New iLGAD detector development at CNM

S. Hidalgo, M. Baselga, P. Fernández, D. Flores, V. Greco, A. Merlos G. Pellegrini, D. Quirion, I. Vila*

Instituto de Microelectrónica de Barcelona (IMB)
Centro Nacional de Microelectrónica (CNM-CSIC)
Barcelona, Spain

(*) Instituto de Física de Cantabria (IFCA-UC-CSIC)
Santander, Spain

Outline

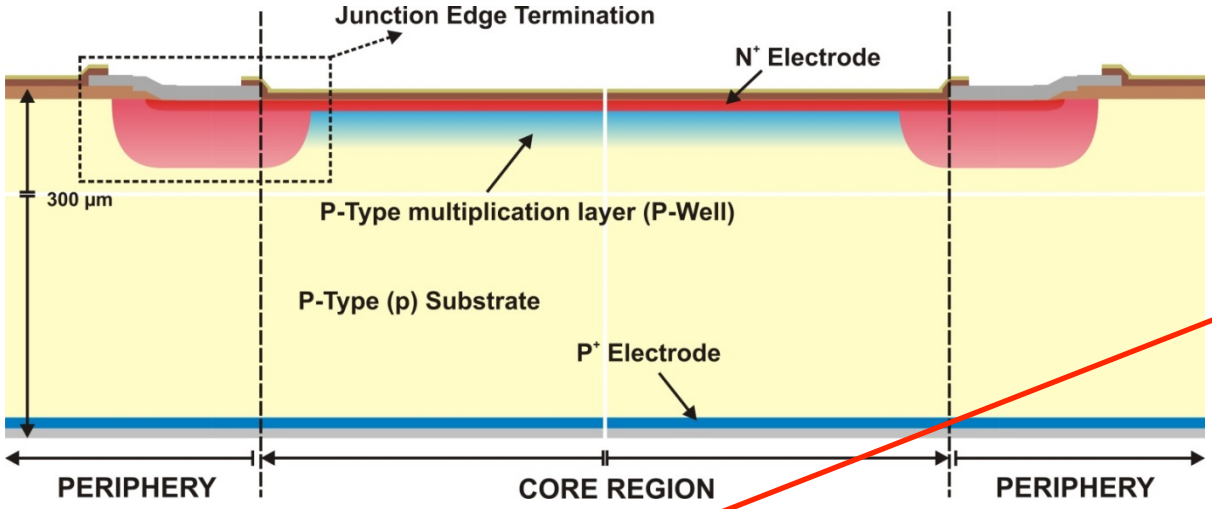
- **Motivation**
  - ✓ Position-Sensitive
  - ✓ Timing
- **LGAD** Basics. **Segmented** Gain Detector
  - ✓ Front-Side Approach
  - ✓ Back-Side Approach
- **iLGAD**. "Inverted" LGAD
  - ✓ Basic Structure
  - ✓ Front-Side. Ohmic Read Out
  - ✓ Back-Side. Amplification
- 2D **Simulation**
  - ✓ Device Optimization
  - ✓ Technological Optimization
  - ✓ Thin Detectors
- First **Mask** Set
  - ✓ LGAD
  - ✓ iLGAD (micro Strips, Pixels)
  - ✓ SIMS Test Structures
  - ✓ Technological Test Structures
- First **Technological** Process
  - ✓ LGAD Base
  - ✓ Double-Side
  - ✓ 12 Mask Levels
  - ✓ 100 Process Steps
  - ✓ 4-5 Months
- **Conclusions**

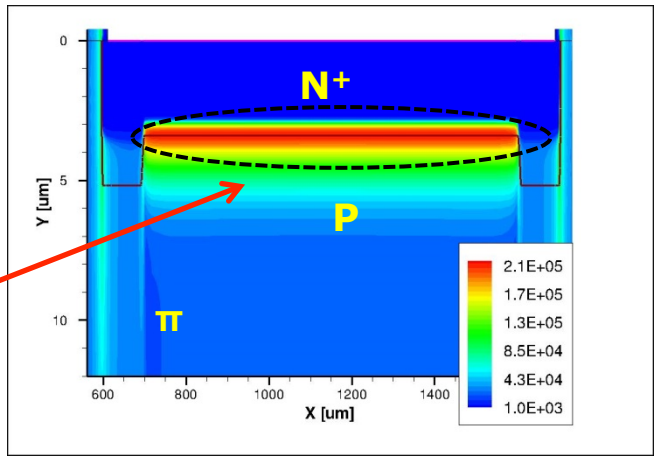
iLGAD Basics

- Implementing a **Small Signal Gain** in Pad, microStrip and Pixelated Sensors can **reduce** the **Thickness** of the sensors **without reducing** the **Signal** Amplitude, keeping the **same** signal to noise ratio (**SNR**) ➡ **Timing Applications**

- **Our Target**: A relatively Small Signal Gain (**5-10**) needed to **allow the use** of **standard readout front-end** without **Signal Saturation**

iLGAD Basics. Low Gain Detector





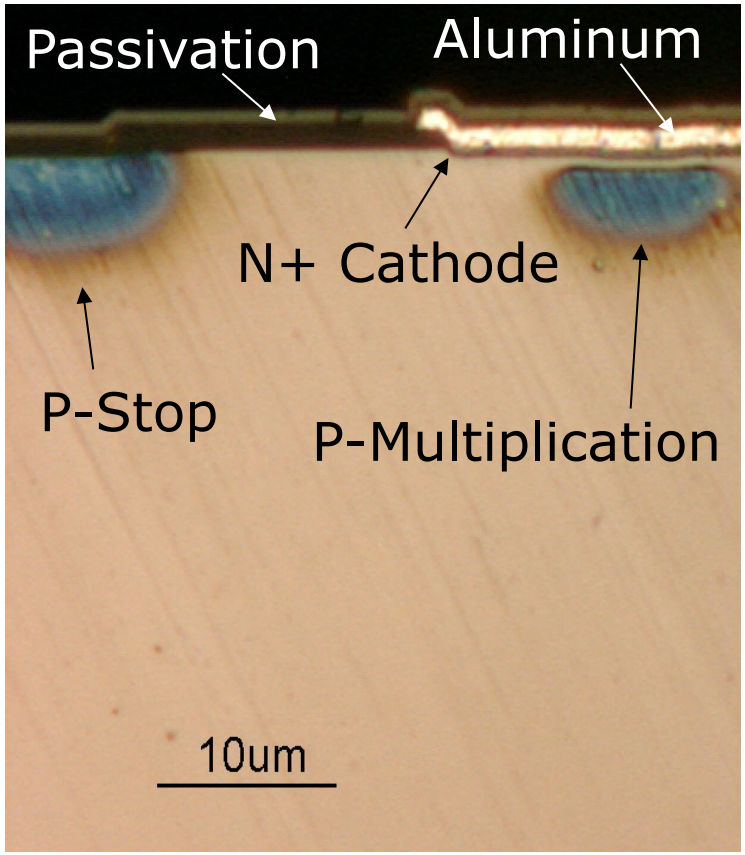
- **Core Region**
  - ✓ **Uniform electric field**, high enough to activate mechanism of **impact ionization** (multiplication)
- **Termination**
  - ✓ **High electric field** confined in the **core region**

$$V_{BD}|_{\text{Termination}} \gg V_{BD}|_{Central}$$

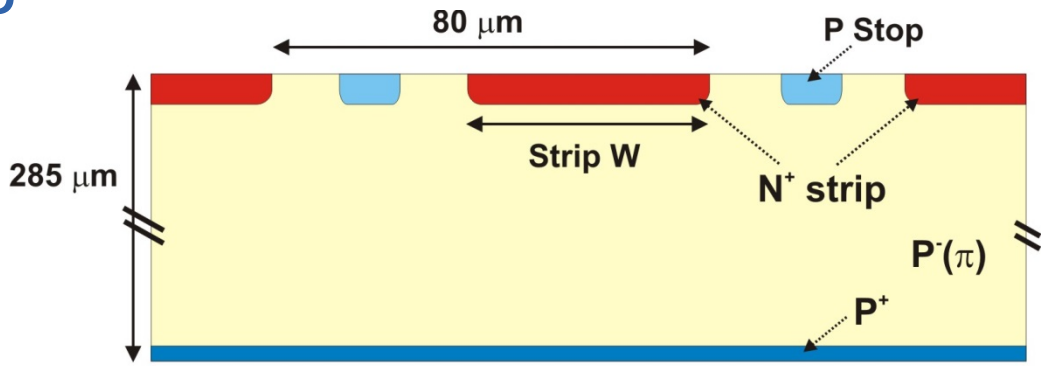
- **Periphery**
  - ✓ **Dead region**. **Charges** should not be collected. **Reduction** of the **leakage currents**

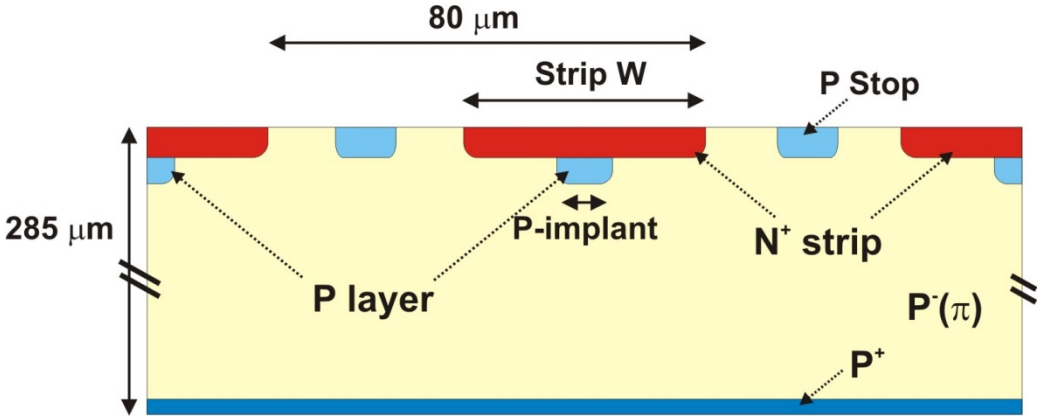
First Approach. Strip LGAD. Segmented Amplification

- **N on P** microStrips. **PiN** vs **LGAD**



N on P microStrip PiN

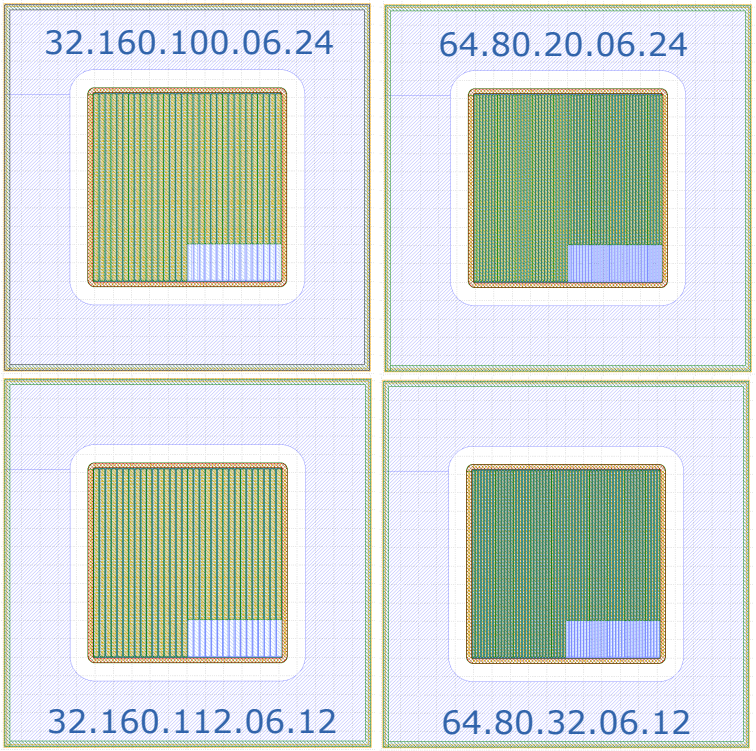


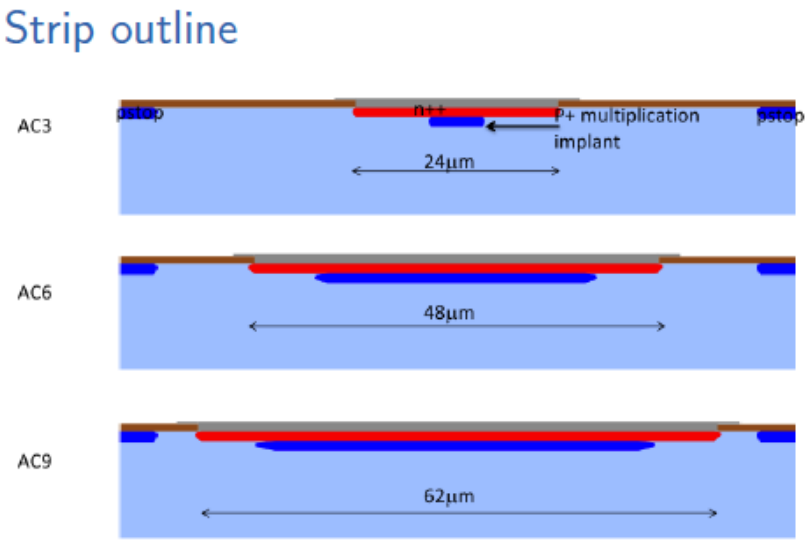


N on P microStrip LGAD

First Approach. Strip LGAD. Segmented Amplification

- **Several** layouts with **different** **p-well width** and **n-well depth** were fabricated
- **Most of them** had **low breakdown voltage** and **high inverse current**
- **Two new** runs with **optimized p-well** engineering just fabricated (7509, 7859)
  - ✓ First prototypes characterization **on going**



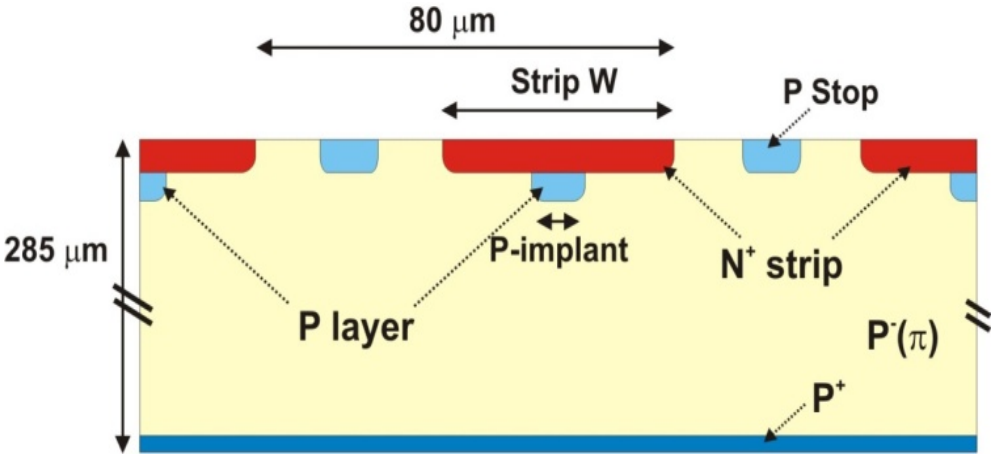


- **Key Legend**
  - ✓ **AA-BB-CC-DD-EE**
  - ✓ **AA,** Channels
  - ✓ **BB,** Pixel Size
  - ✓ **CC,** Multiplication Width
  - ✓ **DD,** P-Stop Width
  - ✓ **EE,** P-Stop Position

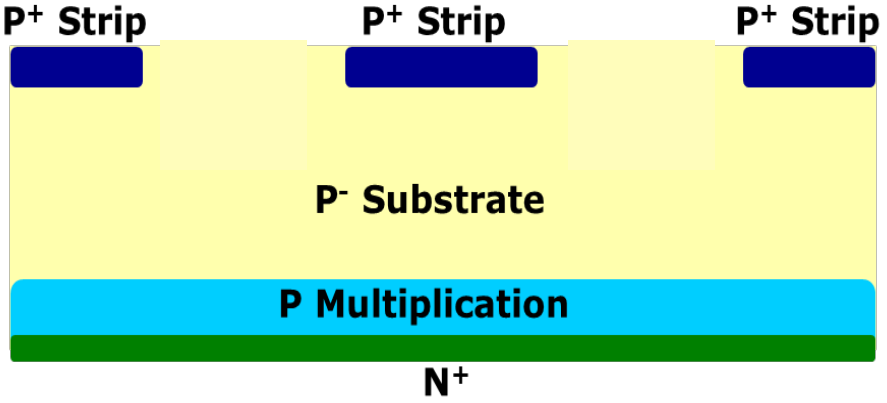
Second Approach. P on P Strip iLGAD: The "Inverted" LGAD

- **Double-sided LGAD** with **pad-like multiplication** structure in the **back-side** and **ohmic read out** strips, or pixels, in the **front-side**

- **N on P** vs **P on P LGAD** microStrips Comparison



N on P microStrip



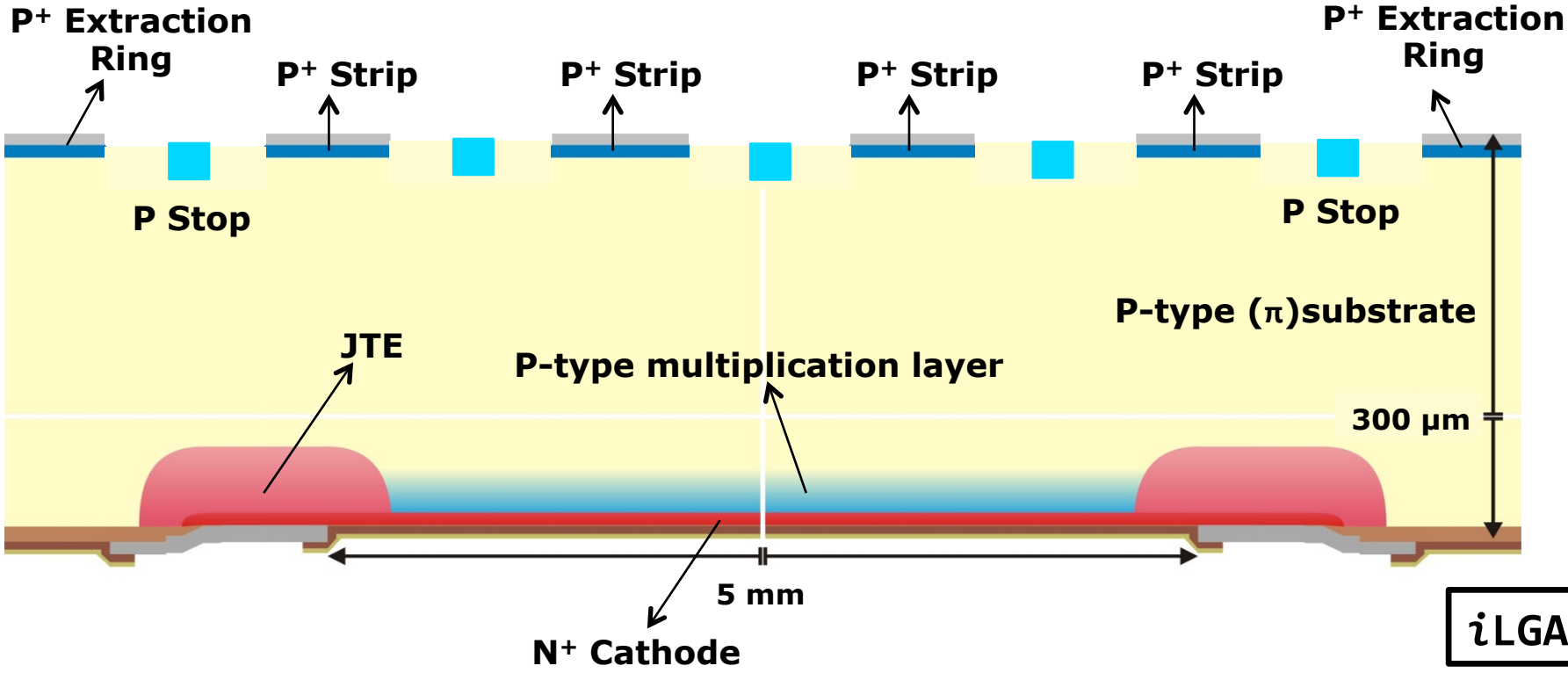
P on P microStrip

iLGAD

Second Approach. P on P Strip iLGAD: The "Inverted" LGAD

- **Double-sided LGAD** with **pad-like multiplication** structure in the **back-side** and **ohmic read out** strips, or pixels, in the **front side**

- **First Design and Run**. Include Pads, microStrips and pixelated i**LGADs**



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]
Webb

[11] **4,129,878**
[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

[56] **References Cited**

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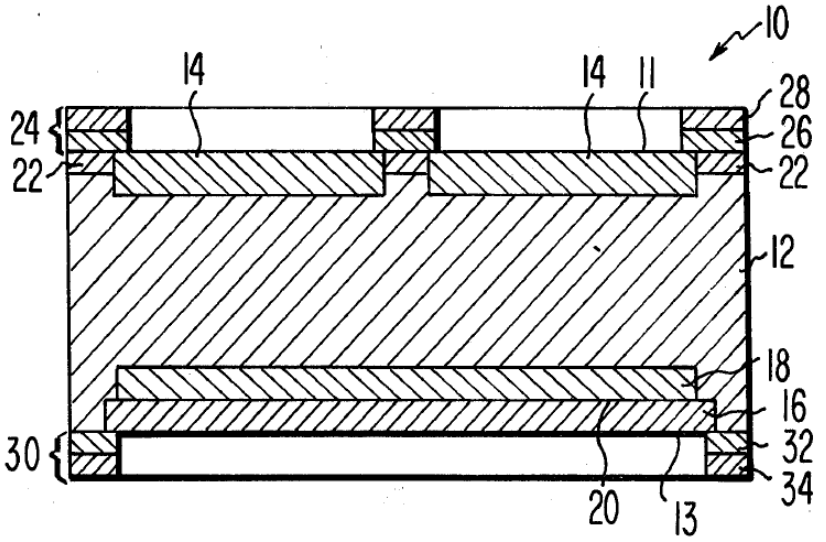
Kanbe et al., *I.E.E.E. Transactions on Electron Devices*, vol. Ed. 23, No. 12, Dec. 1976, pp. 1337–1343.

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]
Lightstone et al.

[11] **Patent Number: 4,654,678**
[45] **Date of Patent: Mar. 31, 1987**

[54] **AVALANCHE PHOTODIODE**

[75] Inventors: **Alexander W. Lightstone; Paul P. Webb; Robert J. McIntyre,** all of Quebec, Canada

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

[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

[56] **References Cited**

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4,586,067	4/1986	Webb	357/13 X

OTHER PUBLICATIONS

Kennedy et al., IRE Transactions on Electron Devices, ED-9 478 (1962).

Primary Examiner—Martin H. Edlow
Assistant Examiner—Sara W. Crane
Attorney, Agent, or Firm—B. E. Morris; W. J. Burke

[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

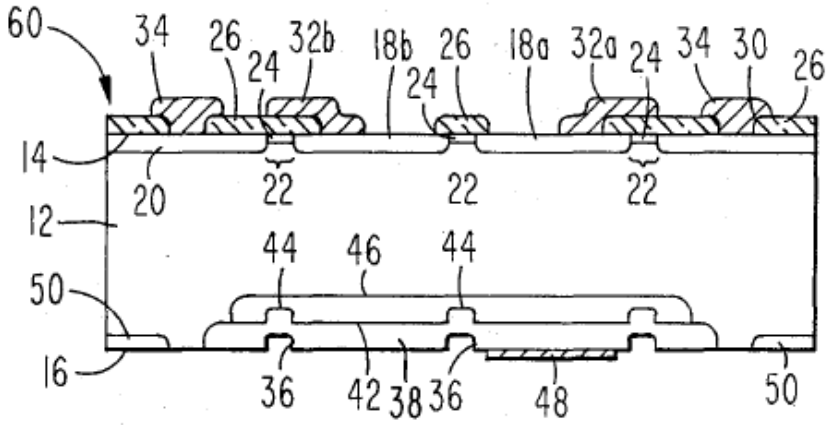
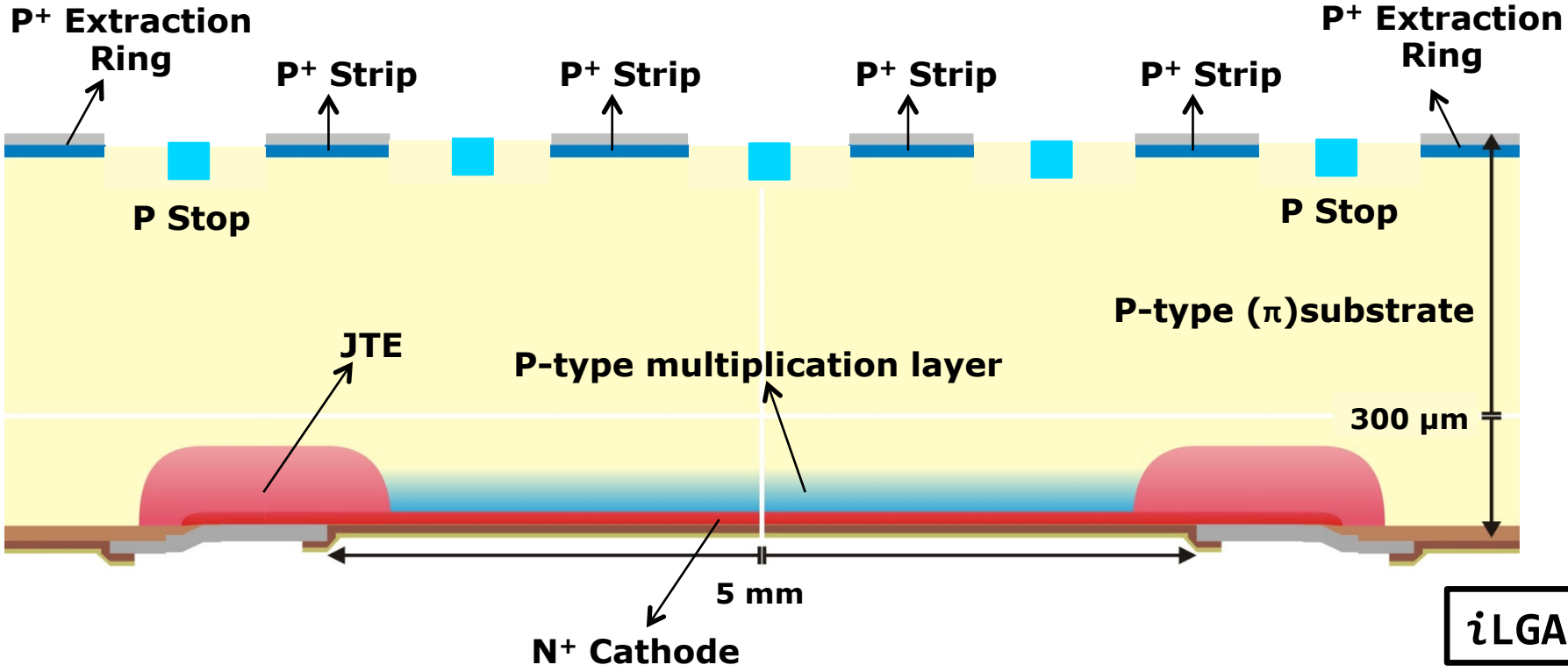


Fig. 2

Second Approach. P on P Strip iLGAD: The "Inverted" LGAD

- **Double-sided LGAD** with **pad-like multiplication** structure in the **back-side** and **ohmic read out** strips, or pixels, in the **front side**

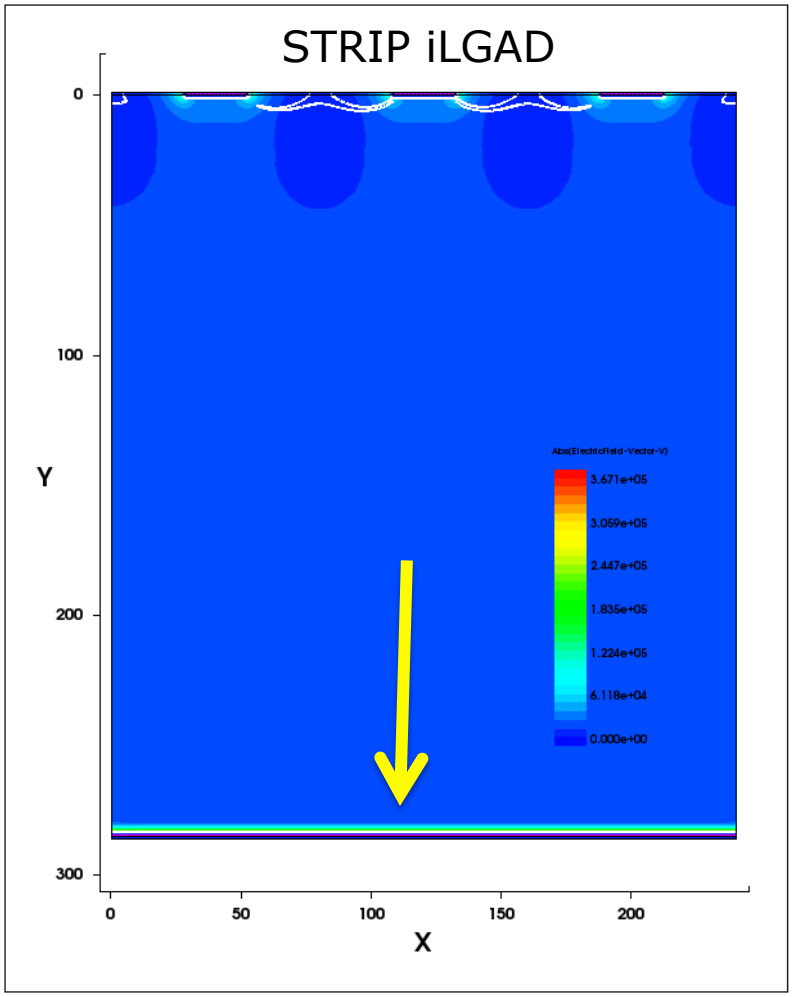
- **First Prototype**. Pads, microStrips and pixelated **LGADs**

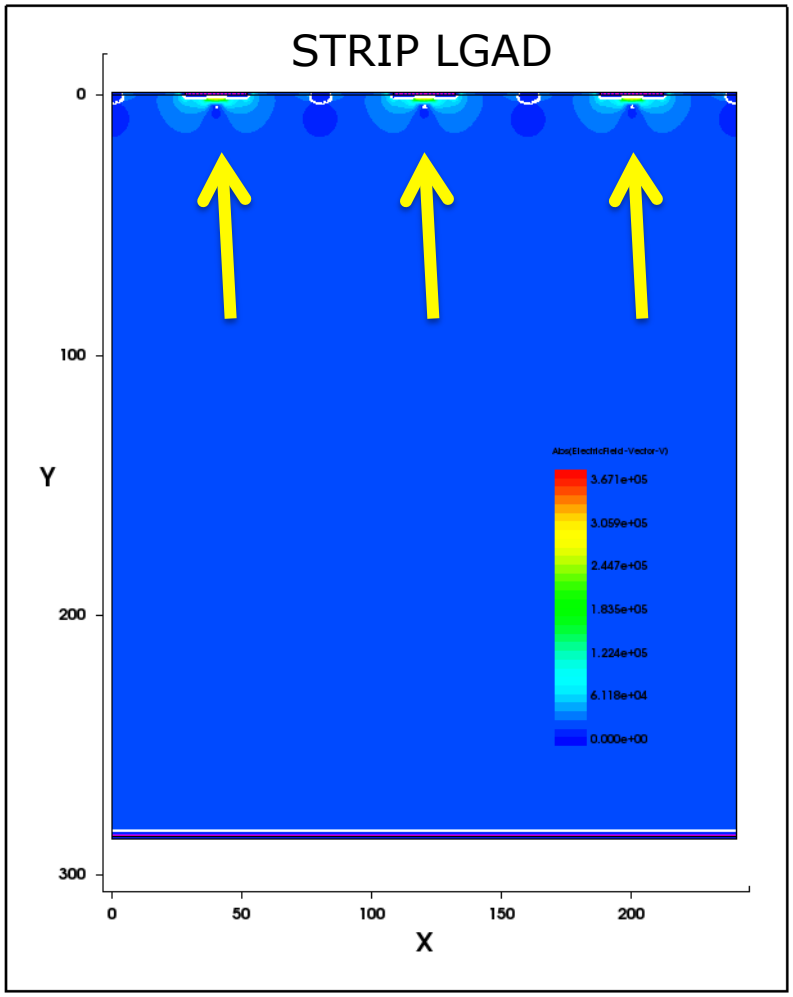


iLGAD

iLGAD. P on P MicroStrips. 2D Simulation

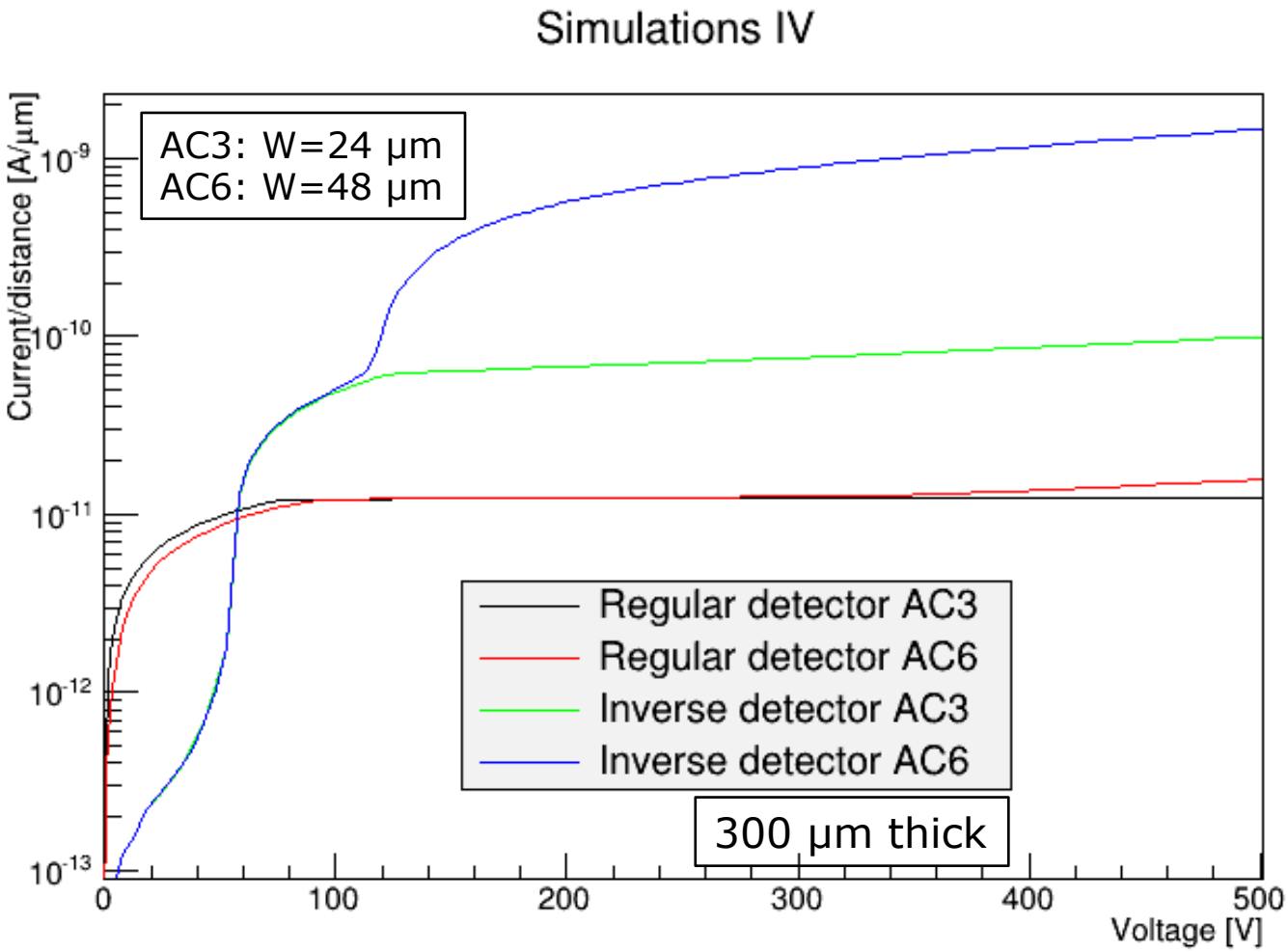
- **Three** microStrips. **Electric Field** Distribution: **Maximum value @ P-N Junctions**





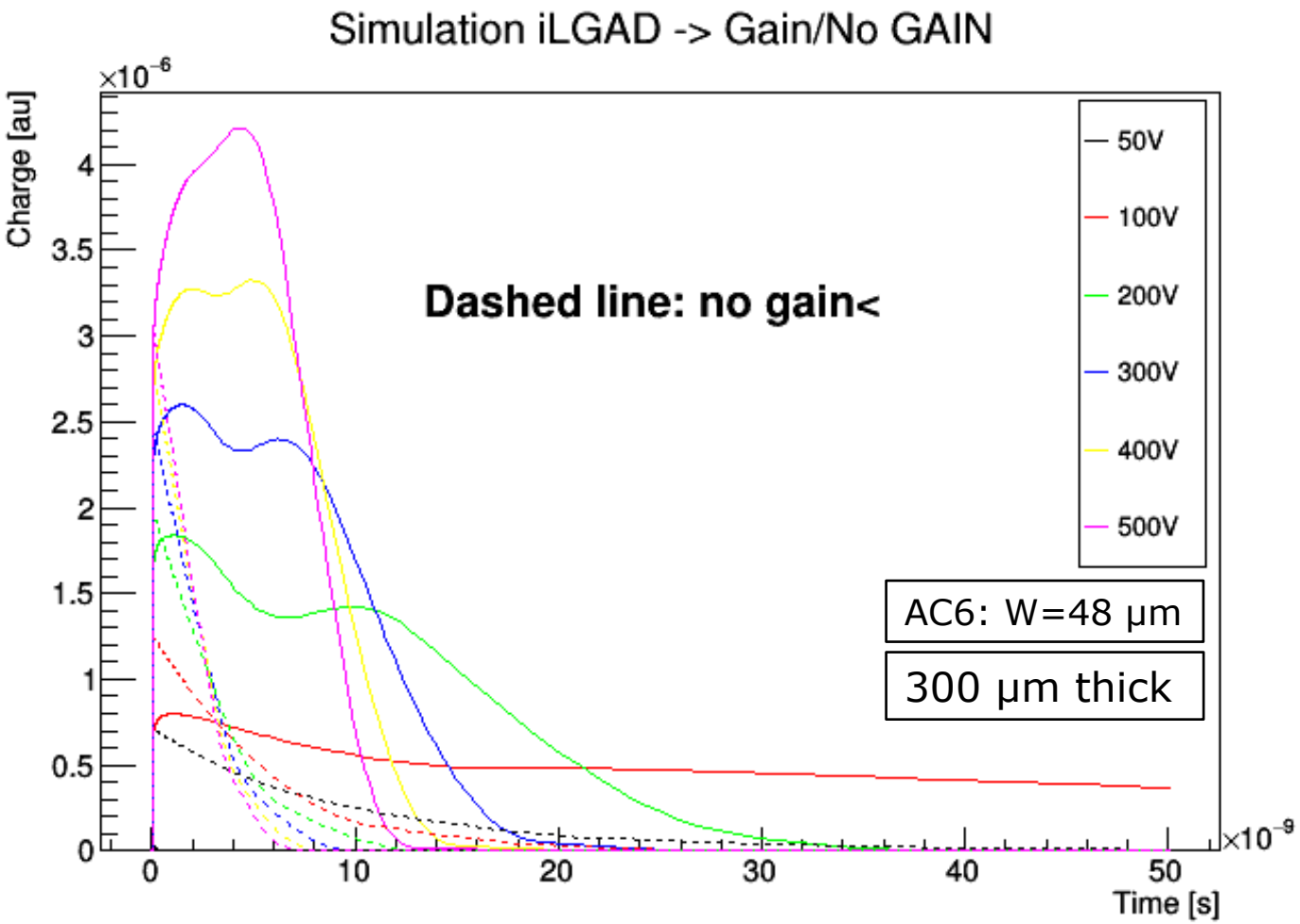
iLGAD. P on P MicroStrips. 2D Simulation

- **Three** microStrips. **I(V)**



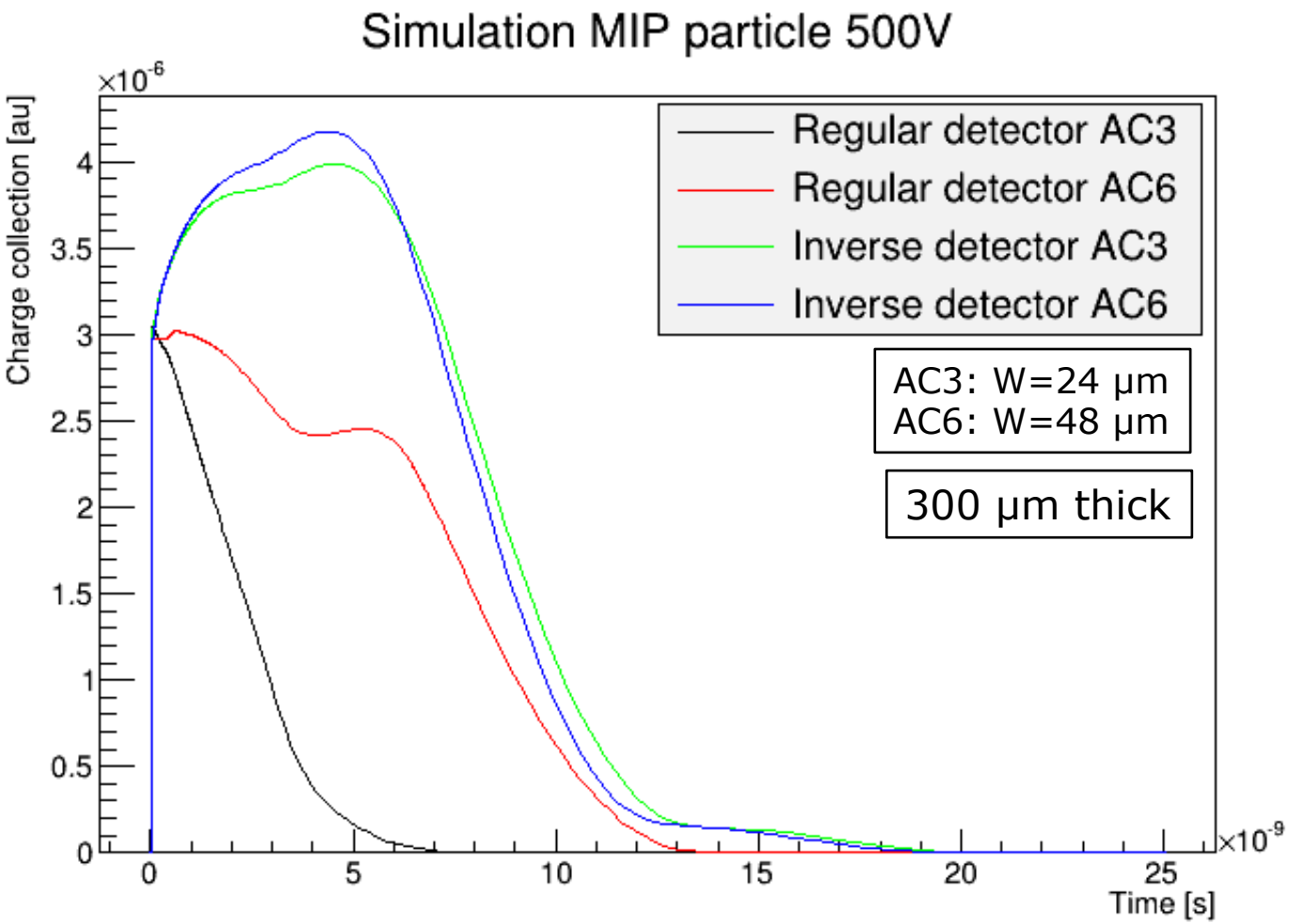
iLGAD. P on P MicroStrips. 2D Simulation

- **MIP** through the middle of the sensors (the central strip). **AC6 Inverse Detector**



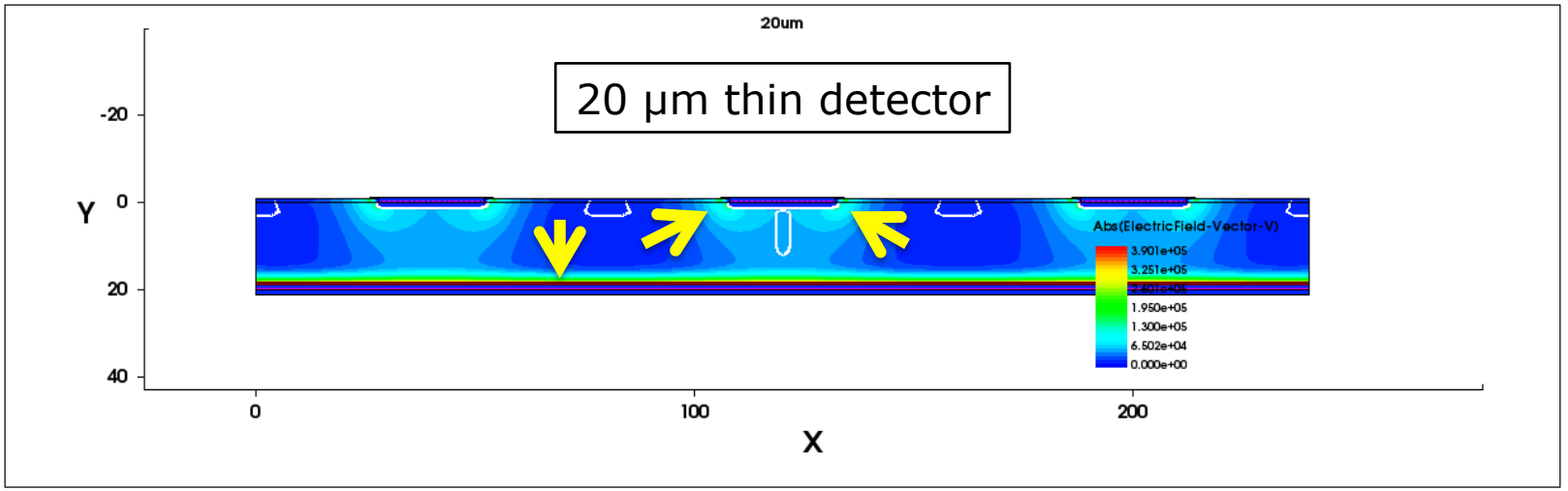
iLGAD. P on P MicroStrips. 2D Simulation

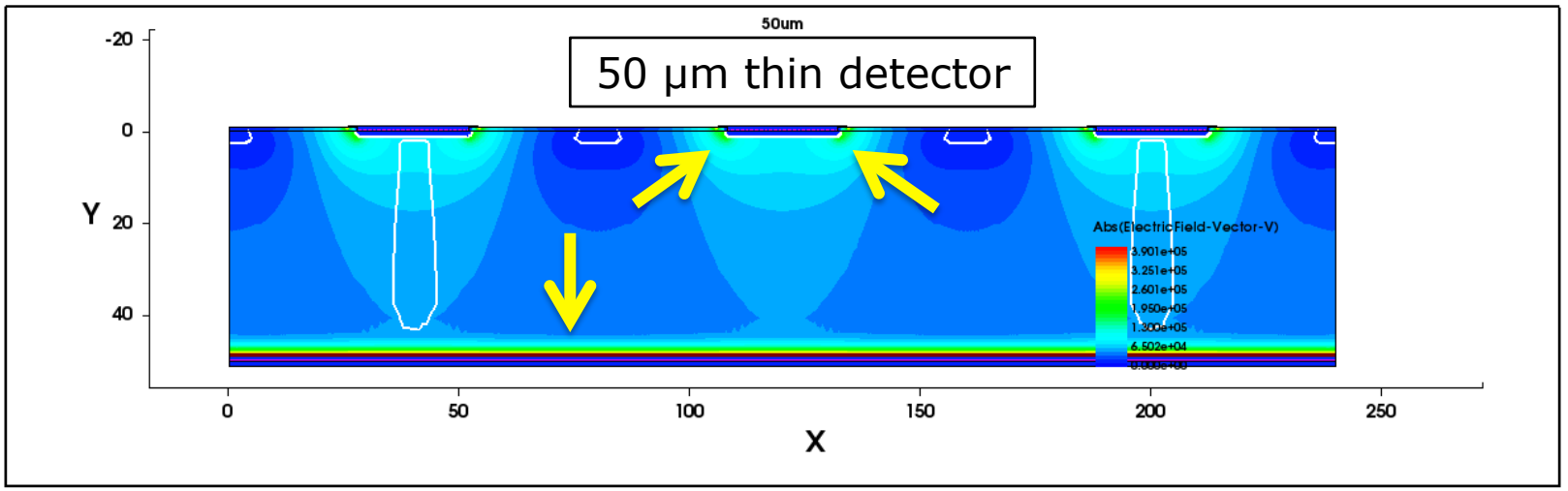
- **MIP** through the middle of the sensors (the central strip) **@ 500 V**



iLGAD. P on P MicroStrips. 2D Simulation

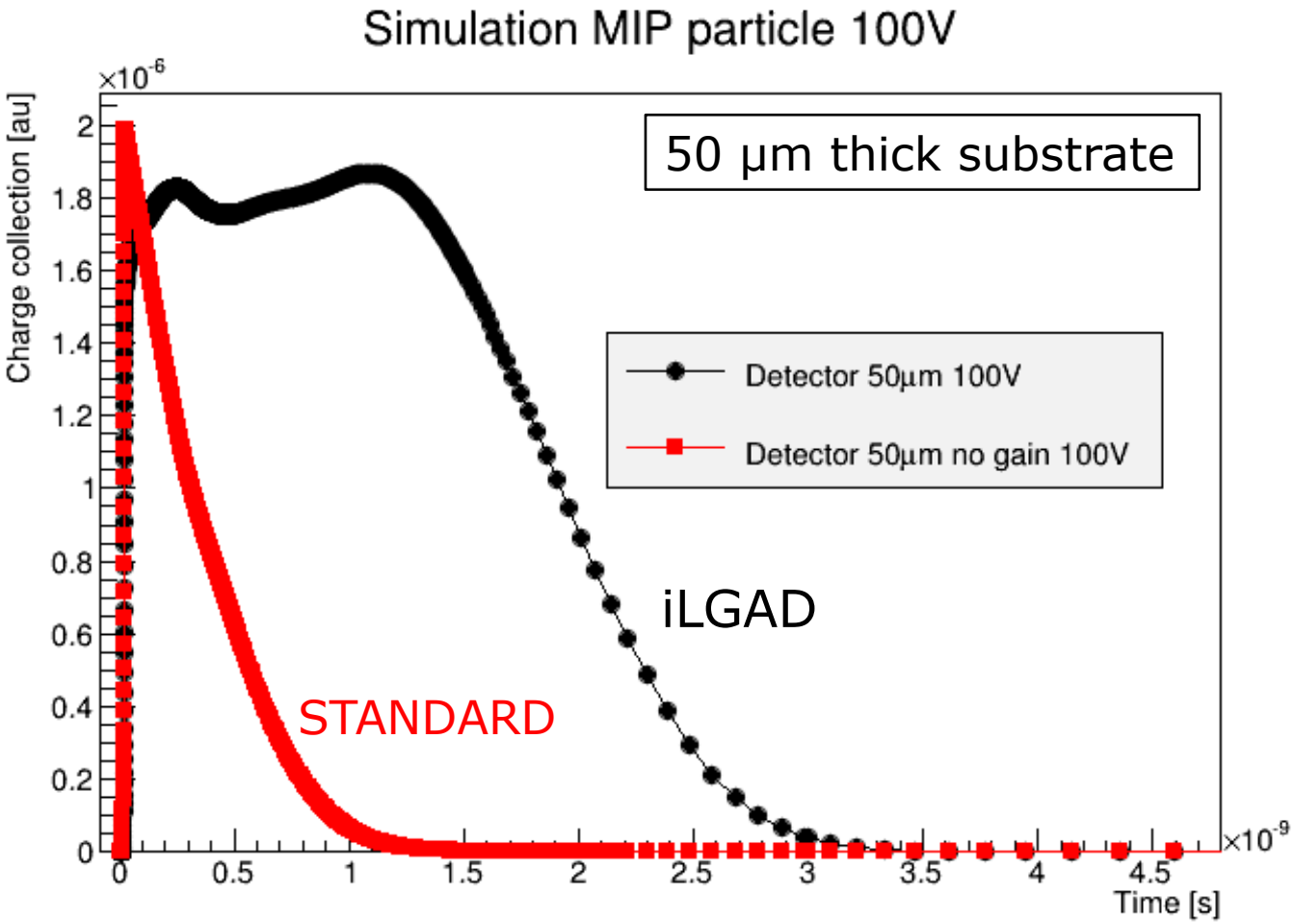
- MicroStrips Simulation. **Electric Field** 2D Distribution @ V_{BR}





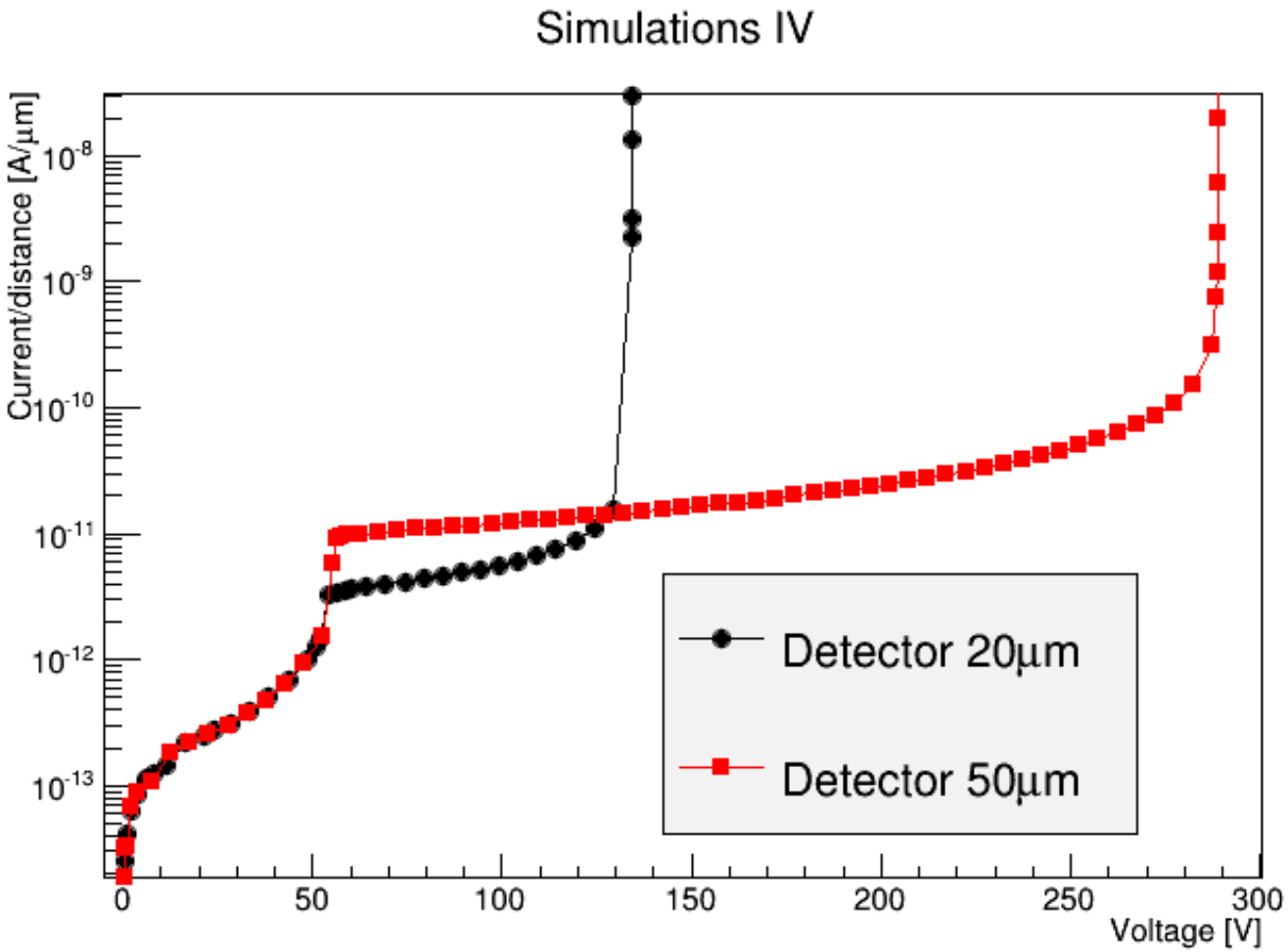
iLGAD. P on P MicroStrips. 2D Simulation

- **MIP** through the middle of the sensors (central strip) **@ 100 V**



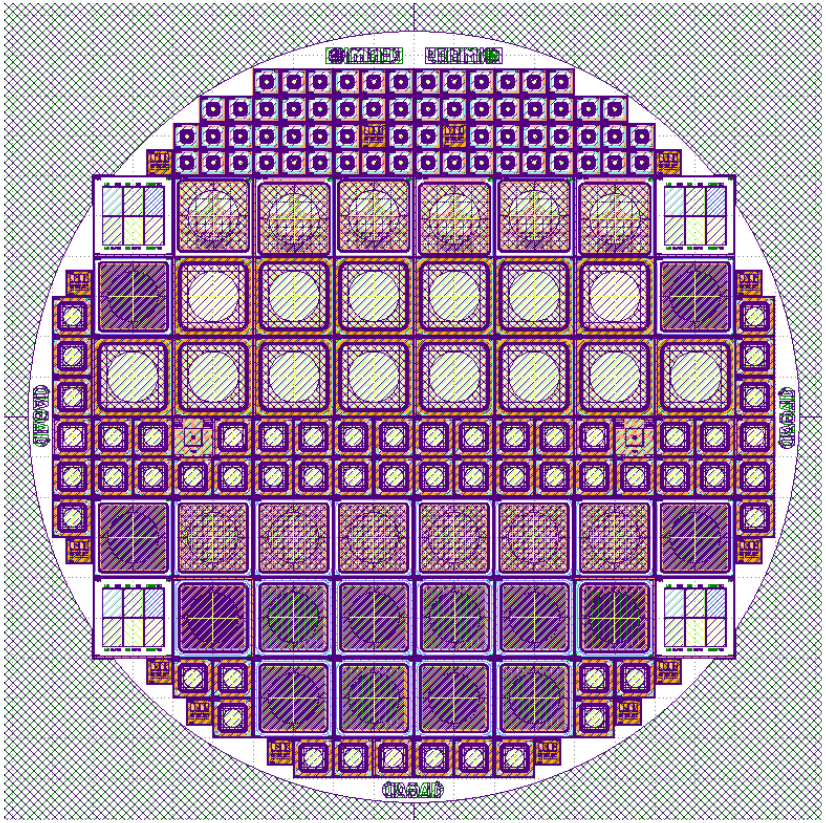
iLGAD. P on P MicroStrips. 2D Simulation

- MicroStrips I(V). **Breakdown** performances **limited** by **Thickness**



iLGAD. First Mask Set Description. Integrated Devices

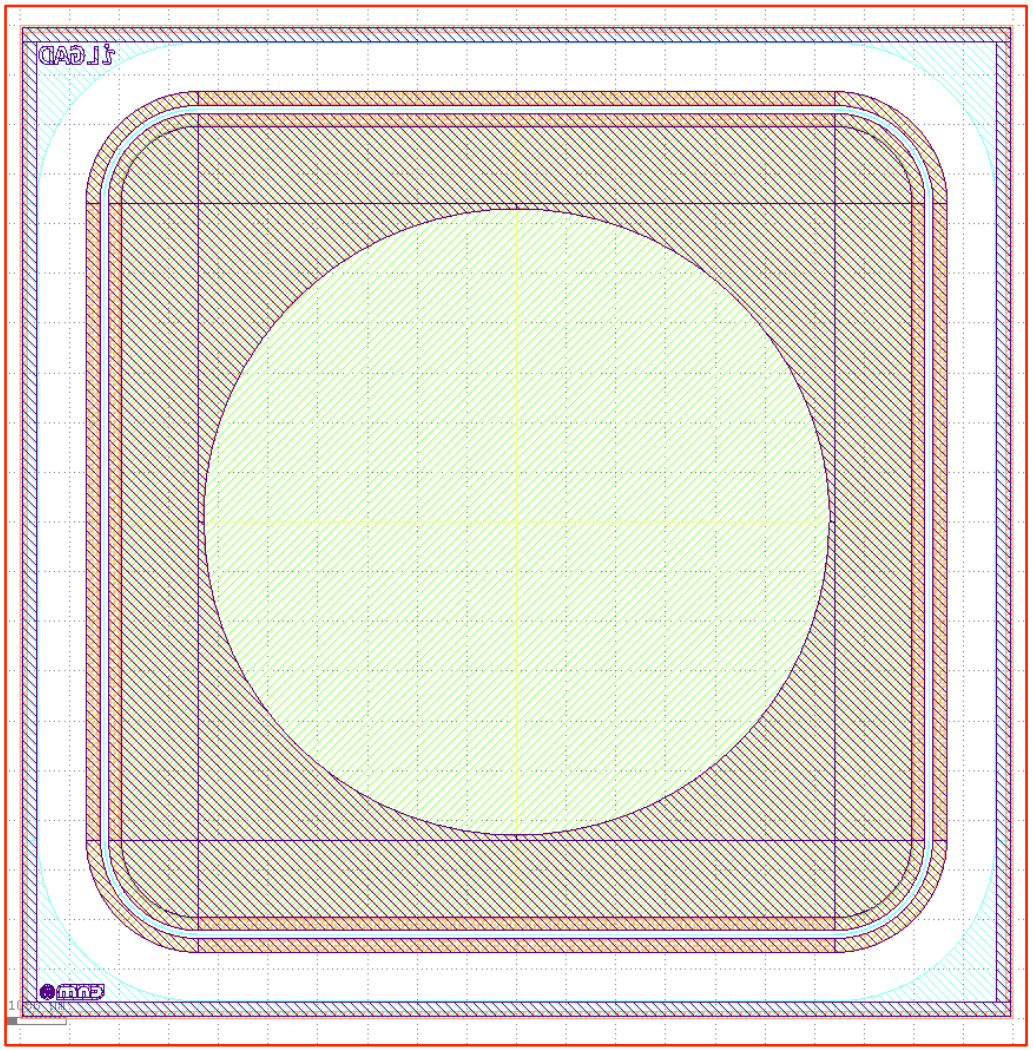
- **176 Chips**
  - ✓ **44** (10 x 10 mm, total area)
  - ✓ **56** (5 x 5 mm, total area)
  - ✓ **76** (3.3 x 3.3 mm, total area)

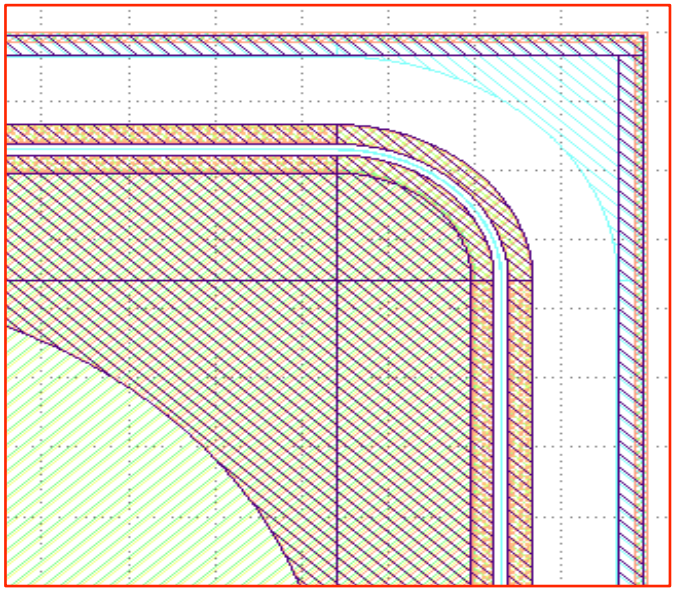


- **113** LGAD Pad Detectors
  - ✓ **12** (8 x 8 mm mult area)
  - ✓ **49** (3 x 3 mm mult area)
  - ✓ **52** (1 x 1 mm mult area)
- **17** PiN Detectors
  - ✓ **2** (8 x 8 mm active area)
  - ✓ **5** (3 x 3 mm active area)
  - ✓ **10** (1 x 1 mm active area)
- **8** iLGAD pStrips Detectors
  - ✓ **4** (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)

iLGAD

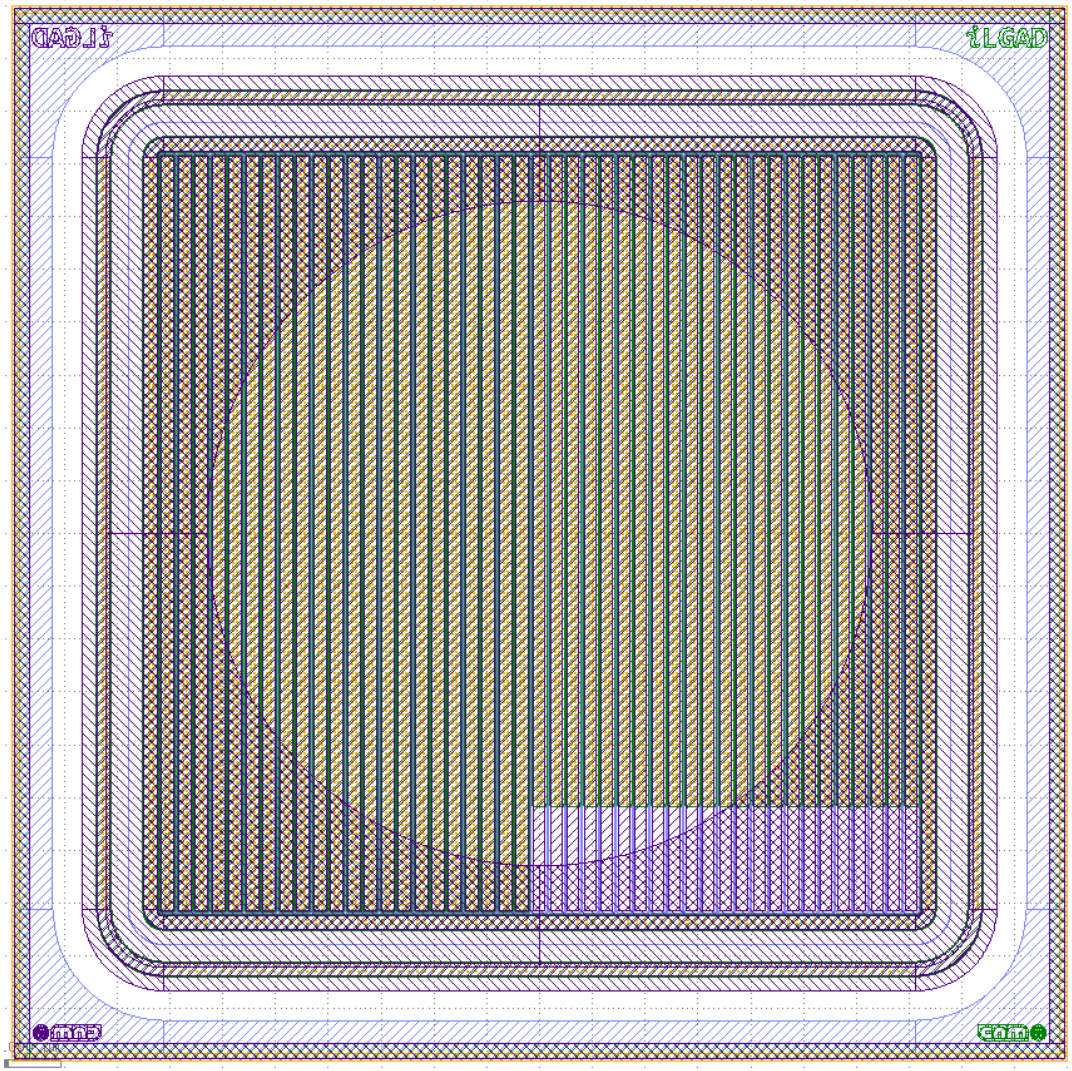
iLGAD. First Mask Set Description. LGAD, PiN Pad

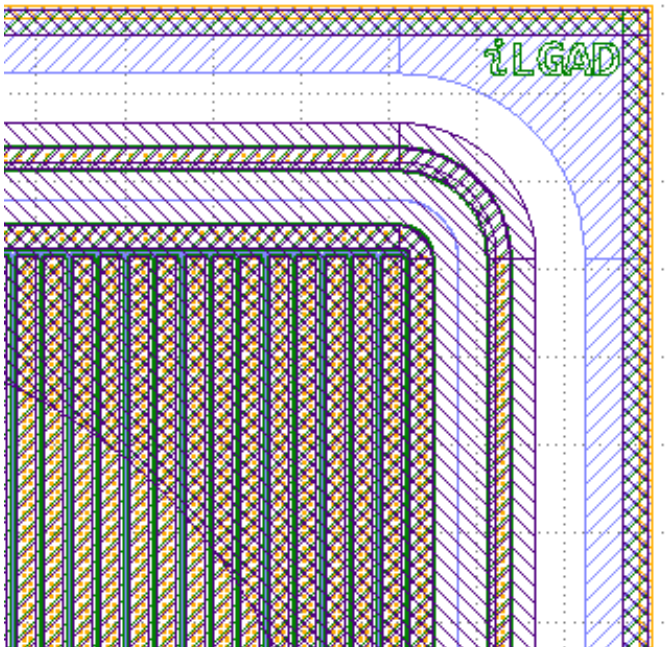




- **113** LGAD Pad Detectors
  - ✓ **12** (8 x 8 mm mult area)
  - ✓ **49** (3 x 3 mm mult area)
  - ✓ **52** (1 x 1 mm mult area)
- **17** PiN Detectors
  - ✓ **2** (8 x 8 mm active area)
  - ✓ **5** (3 x 3 mm active area)
  - ✓ **10** (1 x 1 mm active area)

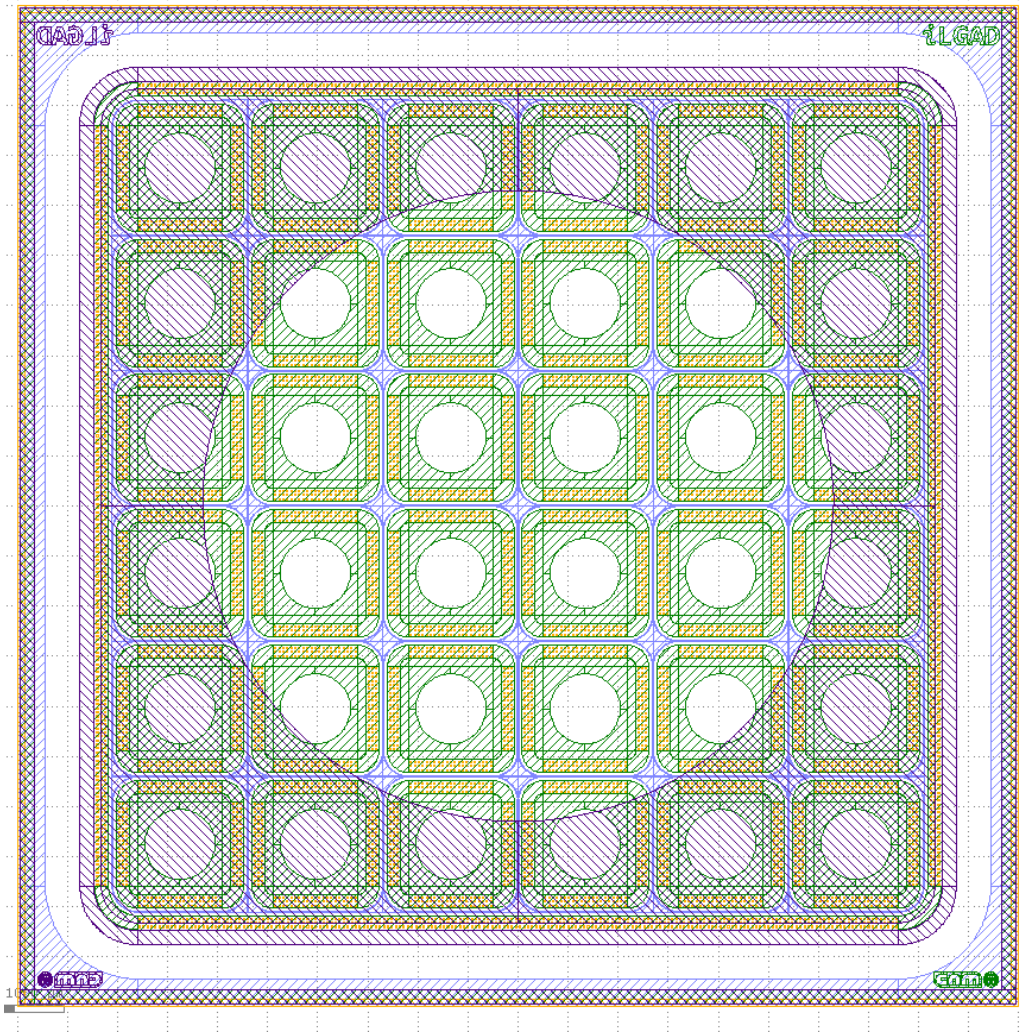
iLGAD. First Mask Set Description. iLGAD, PiN µStrips

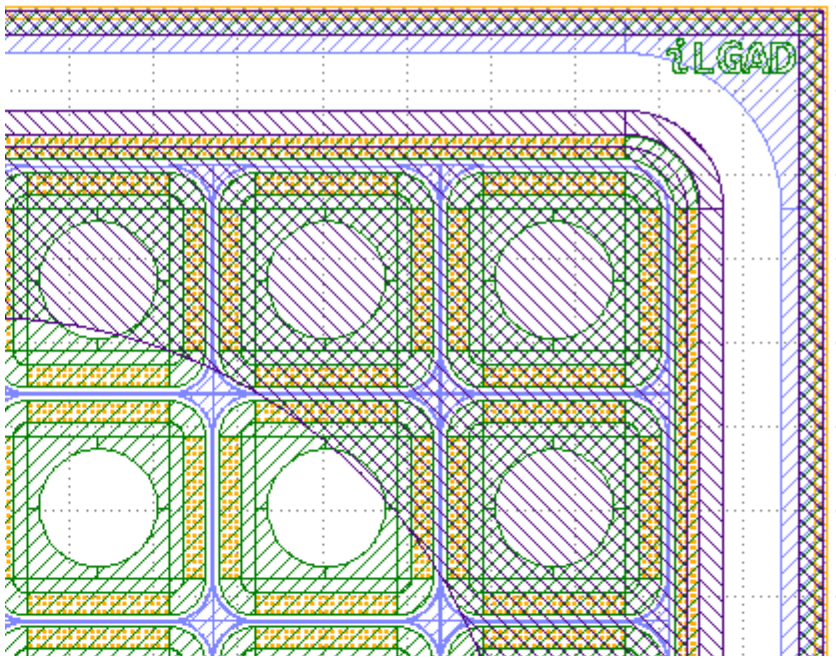




- **8** iLGAD pStrips Detectors
  - ✓ **4** (45 Channels)
  - ✓ **4** (90 Channels)
- **2** PiN pStrips Detectors
  - ✓ **1** (45 Channels)
  - ✓ **1** (90 Channels)

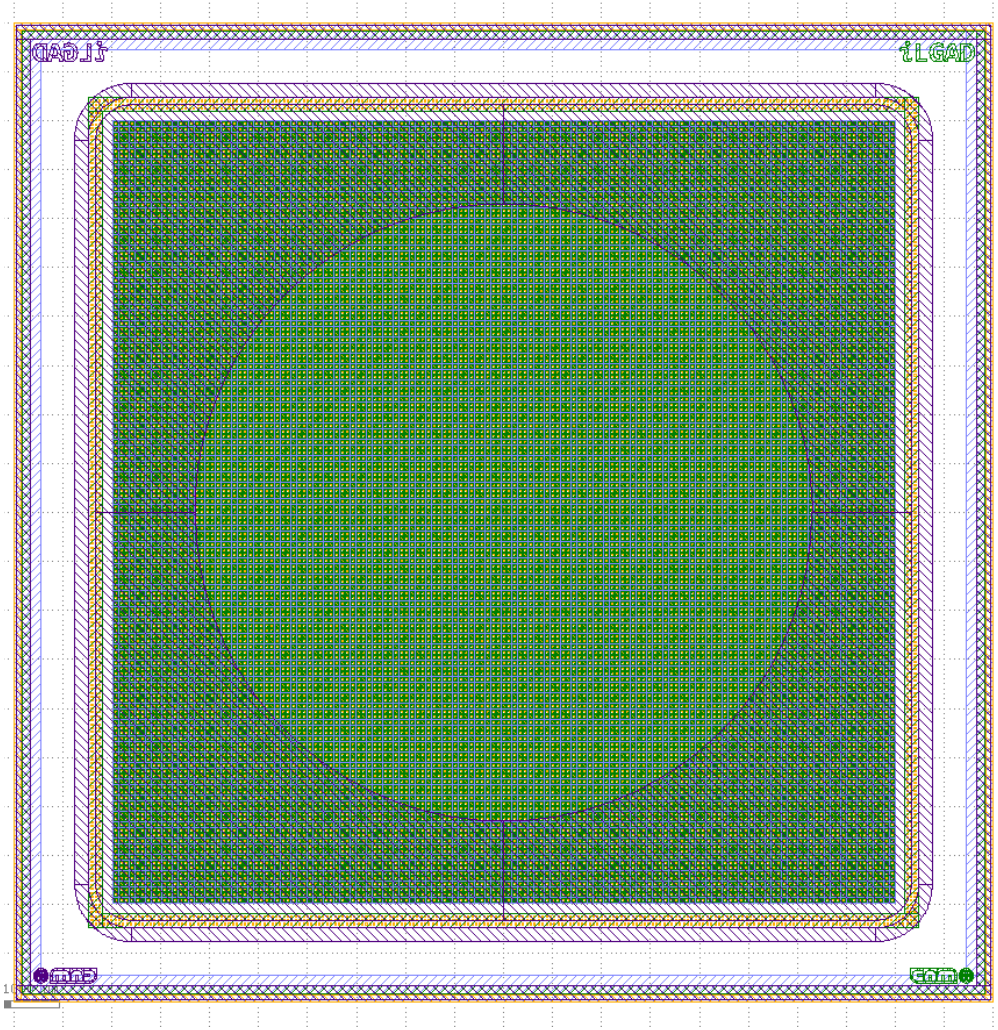
iLGAD. First Mask Set Description. iLGAD Pixels

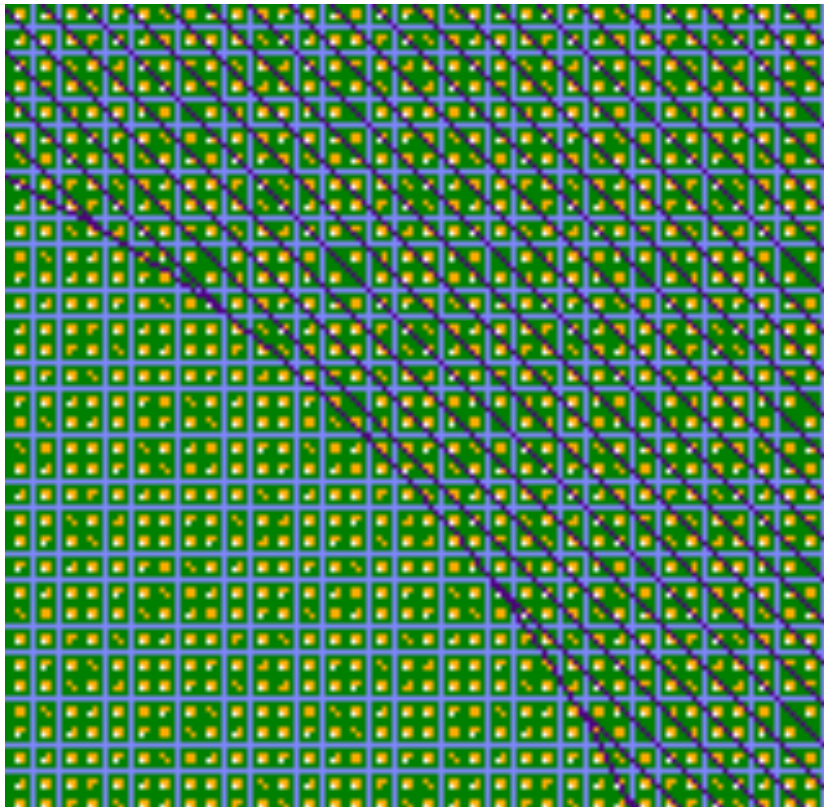




- **6** Pixelated iLGAD Detector (6 x 6 pixels)

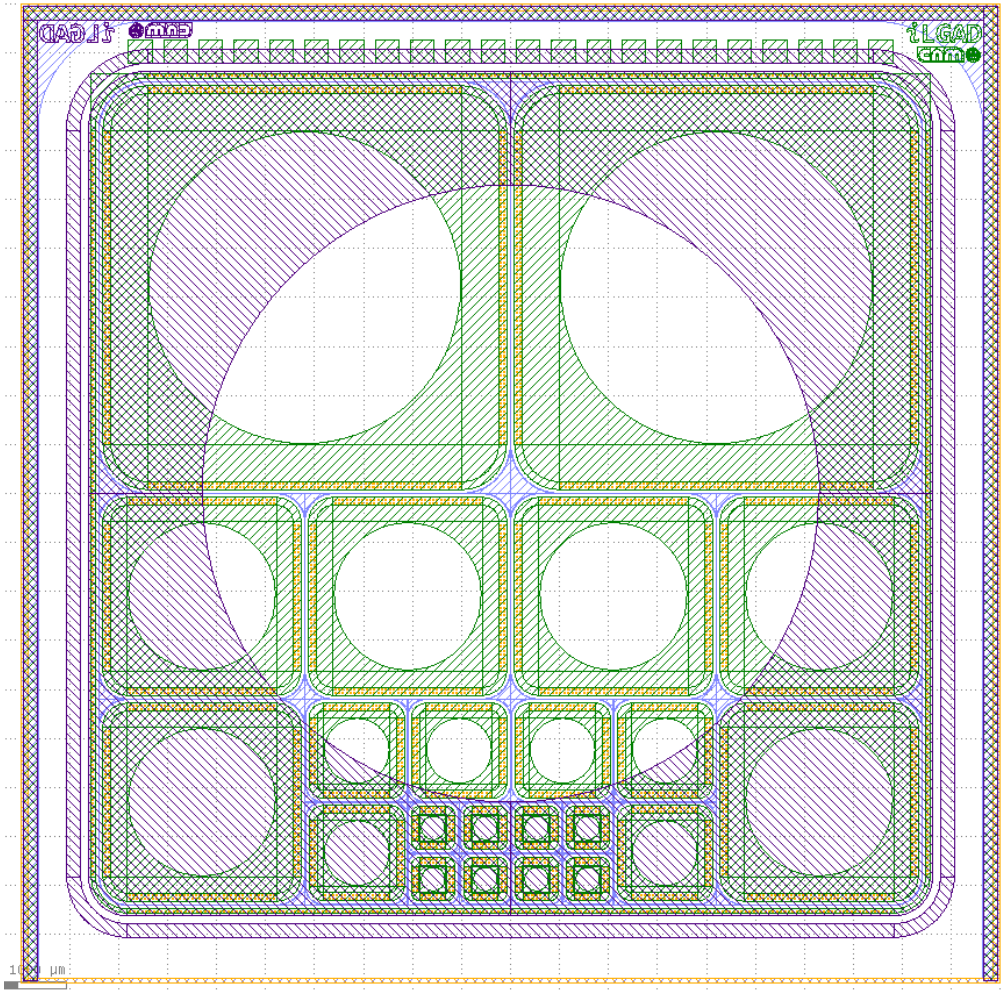
iLGAD. First Mask Set Description. iLGAD Pixels MediPix

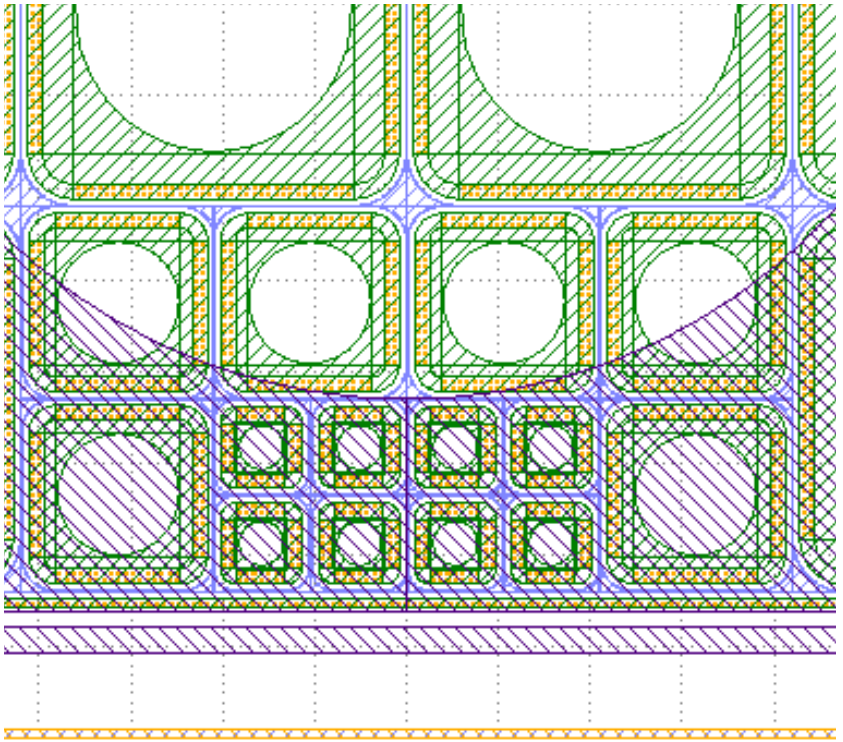




- **4** Pixelated iLGAD MediPix Detector (145 x 145 pixels)

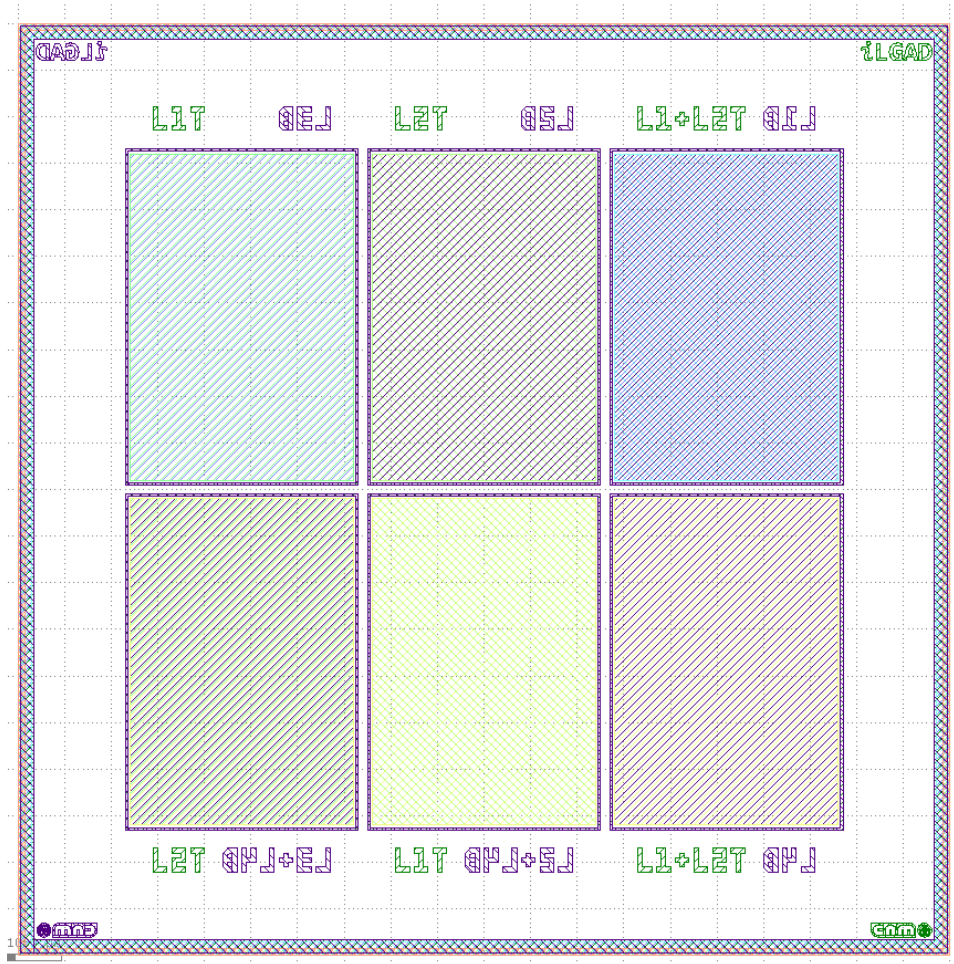
iLGAD. First Mask Set Description. iLGAD Timing

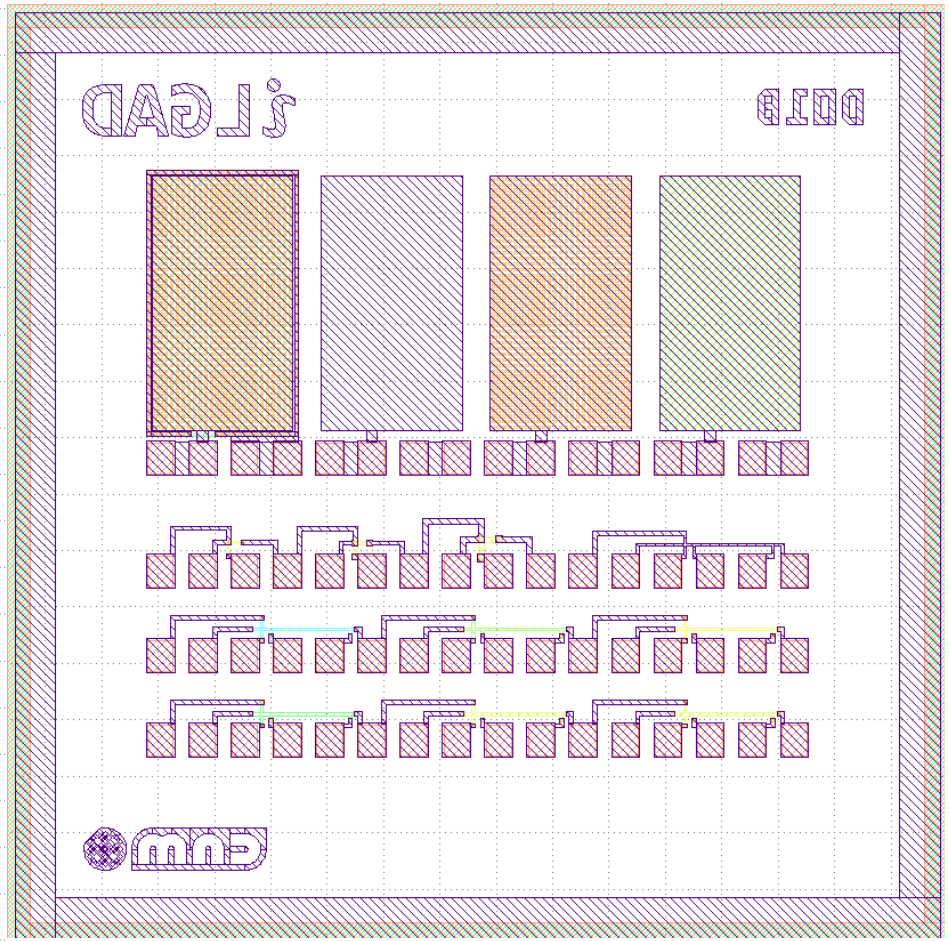




- **6** iLGAD for Timing Applications
  - ✓ **3** (720 µm to cut line)
  - ✓ **3** (370 µm to cut line)

iLGAD. First Mask Set Description. Test Structures



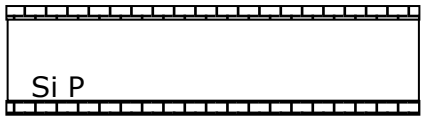


iLGAD. First Fabrication Process

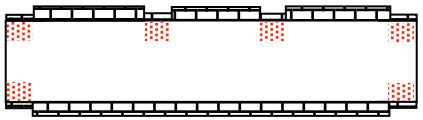
- **Double Side** Technological Process
- **12** Photolithographic Levels
- **100** Process Steps
- **4-5** Months

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

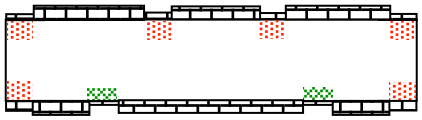
1 - Field Oxide



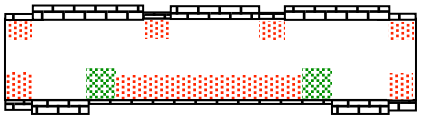
2 - P Channel + P Stop



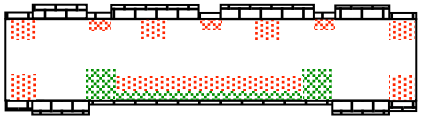
3 - Junction Termination Extension



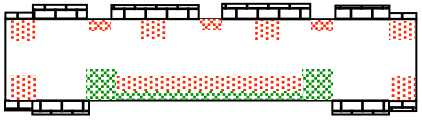
4 - Multiplication Well



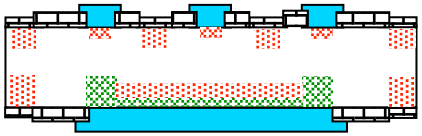
5 - N$^+$ & P$^+$ Wells



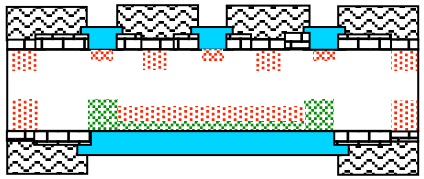
6 - Contacts

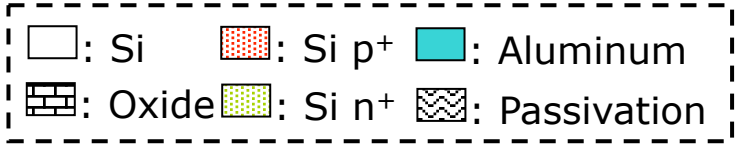


7 - Metallization



8 - Passivation





Conclusions

- First Technological Developments @ CNM
- iLGAD. Low Gain P on P Detector
  - ✓ Position-Sensitive
  - ✓ Timing
- Double-Sided LGAD
  - ✓ Pad LGAD @ Back-side
  - ✓ Ohmic Read Out @ Front-side
- Simulation
  - ✓ Optimization
    - ➢ Technological
    - ➢ Electrical
    - ➢ Thinner Substrates for Timing
- First Mask Set
  - ✓ microStrips
  - ✓ Pixels
- First iLGAD Prototypes
  - ✓ 12 Mask
  - ✓ 100 Steps
  - ✓ 4-5 Months

Thank you for your attention !!!!