Status report on the radiation tolerance assessment of CNM AIDA2020v2 and HPK-P2 LGADs

IFCA:
Measurements by: Richard Jaramillo & Javier Gonzalez Sanchez
Ivan Vila, Marcos Fernandez\(^{(1)}\), Efren Navarrete

CERN:
Measurements by: Esteban Curras & Ana Ventura
Michael Moll, Marcos Fernandez, Julian Boell

UZH:
Anna Macchiolo, Riccardo del Burgo, Matias Senger, Daniel Hernandez

\(^{(1)}\) Also visiting scientist at CERN-SSD
1) Summary of **electrical characterizations** of non-irradiated and irradiated diodes of both, **HPK2** and **CNM AIDA2020 v2** productions, performed by 3 different institutes (CERN-SSD, IFCA, UZH).

2) **Algorithm** for IV measurement analysis:
   1) Automatic extraction of breakdown voltages
   2) Extraction of depletion voltage of gain layer from IV measurements
   3) Acceptor removal fits (IV vs CV)

3) **Timing** characterization of irradiated HPK2 samples
Samples and measurement campaign

CNM-AIDAv2 samples
4×4” wafers, same dose/energy parameters:
50 μm thick, dose medium, energy low
2 samples/fluence

HPK2 samples
4 different doping profile “splits”
W25-S1, W31-S2, W36-S3, W42-S4
50 μm thick
1 detector/split (W42: 2 detector/split)
2 splits/fluence

Common to both:
Measured structures: Single pads (PINs and LGADs): 1.3×1.3 mm²
Characterized both non-irradiated and irradiated with neutrons (Lbj) at: 4e14, 8e14, 1.5e15, 2.5e15 neq/cm²

Measurement campaign:

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1) By comparison with HPK-W42-PIN, gain still well visible until 1.5e15 n_{eq}/cm^2
Gain disappeared at 2.5e15 n_{eq}/cm^2
All PINs behave similar with breakdowns around 620V, for all fluences

LGADs $4e^{14}$, $8e^{14}$: Clear difference from their PINs, pointing at existence of gain at these fluences.

LGADs $1.5e^{15}$, $2.5e^{15}$: LGAD are very PIN similar, probably no gain at this fluences. Similar breakdown voltage for LGAD and PIN.

Notation:

$PX$ = PIN irradiated to Xe14
$CX$ = CNM LGAD irradiated to Xe14
$HX$ = HPK2 LGAD irradiated to Xe14
HPKs:

W25 (split 1, highest gain) breaks ~40 V earlier than W36 (split 3) at 4e14 and 8e14 neq. For \( \Phi \geq 1.5e15 \), W25 (split 1) breaks slightly after W36.

PINs (not shown) measured up to 200V for HPK2

CNM:

CNM 8e14 and 1.5e15 have higher breakdown than HPK2 at same fluence
CNM 2.5e15 breaks earlier than HPK2
Leakage current scaling with fluence

Nominal in Moll's thesis $\sim 4 \times 10^{-17}$ A/cm

CERN HPK2 W25 and W36 PINs
Calculated at $V_{bias} = 105$ V and scaled to $T_R = 20^\circ$C
Breakdown voltage calculation

Breakdown can be calculated automatically using the “K” variable [1]:

\[ K(I, V) = \frac{\Delta I}{\Delta V} \frac{V}{I} \]

K~1 Ohmic resistor

\( V_{BD} \) defined as last bias at which K<8

https://doi.org/10.1016/S0168-9002(00)01207-9
Beneficial effects of fluence and temperature on breakdown voltage:

1) The higher the fluence, the higher the breakdown voltage (substrate resistivity increase?)

2) The lower the Temperature, the higher the breakdown voltage.
Gain layer depletion calculation

The characteristic foot on $1/C^2$ vs V of LGADs is interpreted as the depletion voltage of the gain layer. The position of the foot:

1) depends on fluence, it doesn't seem to depend on frequency (if you take care of zooming in)

2) has little variation with Temperature

Double linear fit of $1/C^2$ can be:

1) Disturbed by “bumps” near the foot

2) Usually done by hand: different slopes in the raising part or zoom levels can turn fit subjective.

We propose another method to calculate the gain depletion voltage, based on the measurement of the leakage current.
Gain layer depletion calculation

**Leakage current** of LGADs shows a distinct kink [1]:

1) at low bias → leakage current increase by multiplication in gain layer.

2) Then abrupt increase (kink position depends on Fluence) when field extends quickly into bulk

The formerly introduced K-variable is also very sensitive to the kink in leakage current.

In this case it **does not indicate a breakdown** but a transition.

https://doi.org/10.1016/j.nima.2020.164814
Comparison of $V_{gl}$ from IV and CV

Kink in IV coincides with kink in $1/C^2$ (at 1 kHz, -20 C)

$K(V)$ fitted with a gaussian.

The gain layer depletion voltage calculated from IV as $\mu - 0.5\sigma$ coincides best with $V_{gl}$ from CV.
Gain layer: removal constant (from IV)

- Dependence of gain layer depletion with Fluence for different temperatures

Fitting: $V_{gl}(\Phi) = V_{gl}(\Phi=0) \times \exp(-c\Phi)$

- Note that HPK2 and CNM-AIDAv2 have very different Gain Layer implementations
**Gain layer: removal constant (from \(1/C^2\))**

- Dependence of gain layer depletion with Fluence for different temperatures.

Fitting: \(V_{gl}(\Phi)=V_{gl}(\Phi=0)\times \exp(-c\Phi)\)

- Note that HPK2 and CNM-AIDAv2 have very different Gain Layer implementations

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**This talk**

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<th>S3</th>
<th>S4</th>
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<tr>
<td>Vgl (Lbj, (1/C^2), 10 kHz, 20 C)</td>
<td>4.3</td>
<td>4.5</td>
<td>4.6</td>
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<td>Vgl ((1/C^2), 1 kHz, -20C)</td>
<td>5.0</td>
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<td>4.7</td>
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<td>Vgl from IV</td>
<td>4.6</td>
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Marcos Fernandez

16th Trento Workshop on Advanced Silicon Radiation Detectors

17th Feb 2021
Timing measurements

UZH:

- Temperature control: climate chamber (-20°C)
- Reference sensor: LGAD AIDA-2020 run (35 µm, medium doping)
- Beta source: Sr90 radioactive source
- Readout boards: UCSC v1.1 ROB
- Amplifiers: fast amplifiers (in-house design) (4 GHz, 36 dB)

CERN-SSD:

- New: 3 sensor stack for calibration of 3 samples/run.
- Sensor stack inside Binder MKT 115T climatic chamber, range: [-70,+180] °C
- Amplifiers: Cividec 2 GHz, 40 dB

See J. Boell, 37th RD50 meeting for CERN-SSD HW details

Modified microwave oven used for additional shielding

Marcos Fernandez
Timing measurements

Riccardo Del Burgo, UZH

$\sigma_t$ (ps)

Bias Voltage (V)

$Sr-90$, -20 °C, (4-8-15)E14 $n_{eq}$ cm$^2$

E. Curras
CERN-SSD
PRELIMINARY (current status)
Conclusions

Electrical characterization campaign of CNM AIDAv2 and HPK2 devices, within the framework of the CMS-ETL project, conducted by 3 different institutions.

Comparison between irradiated LGADs to PINs at the same fluences indicate that:
1) HPK2 devices still hold gain until ~$1.5 \times 10^{15}$ $n_{eq}$/cm$^2$.
2) CNM AIDAv2 devices exhibit gain at $4 \times 10^{14}$ and $8 \times 10^{14}$ $n_{eq}$/cm$^2$

Breakdown voltages calculation can be accomplished by using the “K variable” which uses the current derivative weighted by the current over voltage. A value of K=8 was used in this talk.

1) Vbd found to increase with fluence and with lower temperature

Pad current characteristics of LGADs show a distinct kink that marks the transition between the gain layer depletion to the bulk depletion.

1) This kink was used to estimate Vgl without using CV information
2) Results show very good agreement with our $1/C^2$ measurements and measurements from other groups.

First timing measurements just started by UZH and CERN-SSD showing that a time resolution of ~30 ps can be reached for both CNM AIDAv2 and HPK2 devices at the tested fluences (measurements ongoing)
BACKUP
**Measurements performed**

**Common:** 50 um thick detectors. Pads and LGADs available

Different configurations across different institutes. Comparisons can be done “knowing what you do”

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Gain layer: Temperature and Fluence dependence

- As expected, voltage needed to deplete the gain layer decreases with fluence
- Soft dependence of $V_{gl}$ with Temperature
W25 (split 1, highest gain) breaks \(~40\) V earlier than W36 (split 3) at \(4\times10^{14}\) and \(8\times10^{14}\) neq.

After \(1.5\times10^{15}\) (included) W25 (split 1) breaks slightly after W36.
CV foot position and frequency

10 kHz, 30°C
10 kHz, -20°C

100 Hz: no zoom
100 Hz: zoom 1
100 Hz: zoom 2
HPK2-W25, 8e14, CV at different freq and temperatures

\[ C(1 \text{ kHz}, \Phi=0, 20^\circ\text{C} ; 0V)=C(100 \text{ Hz}, 8e14, 10^\circ\text{C} ; 0V) \]

\[ C_p(1 \text{ kHz}, 0V) \text{ depends on } T \]
Semiconductor analyzer settings? It seems to have resolution but no jump in current. Shouldn't GR be floating for non-irrad?

K-algorithm probably better at (+20C, non-irradiated). At -20C we probably measure more surface current instead of bulk current.
$\Phi = 0$

$59.87 - 1.5 \times 3.576 = 54.506$

$55.93 - 1.5 \times 3.438 = 50.773$
Estimation of Vgl non irradiated

-20°C, Φ=0
(from I_{total})

174.5 V

195.7 V

132.9 V

109 V

Non-irradiated:
- CERN IV@20°C
- IFCA IV@-20°C, 22°C
- UZH IV@25°C