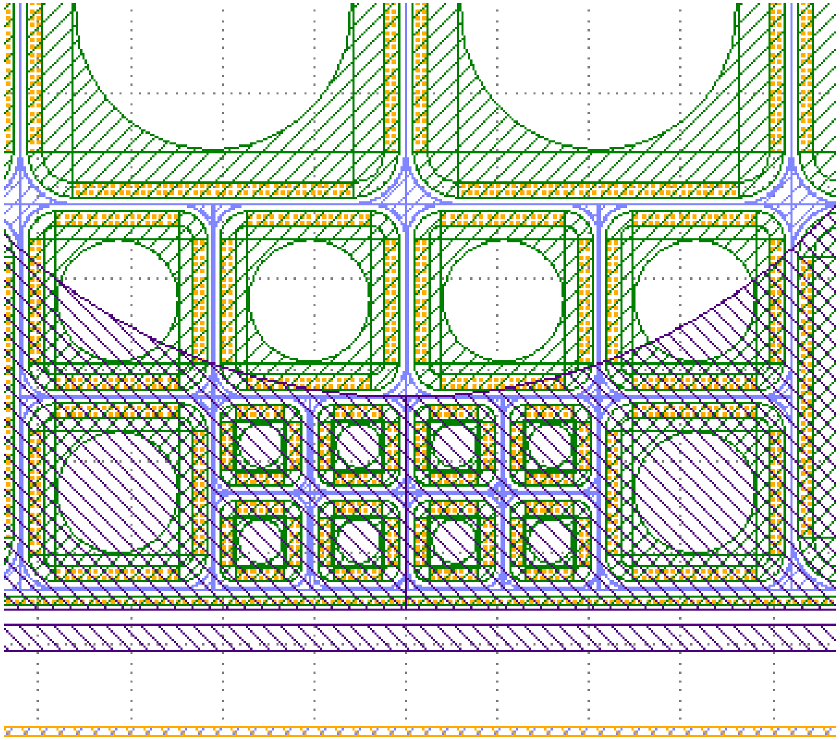




- **4** Pixelated iLGAD MediPix Detector (145 x 145 pixels)

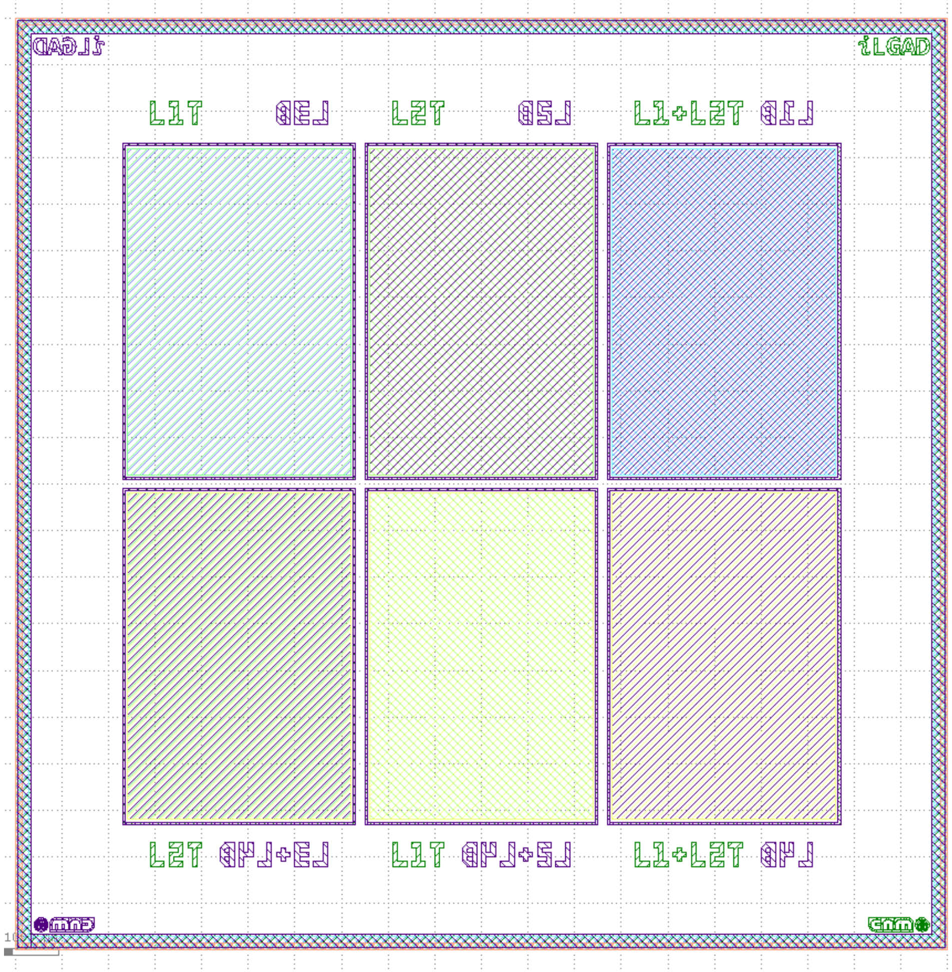
iLGAD. First Mask Set Description. iLGAD Timing

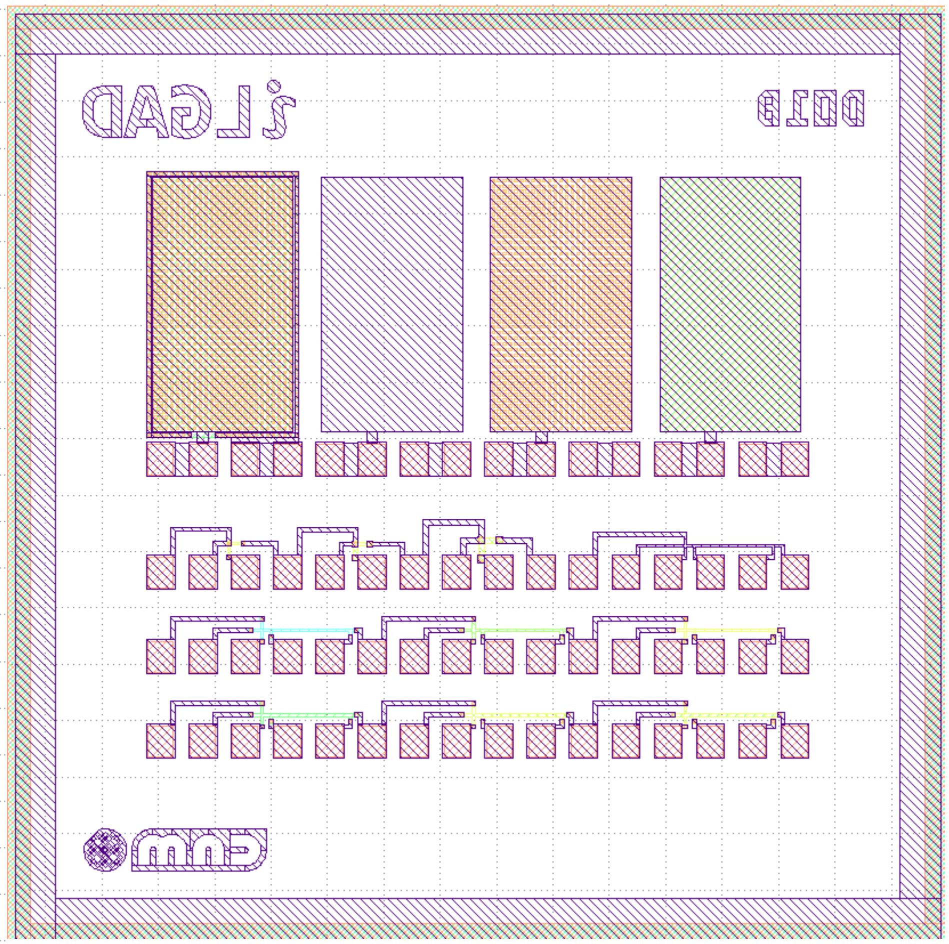




- **6** iLGAD for Timing Applications
  - ✓ **3** (720 μm to cut line)
  - ✓ **3** (370 μm to cut line)

iLGAD. First Mask Set Description. Test Structures





P on P Silicon Detectors. Background

- **1978 United States Patent**. **Paul P. Webb**. RCA Inc. "Multi-element avalanche photodiode having reduced electrical noise"

United States Patent [19] [11] **4,129,878**

Webb [45] **Dec. 12, 1978**

[54] **MULTI-ELEMENT AVALANCHE PHOTODIODE HAVING REDUCED ELECTRICAL NOISE**

[75] Inventor: **Paul P. Webb**, Quebec, Canada

[73] Assignee: **RCA Limited**, Ste. Anne de Bellevue, Canada

[21] Appl. No.: **843,041**

[22] Filed: **Oct. 17, 1977**

[30] **Foreign Application Priority Data**

Sep. 21, 1977 [CA] Canada 287176

[51] **Int. Cl.**^{2} **H01L 29/90**; H01L 27/14

[52] **U.S. Cl.** **357/13**; 357/30; 357/90

[58] **Field of Search** 357/13, 30, 90

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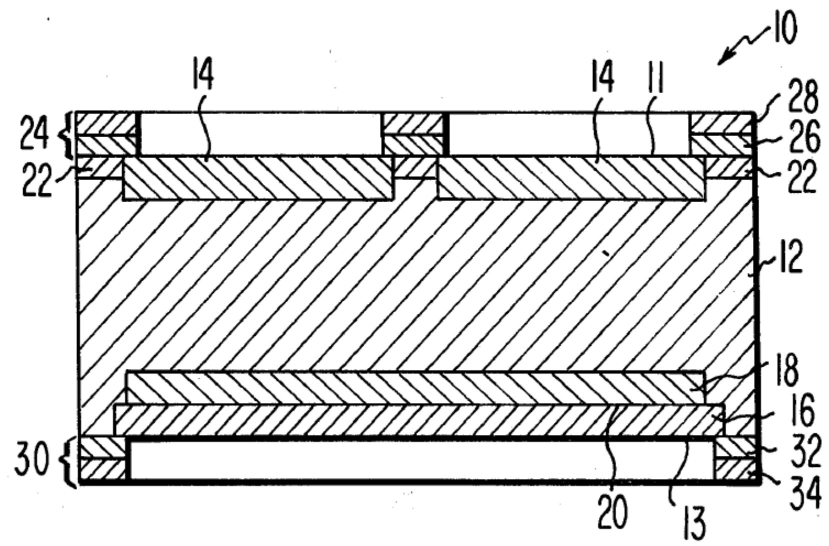
Primary Examiner—Martin H. Edlow
Attorney, Agent, or Firm—H. Christoffersen; Birgit E. Morris

[57] **ABSTRACT**

Avalanche photodiodes include a substrate of a high resistivity material having at least a first surface. The substrate is of a particular conductivity type. In the substrate and at the first surface are a plurality of spaced apart regions of the same conductivity type as the substrate and defining the individual photodiode elements of the avalanche photodiode. Occupying the area at the first surface of the substrate not occupied by the spaced regions and extending into the substrate is a discontinuous layer of the same conductivity type as the spaced regions but of a conductivity concentration much lower than the conductivity concentration of the spaced regions. On the first surface of the substrate covering the discontinuous layer and slightly overlapping the spaced regions is a patterned passivation layer. The improvement of the present invention over the prior art is the addition of the discontinuous layer which reduces the electrical noise in the output signal of the avalanche photodiode.

8 Claims, 2 Drawing Figures



P on P Silicon Detectors. Background

- **1987 United States Patent**. **Paul P. Webb** et al. RCA Inc. “Avalanche photodiode”

United States Patent [19] [11] **Patent Number: 4,654,678**
Lightstone et al. [45] **Date of Patent: Mar. 31, 1987**

[54] **AVALANCHE PHOTODIODE**

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[21] Appl. No.: **771,356**

[22] Filed: **Aug. 30, 1985**

[51] **Int. Cl.⁴** **H01L 29/90**
[52] **U.S. Cl.** **357/13;** 357/30; 357/55
[58] **Field of Search** .... 357/13, 13 PT, 13 LM, 357/13 U, 20, 52, 90, 55, 30

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[57] **ABSTRACT**

The invention is an improved avalanche photodiode having reduced electrical noise arising from spurious surface generation of charge carriers. The avalanche photodiode includes active and neighboring regions adjacent a first surface of a semiconductor body with a gap region therebetween and a channel extending a distance into the semiconductor body from a portion of the second opposed surface opposite the gap region. A P-N junction is formed between regions of opposite conductivity type including a portion thereof over the channel. Since the dopant concentration at the junction is less over the channel, the local avalanche gain over the channel is less, thereby reducing the noise contribution from carriers generated in the gap region.

5 Claims, 2 Drawing Figures

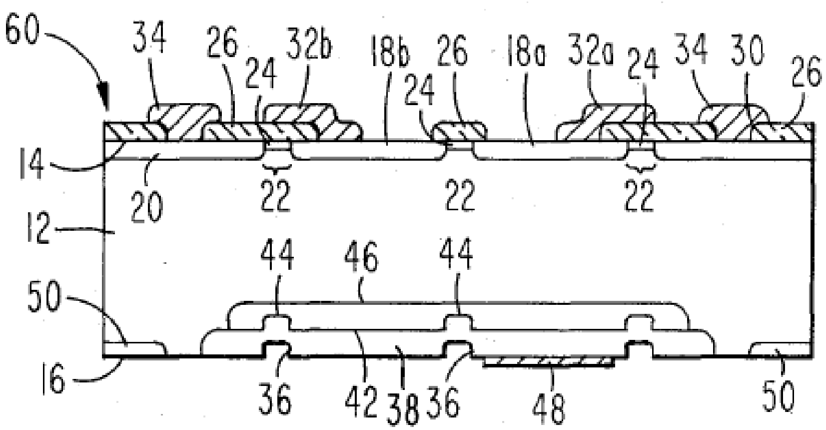

Fig. 2