

Technological development and performance of LGAD at IMB-CNM

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LGAD IMB-CNM



- 1. Run Overview**
- 2. Electrical Characterization before and after neutron irradiation**
- 3. Effects of high-energy carbon co-doping on LGAD performance**
- 4. Gain Measurements**

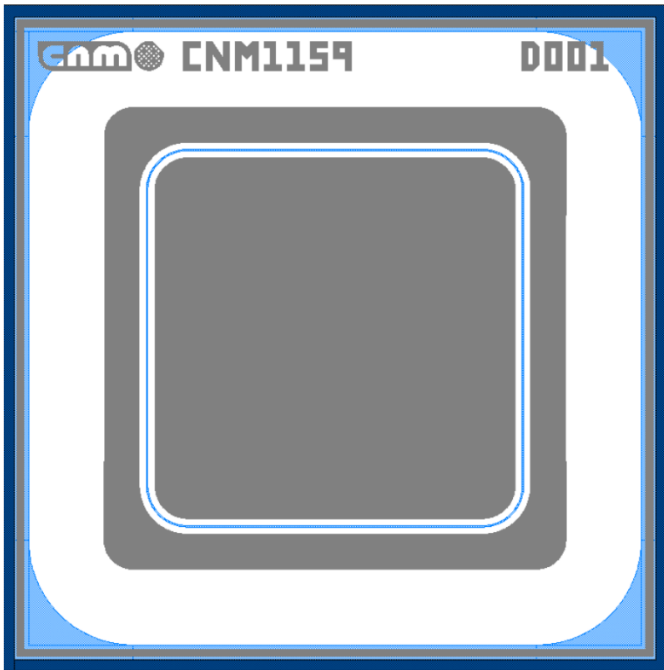


1. Run Overview

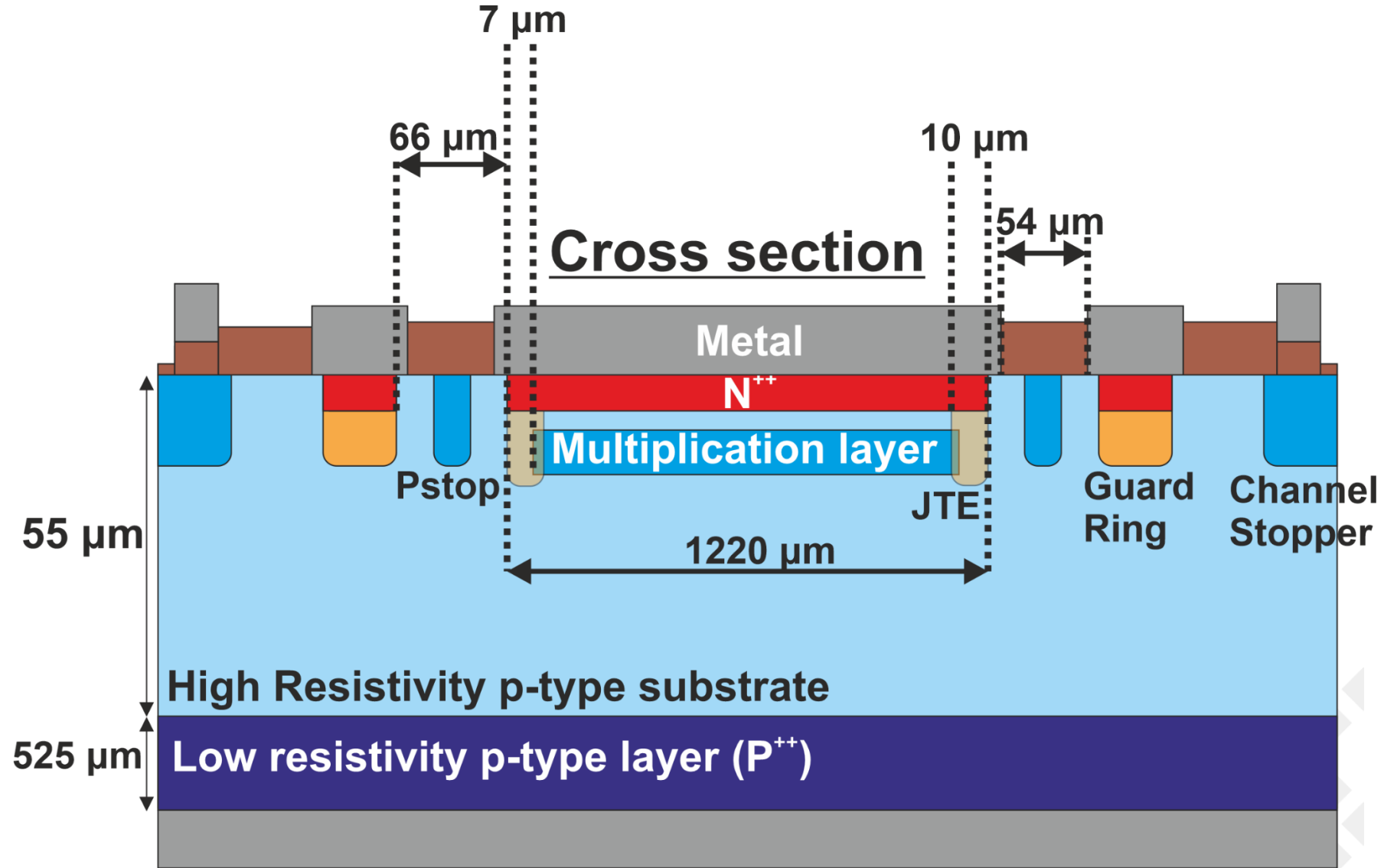


Run Overview

Front view



Cross section

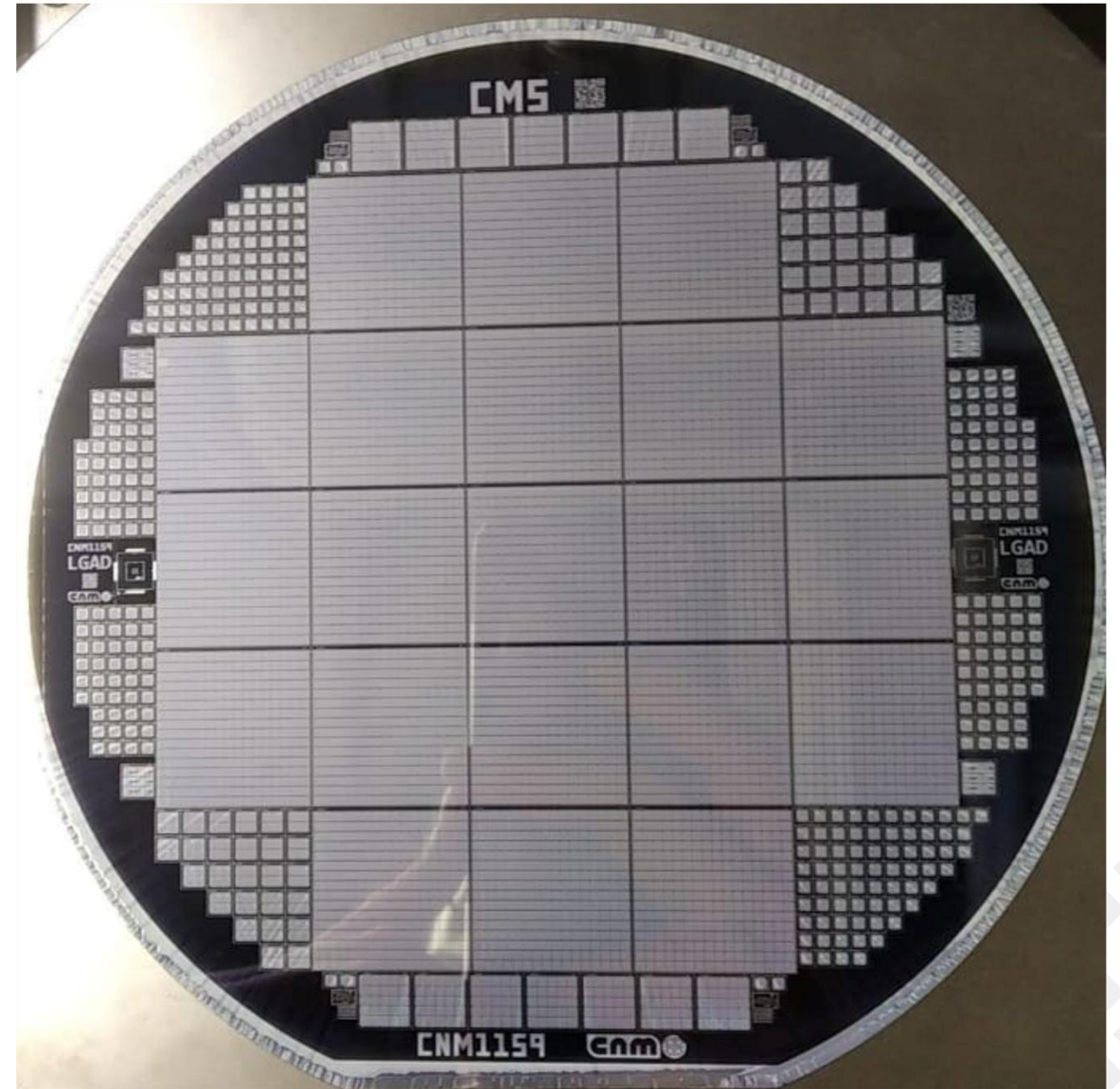


Run Overview

- Epitaxial wafers (55 μm active thickness on 585 μm P++ handle wafer)
- Pixel size (enclosed by p-stop) : 1.3x1.3 mm^2
- Pixel size (enclosed by multiplication layer): 1.22x1.22 mm^2
- Interpad distance (IP) = 80 μm

Wafer	D _{Boron} (at/cm ²)	D _{Carbon} (at/cm ²)
1	2.00e12	5e13
2	2.25e12	5e13
3	2.50e12	5e13
4	2.00e12	-
5	2.50e12	-

Presentation of single-pad analysis from wafer 3 and 5



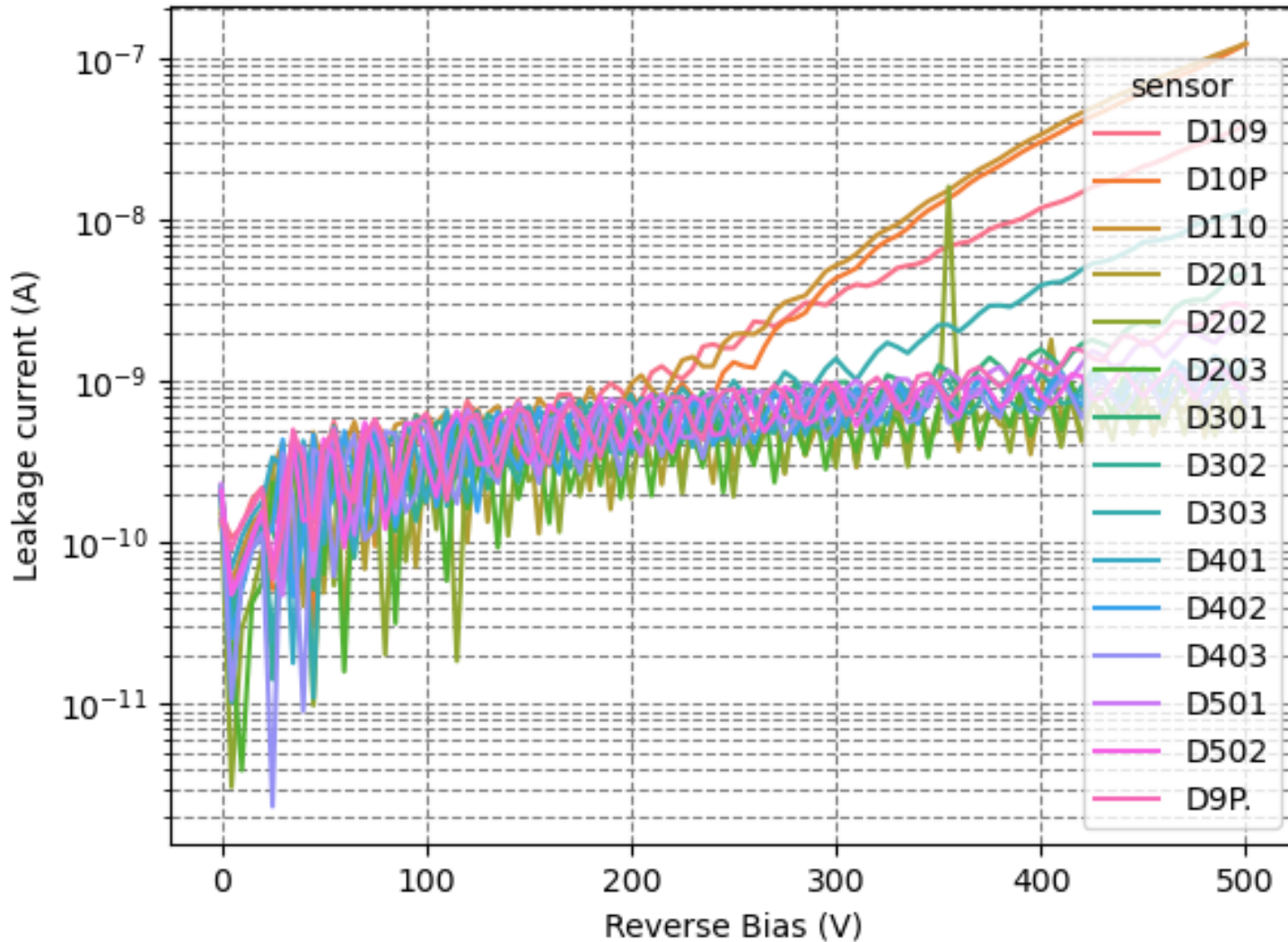
2.

Electrical Characterization before and after neutron irradiation



IV measurements - PiN

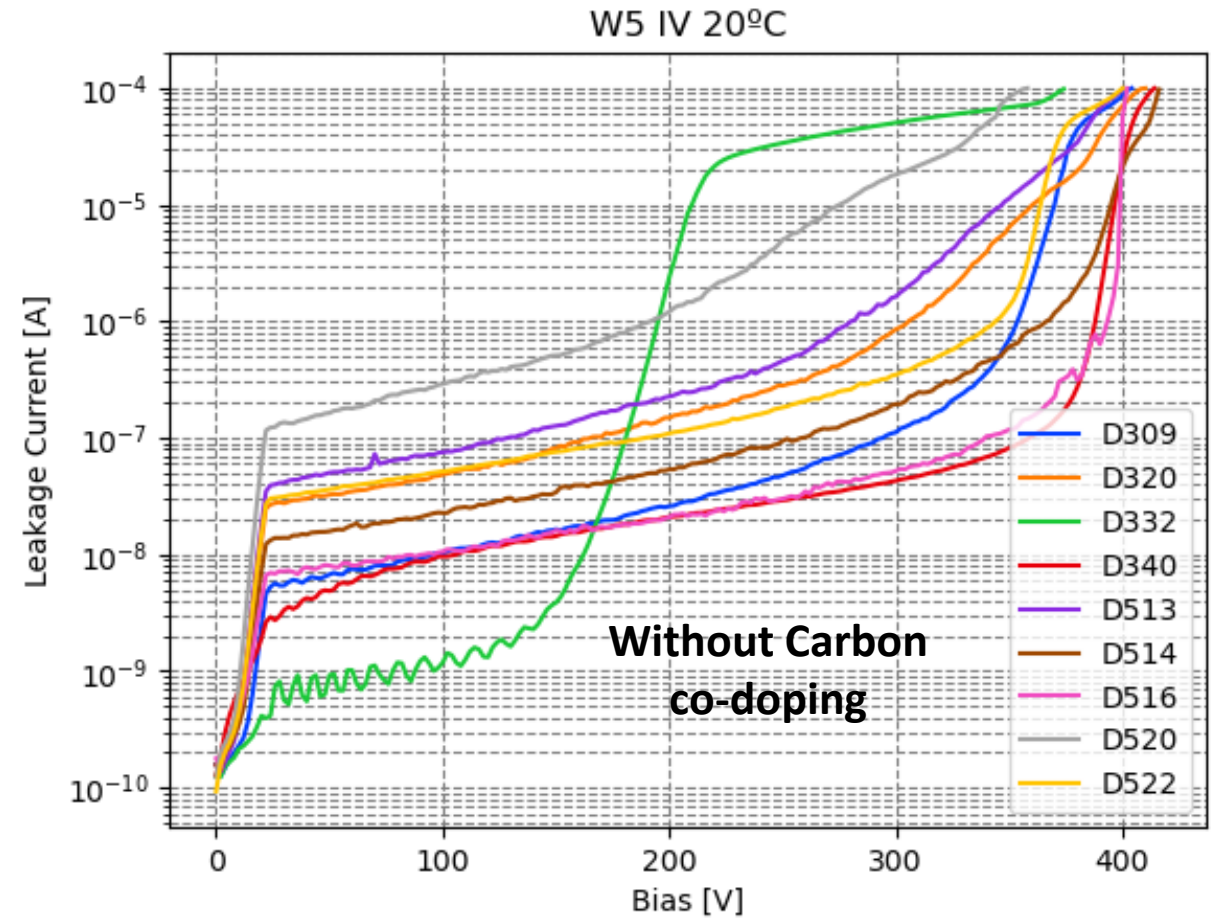
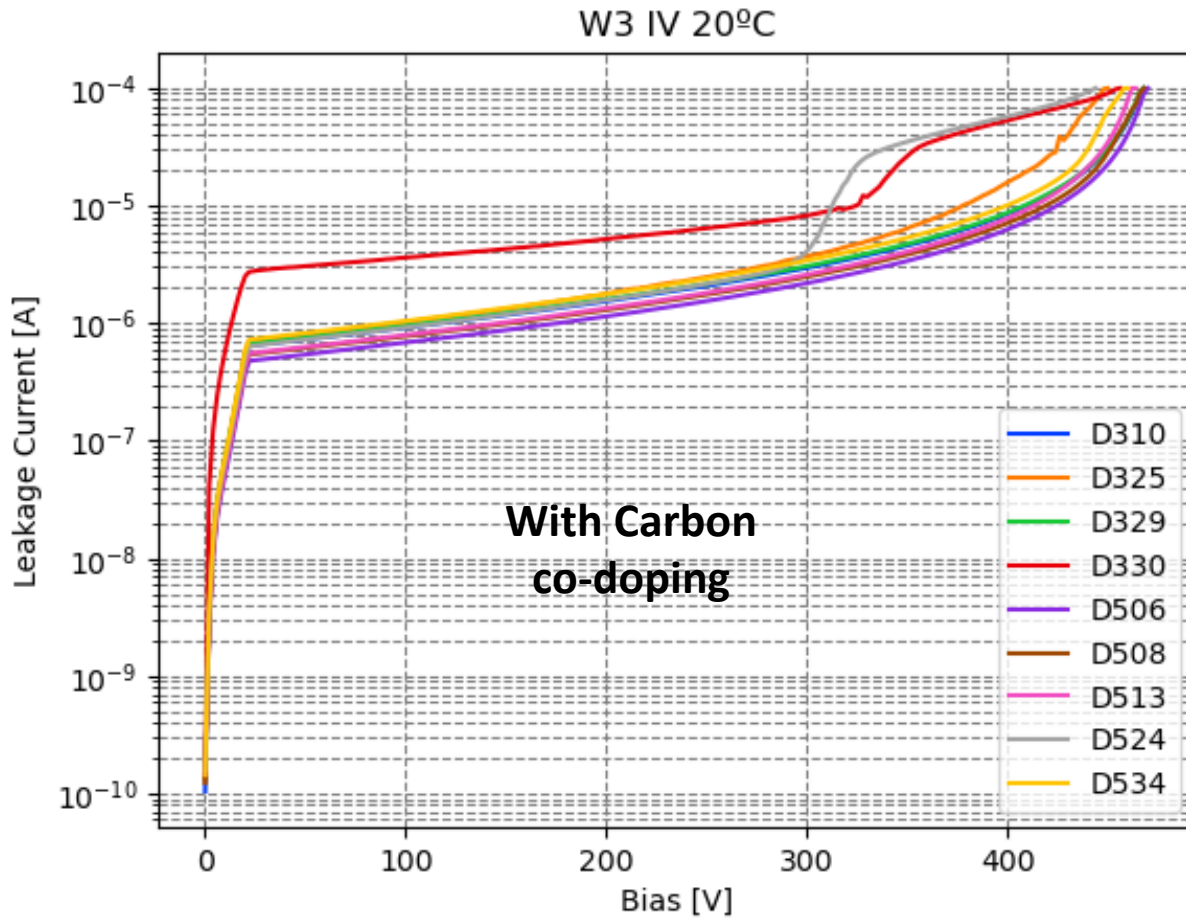
PiN IV at -25°C



IV behavior is reasonable, with high leakage current observed in some devices located at the outermost periphery of the wafer



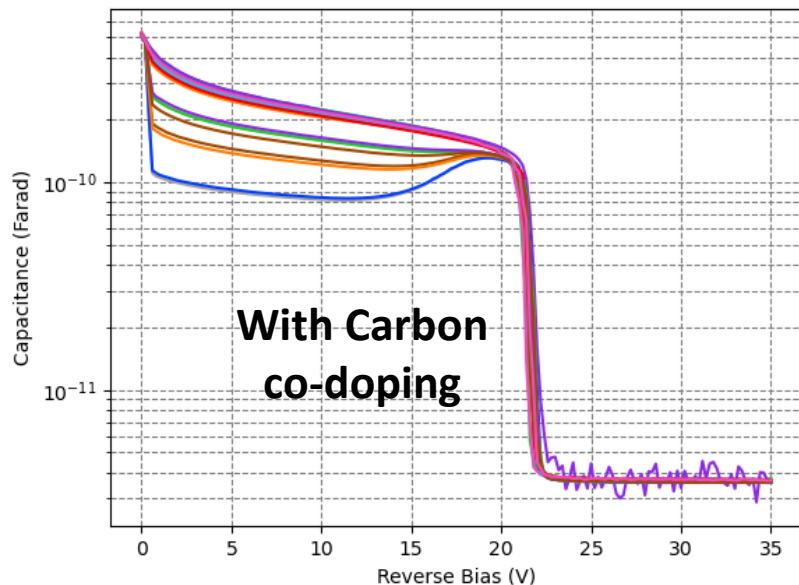
IV measurements - Before irradiation



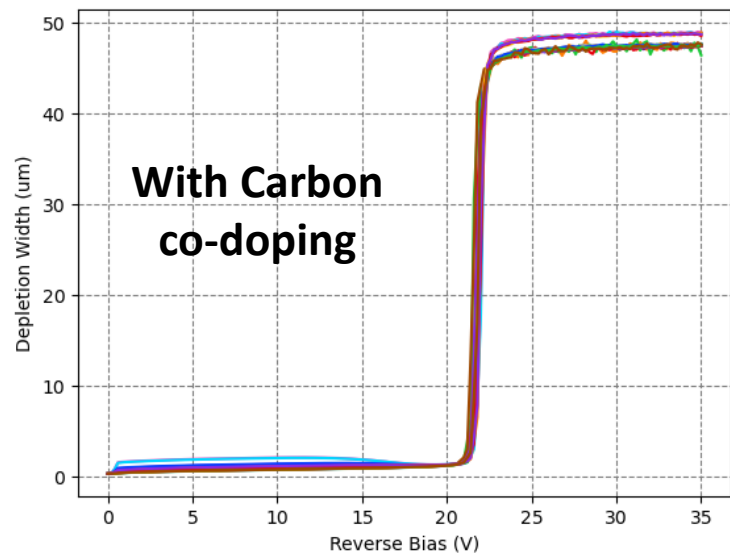
- Breakdown voltage > 300V
 - Higher Leakage current for devices with carbon co-doping
- Better uniformity of the breakdown voltage for devices with carbon co-doping

CV measurements - Before Irradiation

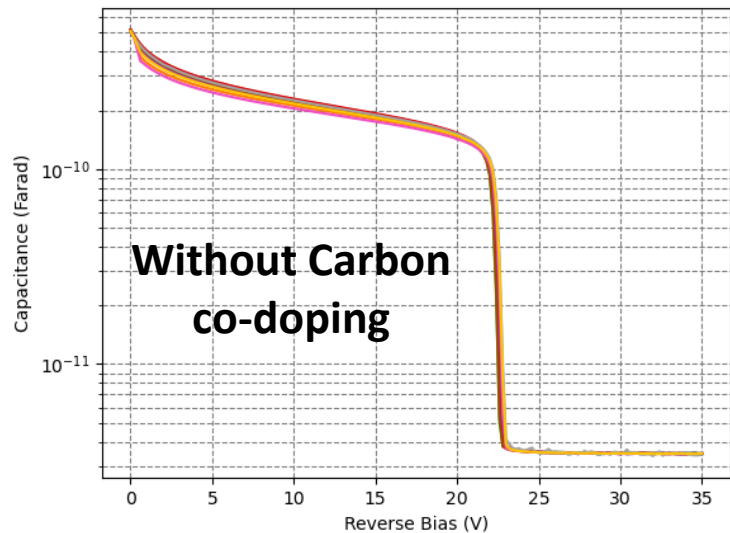
W3 CV Parallel Mode 200mV 1kHz



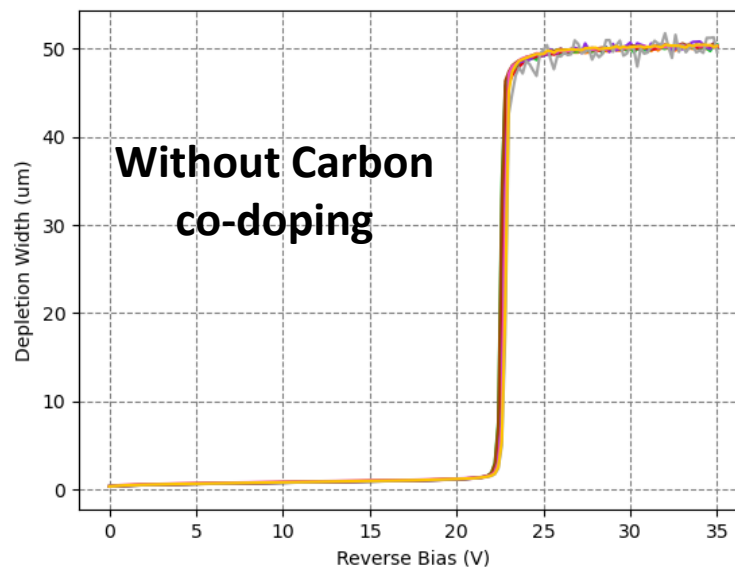
W3 CV Parallel Mode 200mV 1kHz



W5 CV Parallel Mode 200mV 1kHz



W5 CV Parallel Mode 200mV 1kHz



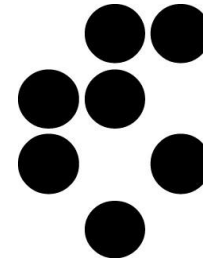
- Discrepancy of the capacitance during the depletion of the gain layer, probably coming from implantation induced defects
- Good uniformity of the V_{gl} among the various sensors $\sim 22-23$ V



Neutron Irradiation of 1 MeV at JSI TRIGA Reactor

Fluences of neutron Irradiation:

- 3 sensors at $8e14 \text{ n}_{\text{eq}}/\text{cm}^2$
- 3 sensors at $1.5e15 \text{ n}_{\text{eq}}/\text{cm}^2$
- 3 sensors at $2.5e15 \text{ n}_{\text{eq}}/\text{cm}^2$



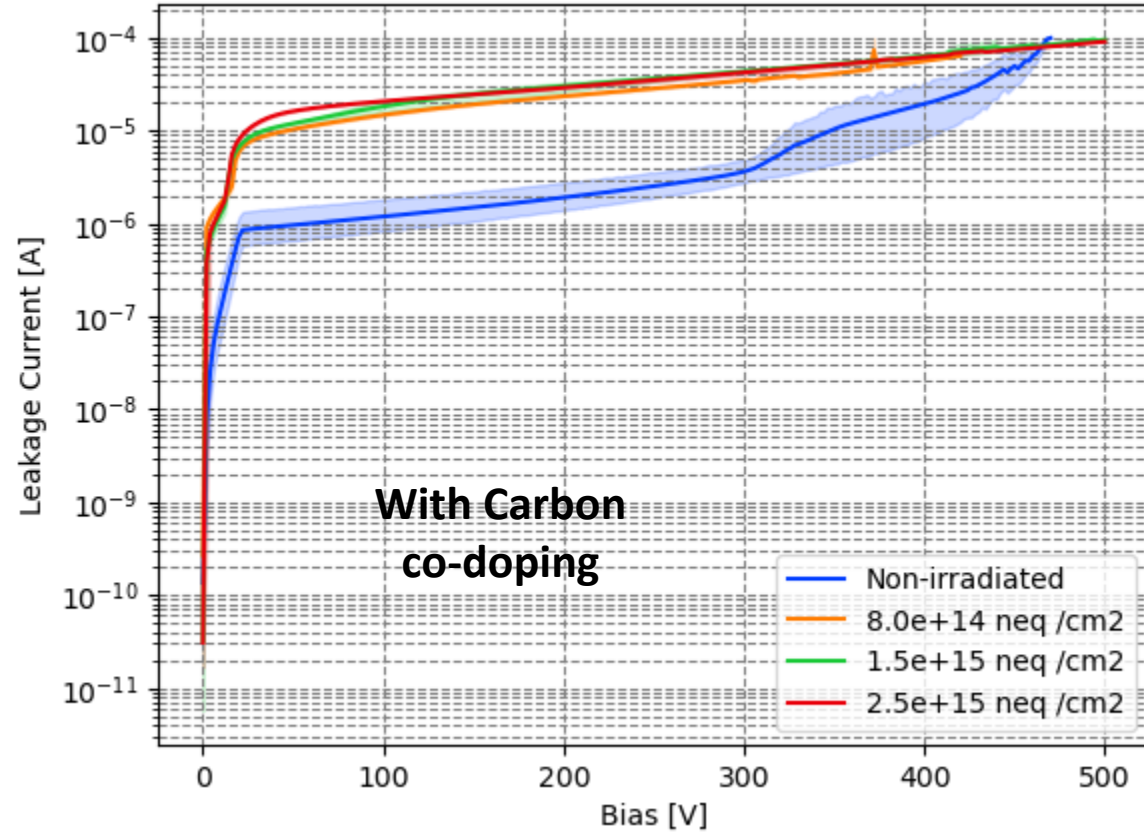
Jožef Stefan Institute
Ljubljana, Slovenia



IV measurements - after irradiation

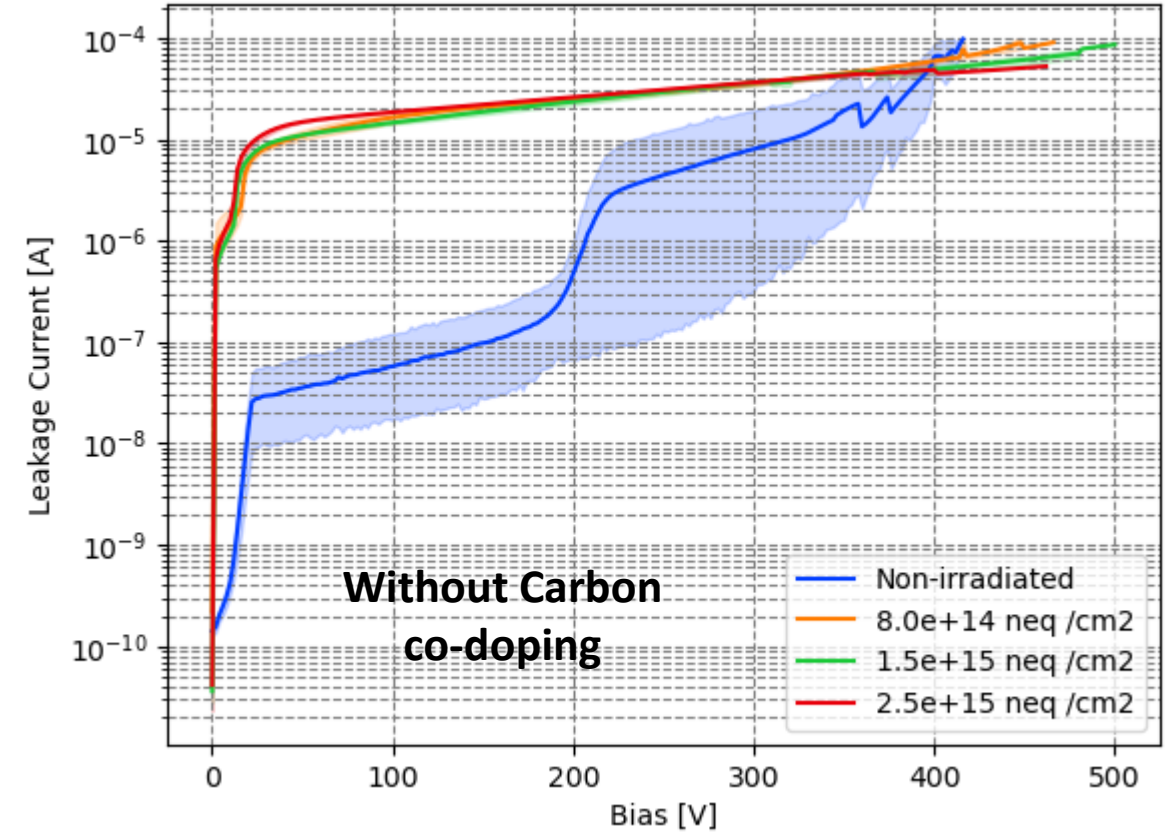
IV parameters: 0-500V, step of 2V

W3 IV 20°C



- Saturation of the leakage current observed
- Same behavior for devices with or without carbon co-doping

W5 IV 20°C



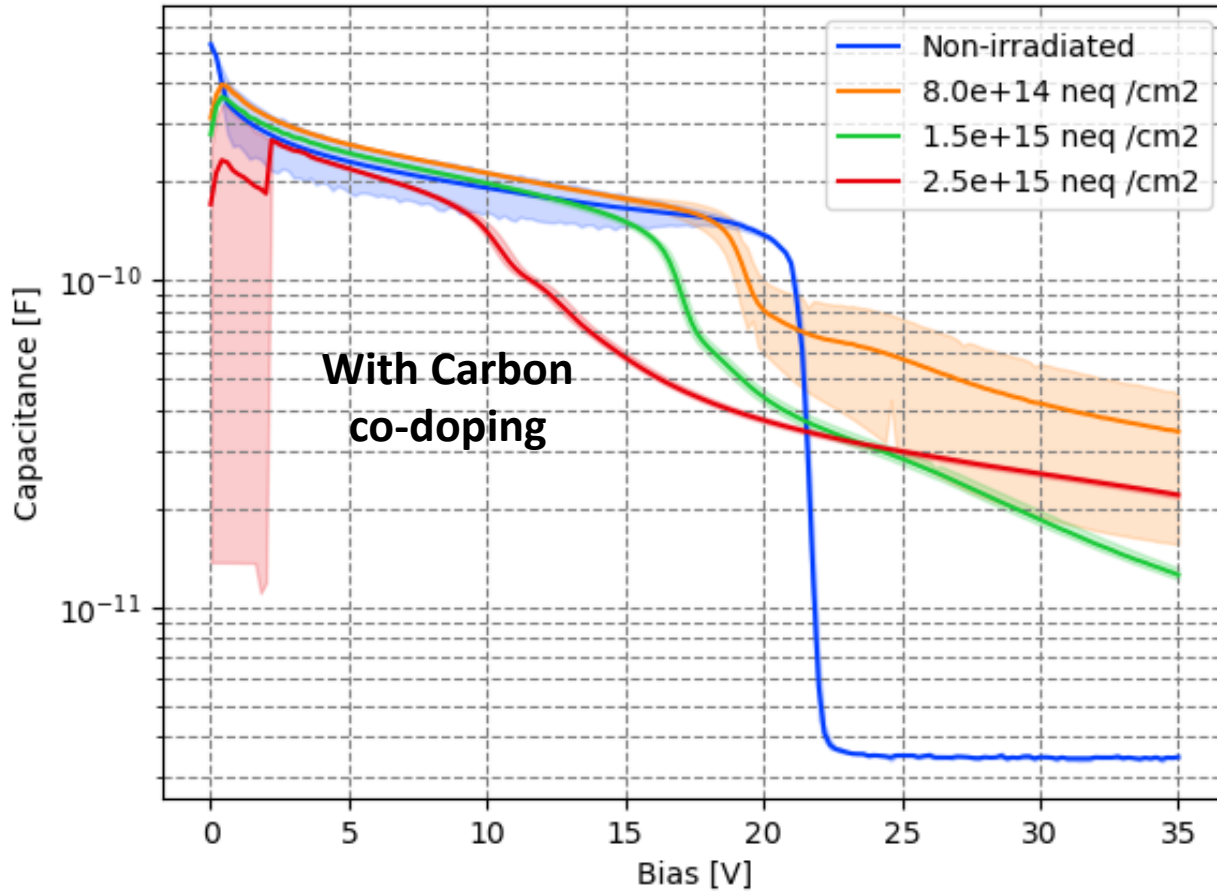
Results at 20 °C in concordance with the ones reported in literature:

J. Sorenson *et al* 2024 *JINST* **19** P05012
DOI [10.1088/1748-0221/19/05/P05012](https://doi.org/10.1088/1748-0221/19/05/P05012)

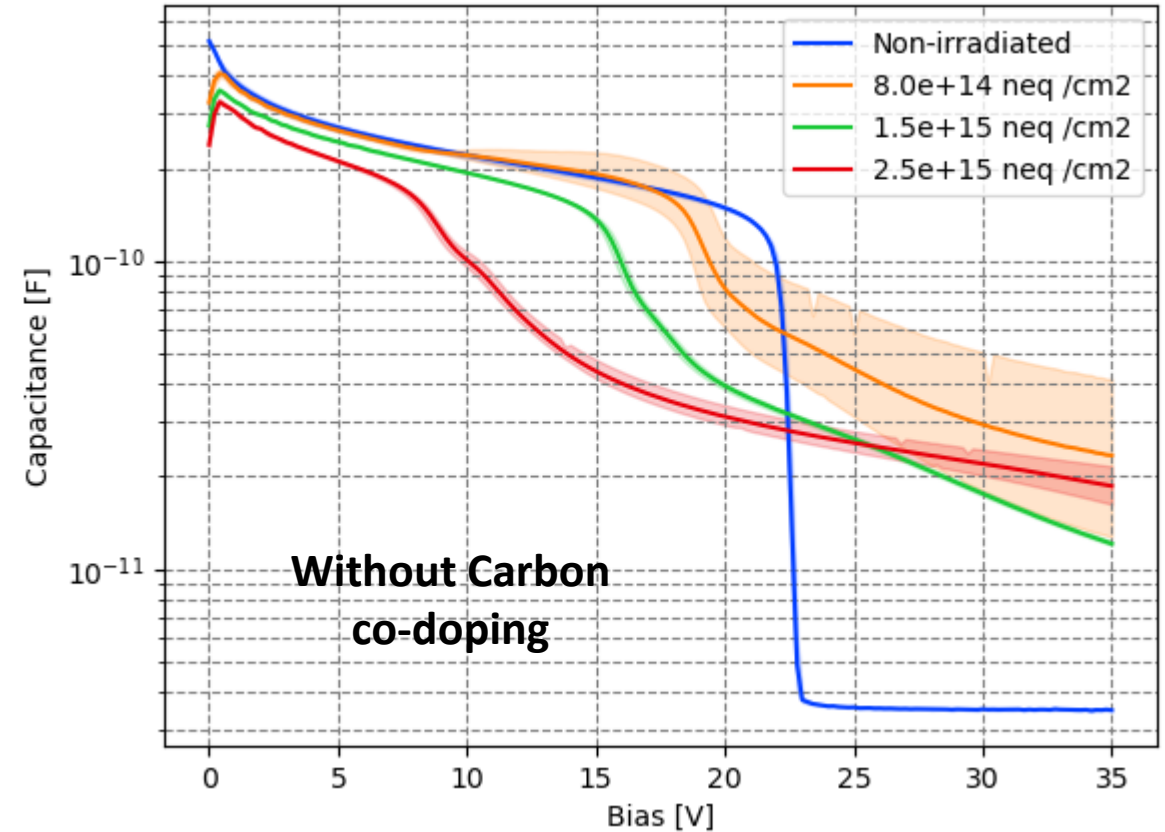
CV measurements - after irradiation

CV parameters: 0-35V, step of 0.2V, frequency 1kHz, amplitude 200 mV

W3 CV 1kHz 200mV 20°C



W5 CV 1kHz 200mV 20°C



Ongoing work:

- Extraction of acceptor removal constant from IV/CV measurements
- Timing and gain measurements with Sr90

3.

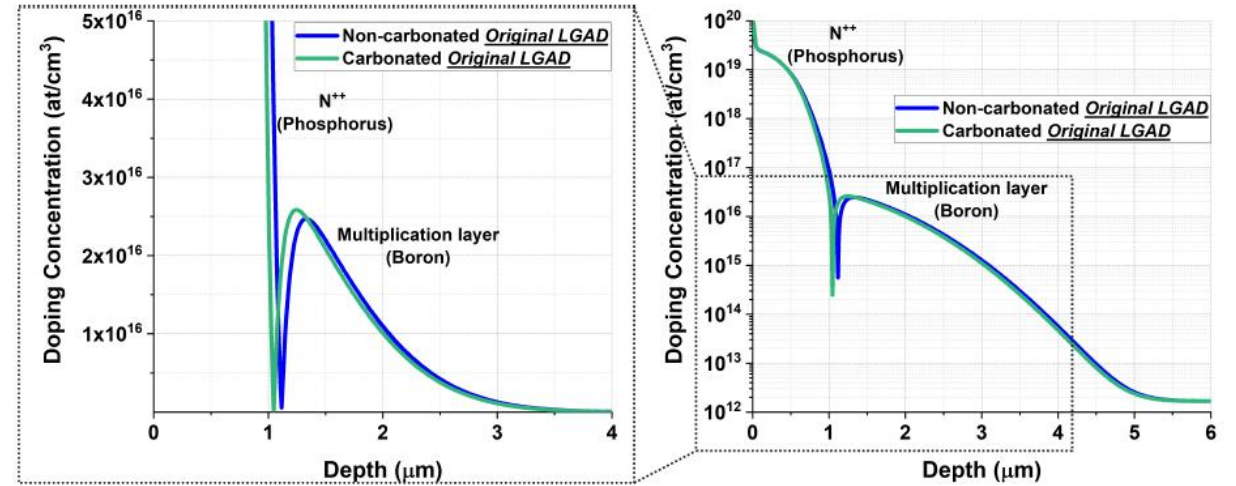
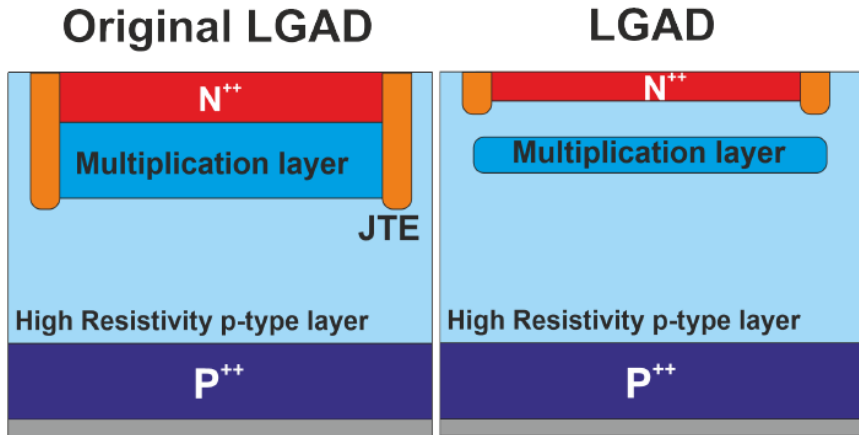
Effects of high-energy carbon co-doping on LGAD performance

The Effects of High-Energy Carbon Co-Doping on IMB-CNM LGAD Fabrication and Performance.

J. Villegas, F.Dougados, *et al* *Sensors* 2025, 25, 5571.

DOI [10.3390/s25175571](https://doi.org/10.3390/s25175571)

Doping Profiles from TCAD



Shallow Gain Layer with carbon co-doping

Deep Gain Layer with carbon co-doping

Slower diffusion of Boron

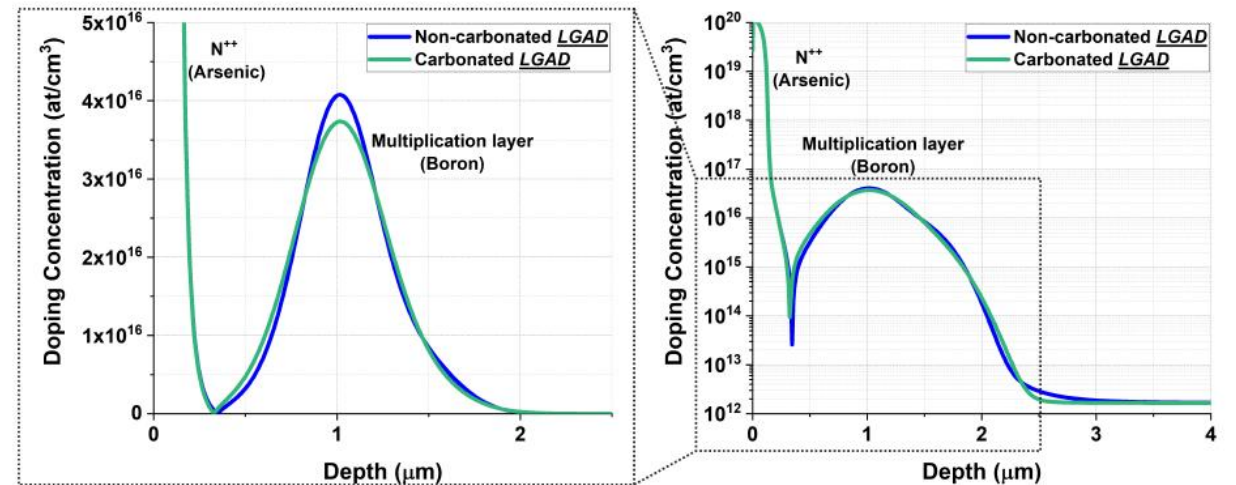
Faster diffusion of Boron

Carbon atoms blocking excess interstitial paths

Higher lattice damage from the high-energy implantation

Higher doping peak than devices without carbon co-doping

Lower doping peak than devices without carbon co-doping

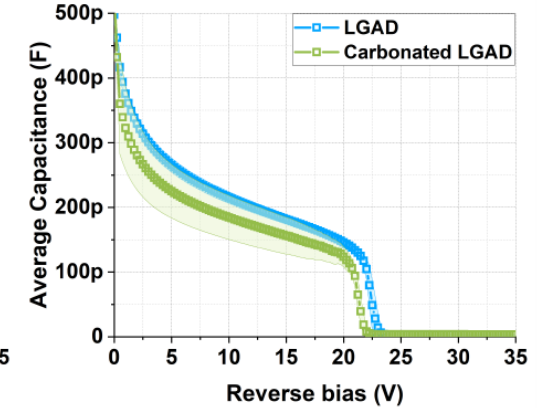
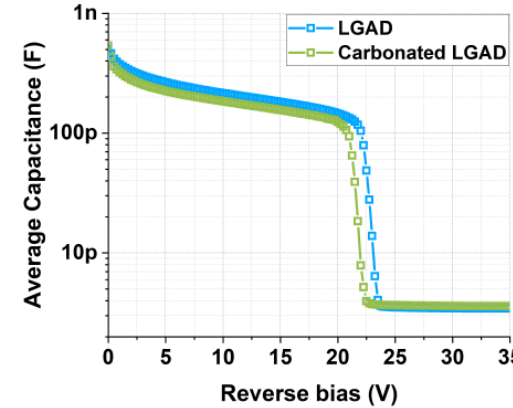
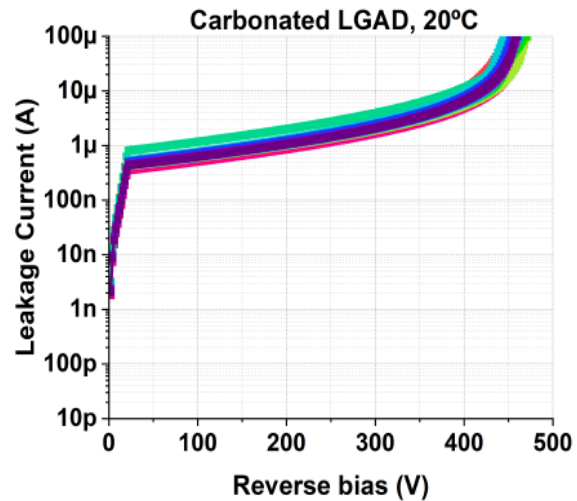
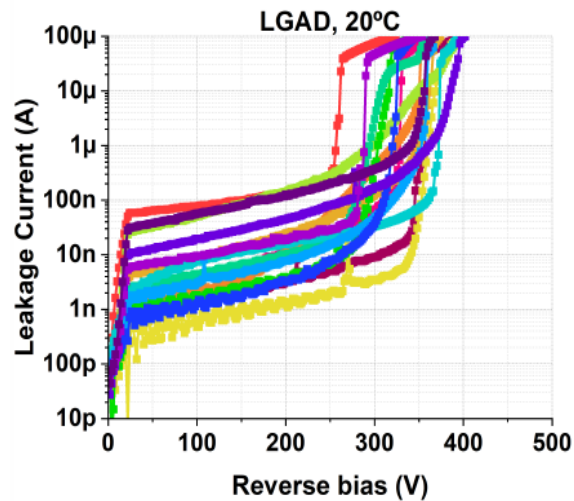
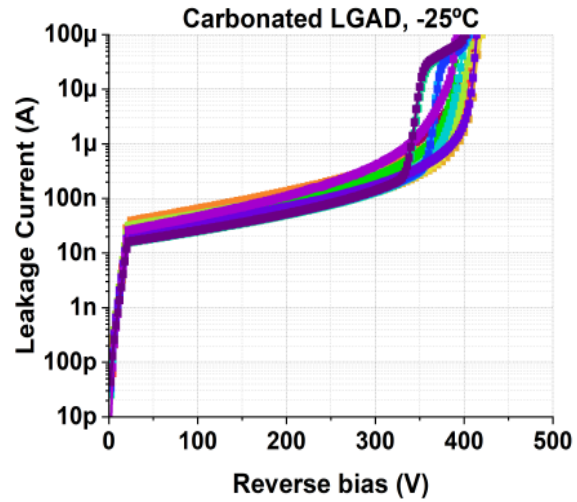
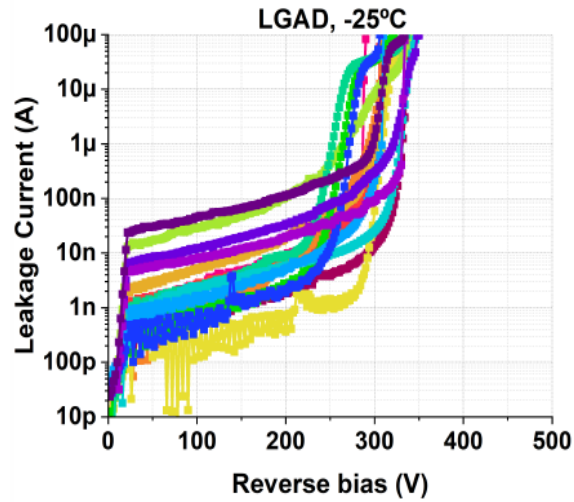


Previous paper:

The effects in fabrication and performance of carbon doping on IMB-CNM manufactured LGADs

J. Villegas *et al* NIMA 2024 1064(12):169424 DOI [10.1016/j.nima.2024.169424](https://doi.org/10.1016/j.nima.2024.169424)

Electrical Characterization



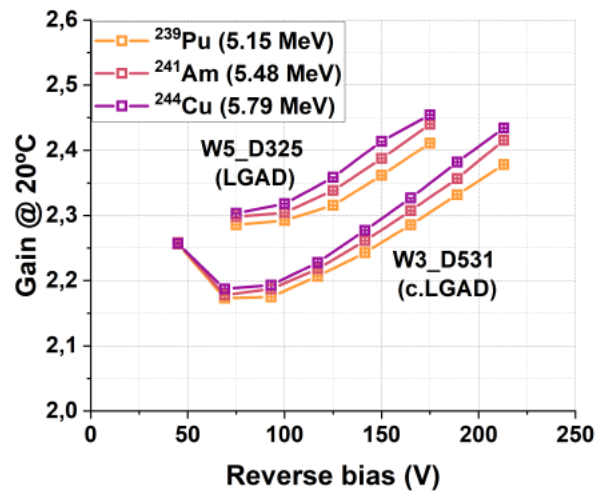
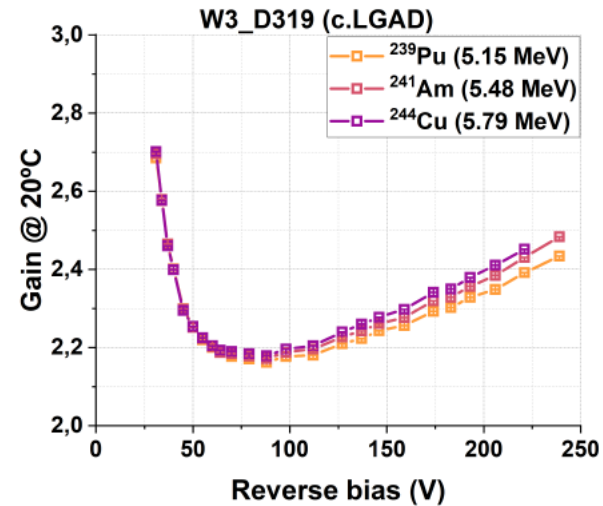
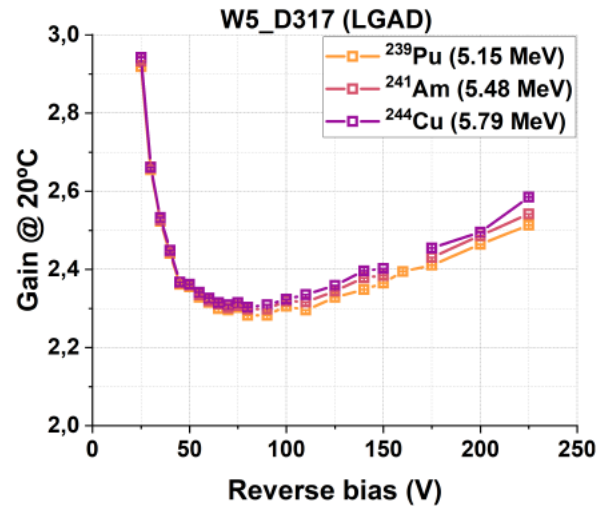
With carbon co-doping

Higher leakage current

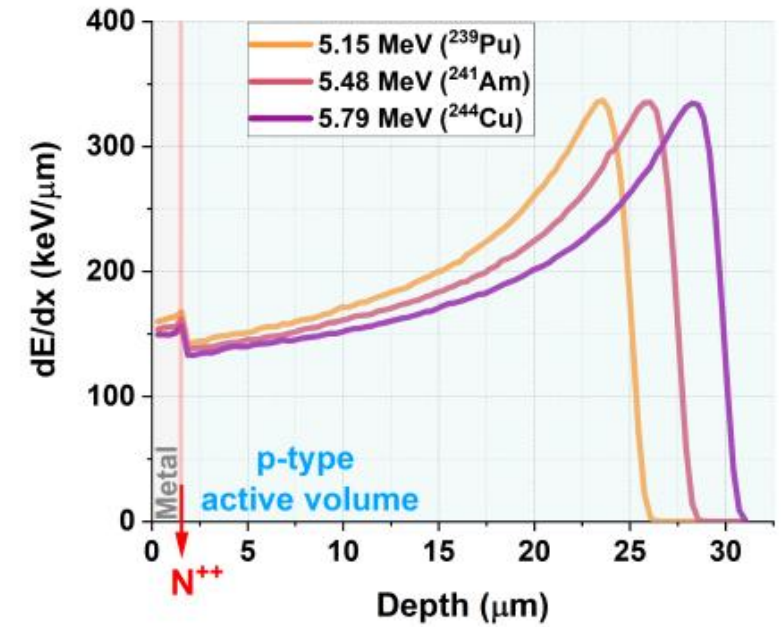
Higher breakdown voltage

Lower depletion voltage of the multiplication layer

Gain measurements with tri-alphas at CNA



- Higher gain for devices without carbon co-doping
- Higher gain suppression the closer the Bragg Peak is to the PN Junction



Summary

- Carbon co-doping effects differ for LGAD with deep gain layer than ones with shallow gain layer
 - Higher V_{gl} , higher gain response and lower V_{bd} without carbon co-doping
 - Correlation with the number of implanted carbon atoms occupying interstitial sites after annealing
- Change in the annealing strategies might alter the influence of carbon co-doping on the electrical performance



4.

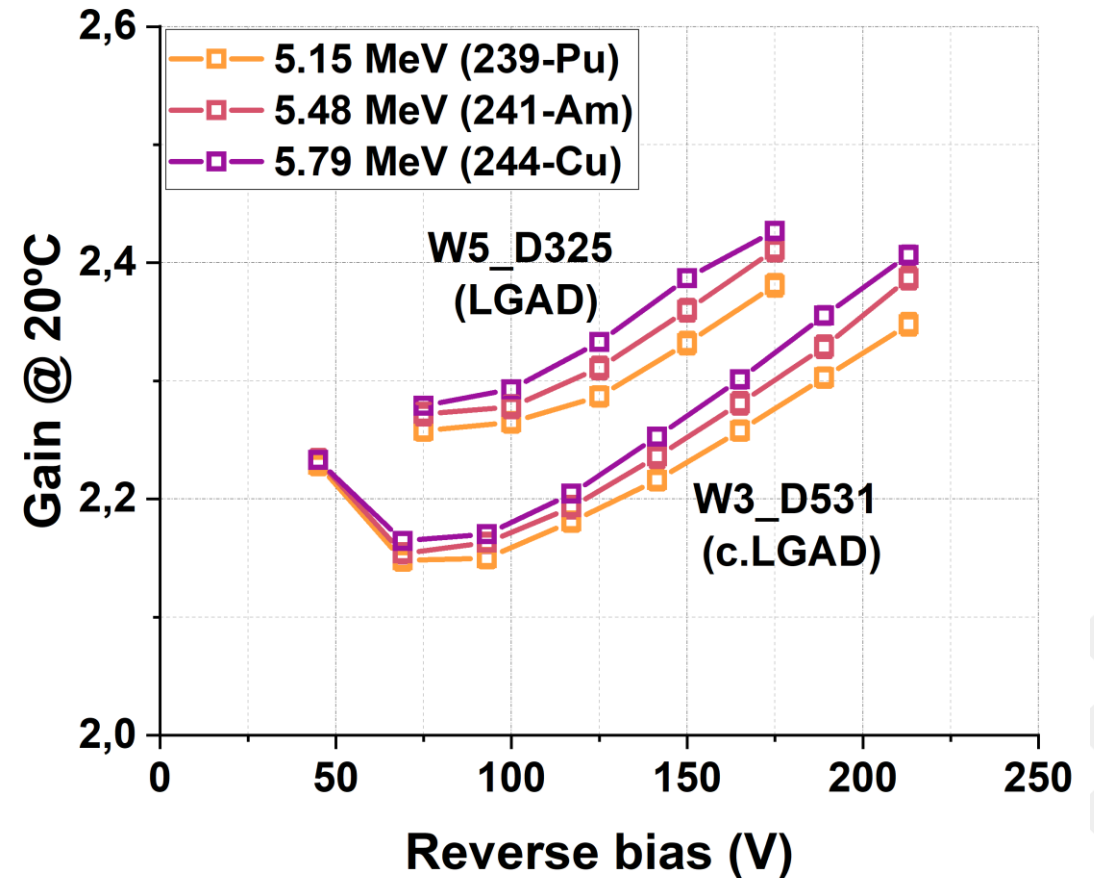
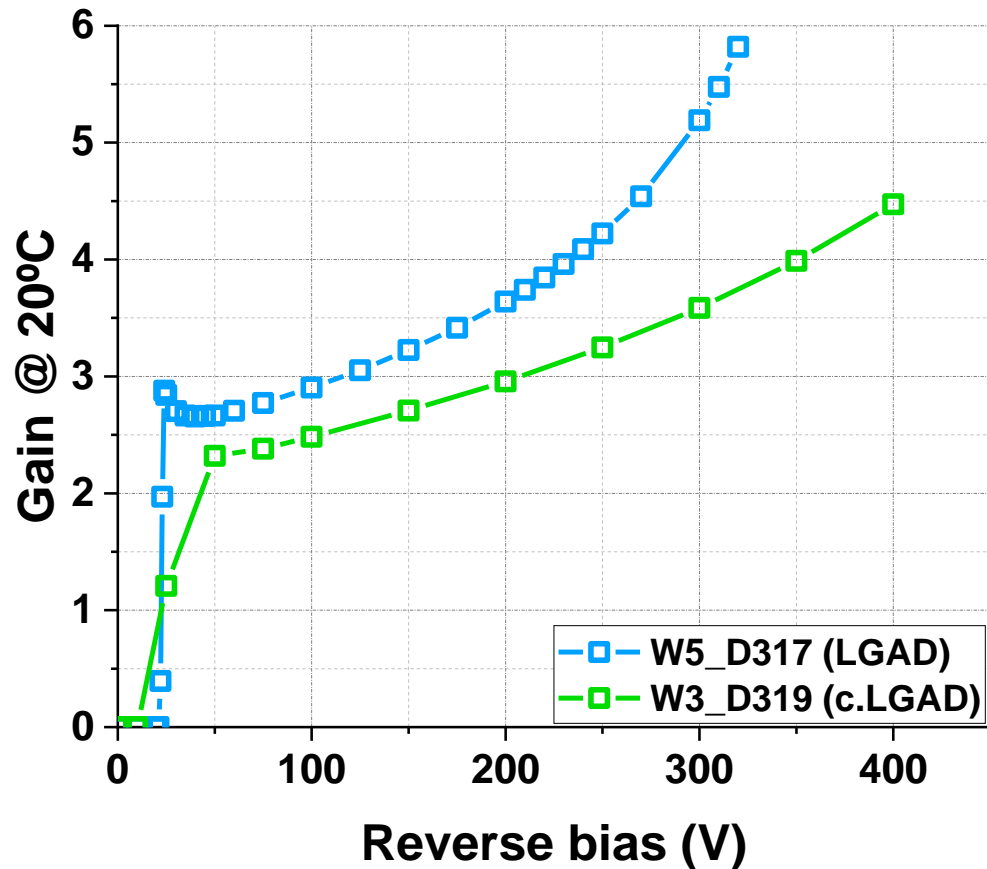
Gain measurements



Gain Measurements

Gain measurements done at CNA → See Jairo Villegas [presentation](#)

Gain to 2.3 MeV protons at normal incidence



Thank you for your attention!

Acknowledgements

This work was funded by the Spanish Ministry of Science, Innovation, and Universities (MICIU/AEI/10.13039/501100011033/) and by the European Union's ERDF program "A way of making Europe", under grant numbers CEX2023-001397-M, PID2023-148418NB-C42, PID2023-148418NB-C44, and PDC2023-145925-C32.

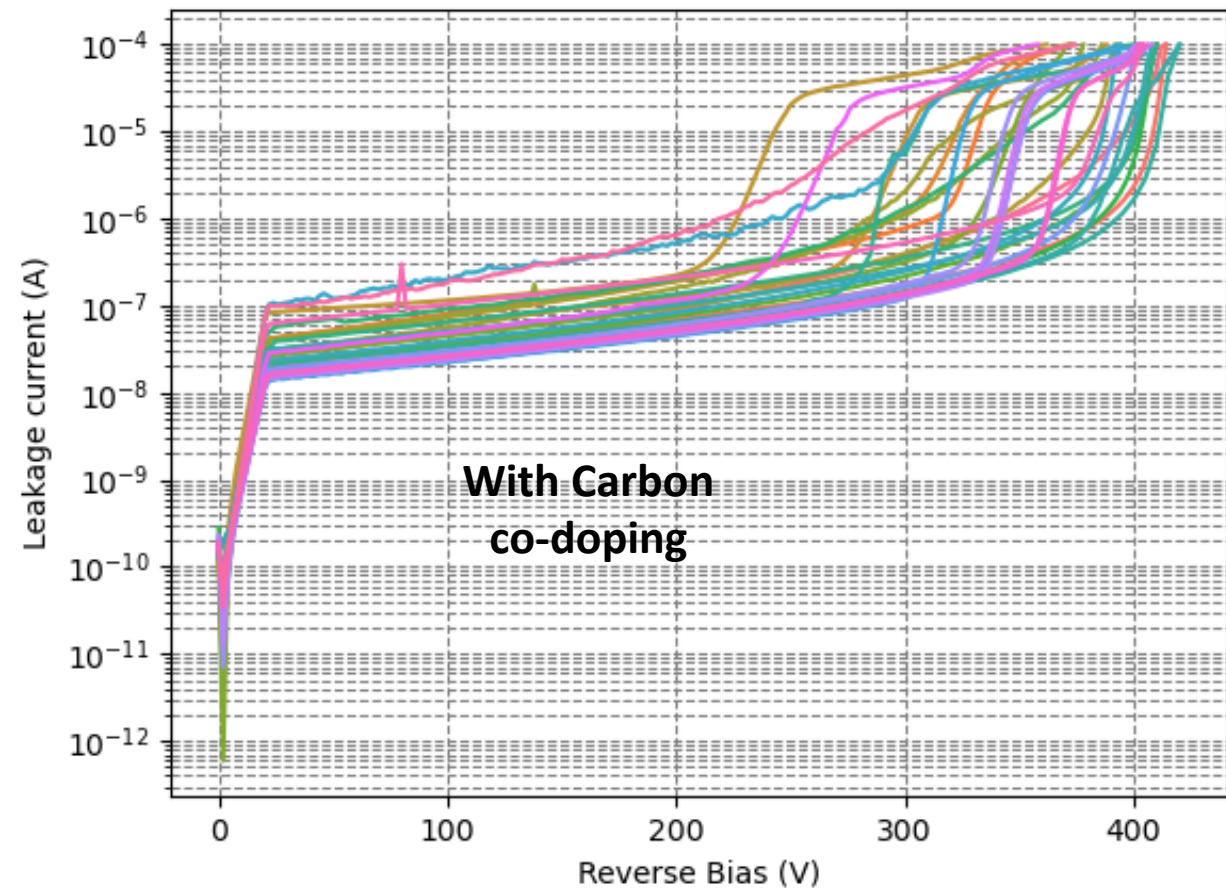
P. Fernandez-Martinez was funded by the Programa Ramon y Cajal of the Spanish Agencia Estatal de Investigación, grant RYC2022-037296-I. The irradiations had been carried out under the Euro-Labs program.



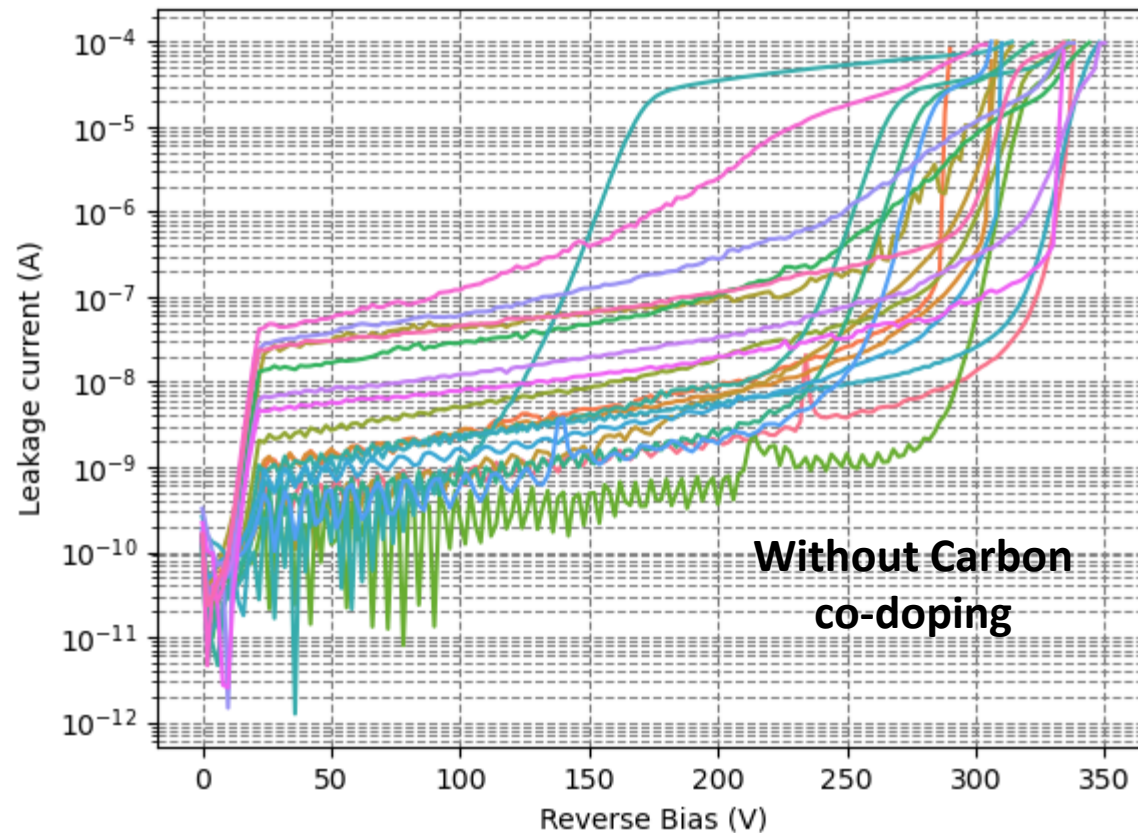
Back-up slides

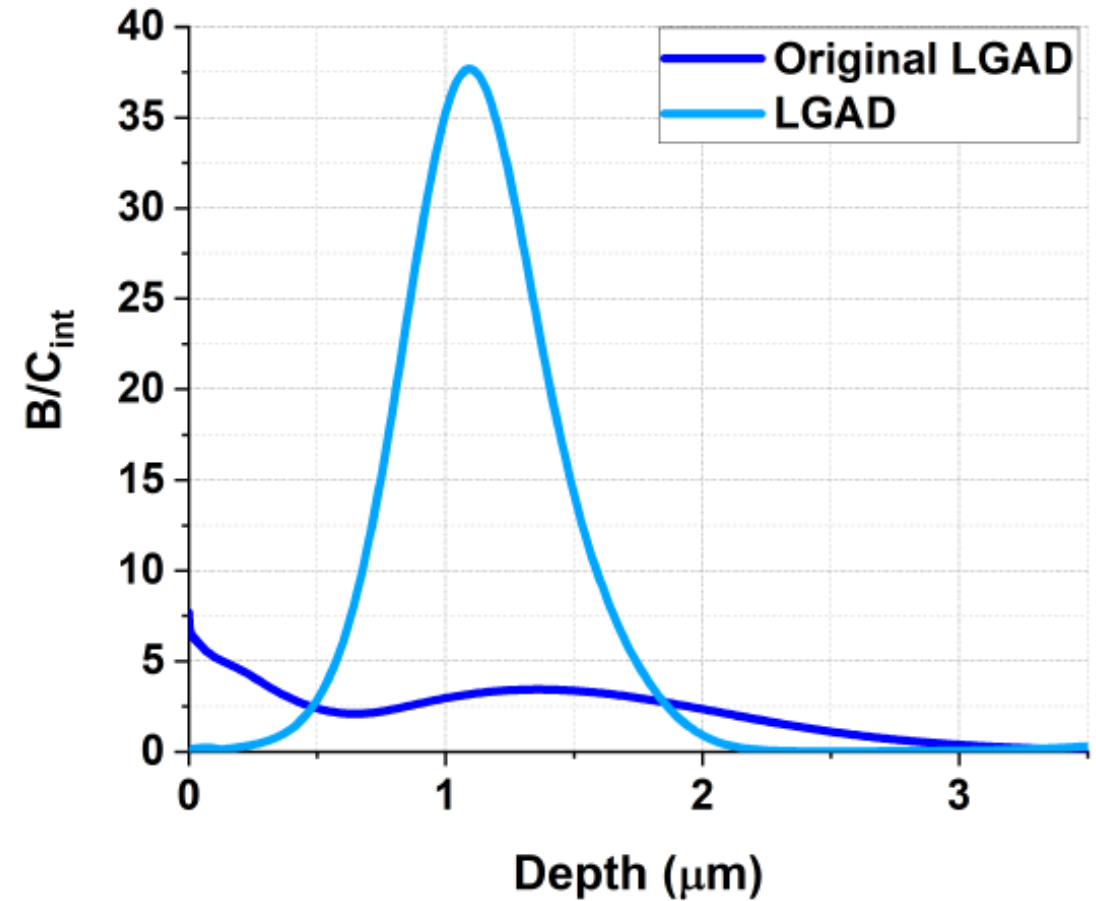
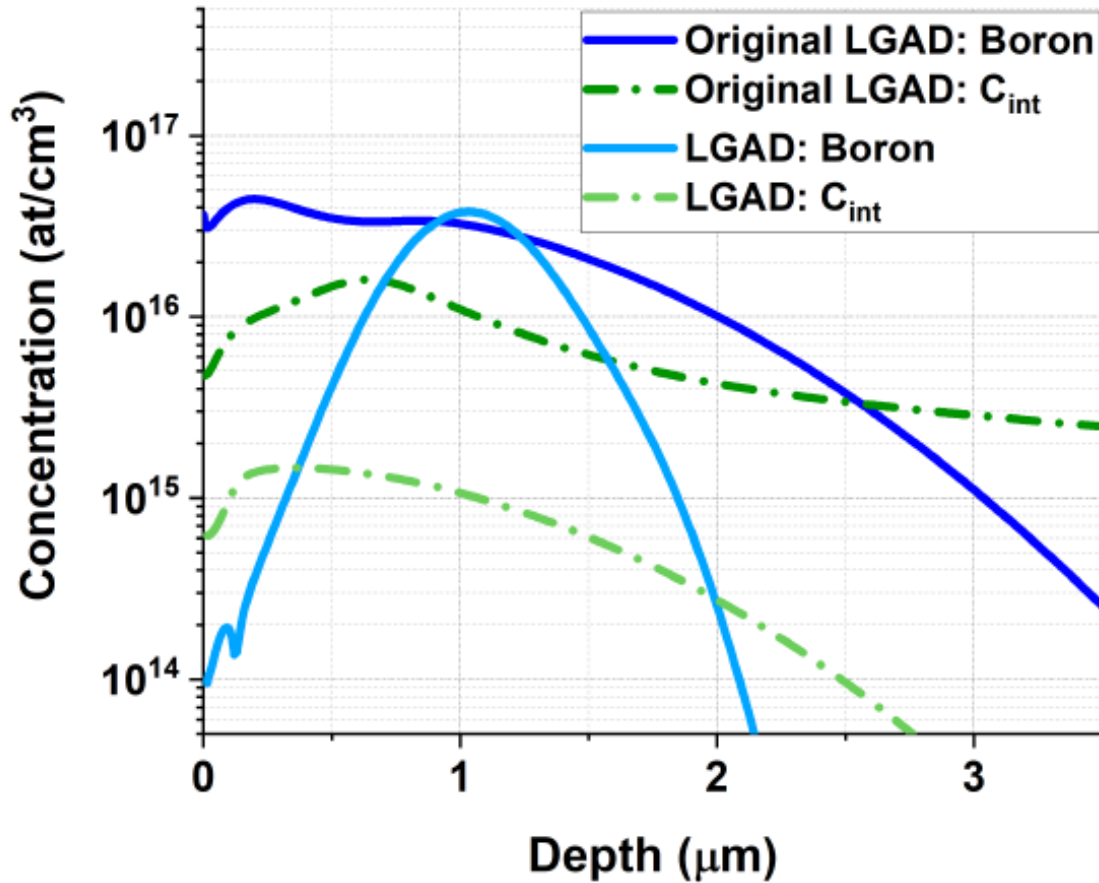


W3 IV at -25°C



W5 IV at -25°C





TCAD simulations of boron and interstitial carbon for both gain layer designs

