Technological Developments on iLGAD Detectors for Tracking and Timing Applications

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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-established 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.

Doping Profile: N+ on Pwell

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.
**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).

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**CERN Measurements:**

- Gain values obtained at 700 V for each type of measurement:

<table>
<thead>
<tr>
<th>Type</th>
<th>1.8 x 10^{13} cm^{-2}</th>
<th>2.0 x 10^{13} cm^{-2}</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCT - IR back</td>
<td>5.7</td>
<td>31.9</td>
</tr>
<tr>
<td>TCT - Red back</td>
<td>6.2</td>
<td>21.4</td>
</tr>
<tr>
<td>TCT - Red front</td>
<td>4.3</td>
<td>W3 = 10.6</td>
</tr>
<tr>
<td>Sr-90</td>
<td>4.4</td>
<td>W4 = 11.7</td>
</tr>
</tbody>
</table>

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

![Diagram of LGAD and iLGAD microstrips](image-url)
**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 iLGAD 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.

**Zoom**
**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.

![iLGAD MIP Simulation](image1)

![LGAD Strips MIP Simulation](image2)
2D Simulation. MIP (300 um Thickness)

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

**iLGAD Gain Simulation**

```
Gain

MIP1_iLGAD
MIP2_iLGAD

Reverse Bias (V)
```

**LGAD Strip Gain Simulation**

```
Gain

MIP1_LGAD_Strips
MIP2_LGAD_Strips

Reverse Bias (V)
```
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**

- **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
iLGAD. First Fabrication Process

- **Critical Step**
  - Multiplication Layer Formation
    - Boron Implantation 100 keV @ 1.8, 1.9 and 2.0E13 atoms/cm²
    - 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

Symbols:
- Si: Light gray
- Si p⁺: Red
- Al: Cyan
- Oxide: Dark gray
- Si n⁺: Beige
- Passivation: Light gray and beige

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Instituto de Microelectrónica de Barcelona
iLGAD. First Fabrication Process

**FRONT-SIDE**

**BACK-SIDE**

**Microstrips**

**Pixel**
**iLGAD. First IV & CV Measurements**

**IV Characteristic LGAD4**

- **Dose = 1.8 \times 10^{13} \text{ cm}^{-2}**
- **Dose = 1.9 \times 10^{13} \text{ cm}^{-2}**

**Capacitance Characteristic of iLGAD Diodes**

- **$V_{FD} = 70\text{V}$**
- **30V**
- **34V**

- Dose = 1.8 \times 10^{13} \text{ cm}^{-2}
- Dose = 1.9 \times 10^{13} \text{ cm}^{-2}
**iLGAD. TCT Measurements at IFCA**

- Sensors: W1-K037 (STR.45.160.8000.06.12)
- Laser: 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.
Conclusions

- iLGAD designed, optimized and fabricated @ CNM

- iLGAD advantages
  - ✓ More uniform charge amplification
  - ✓ Based on a well established 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 !!!!

“Thats all Folks!”
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)

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- 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

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iLGAD. First Mask Set Description. Test Structures
Technological Developments on iLGAD Detectors

P on P Silicon Detectors. Background


United States Patent [19]

Lightstone et al.

[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


[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

References Cited

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4,586,066 4/1986 McIntyre .......................... 357/56 X


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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