DC-LGAD in Taiwan

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Outline

- ✓DC LGAD current progress at TSRI
- ✓LGAD process flow
- ✓LGAD Process parameter decision by TCAD simulation
- ✓LGAD CV & IV characteristics
- ✓ Layout design
- ✓Future plans : AC-LGAD

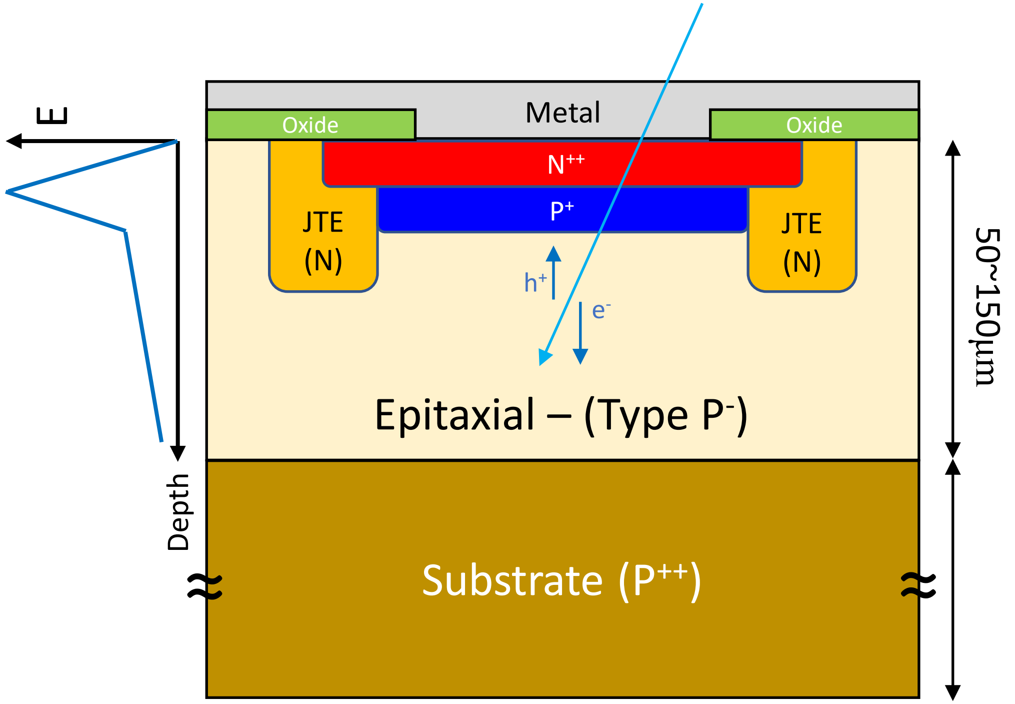
Low Gain Avalanche Detector (LGAD)

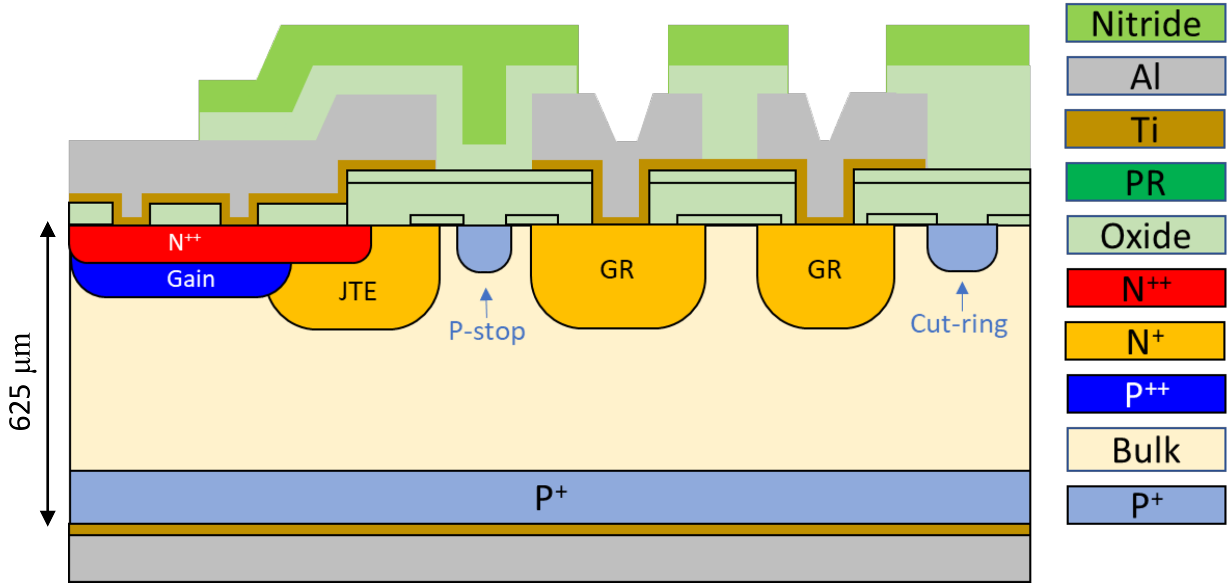
Feature

- High field obtained by adding an extra p^+ below the n^+
- controllable moderate internal gain ~10
- High time resolution of ~50ps
- Thin active layer

Real status

- 6″ p-type, 625 µm, FZ-wafer with 5KΩ-cm resistivity (due to equipment of TSRI)
- Gain layer parameter control
- Junction Termination Extension (JTE)
- P-Stop





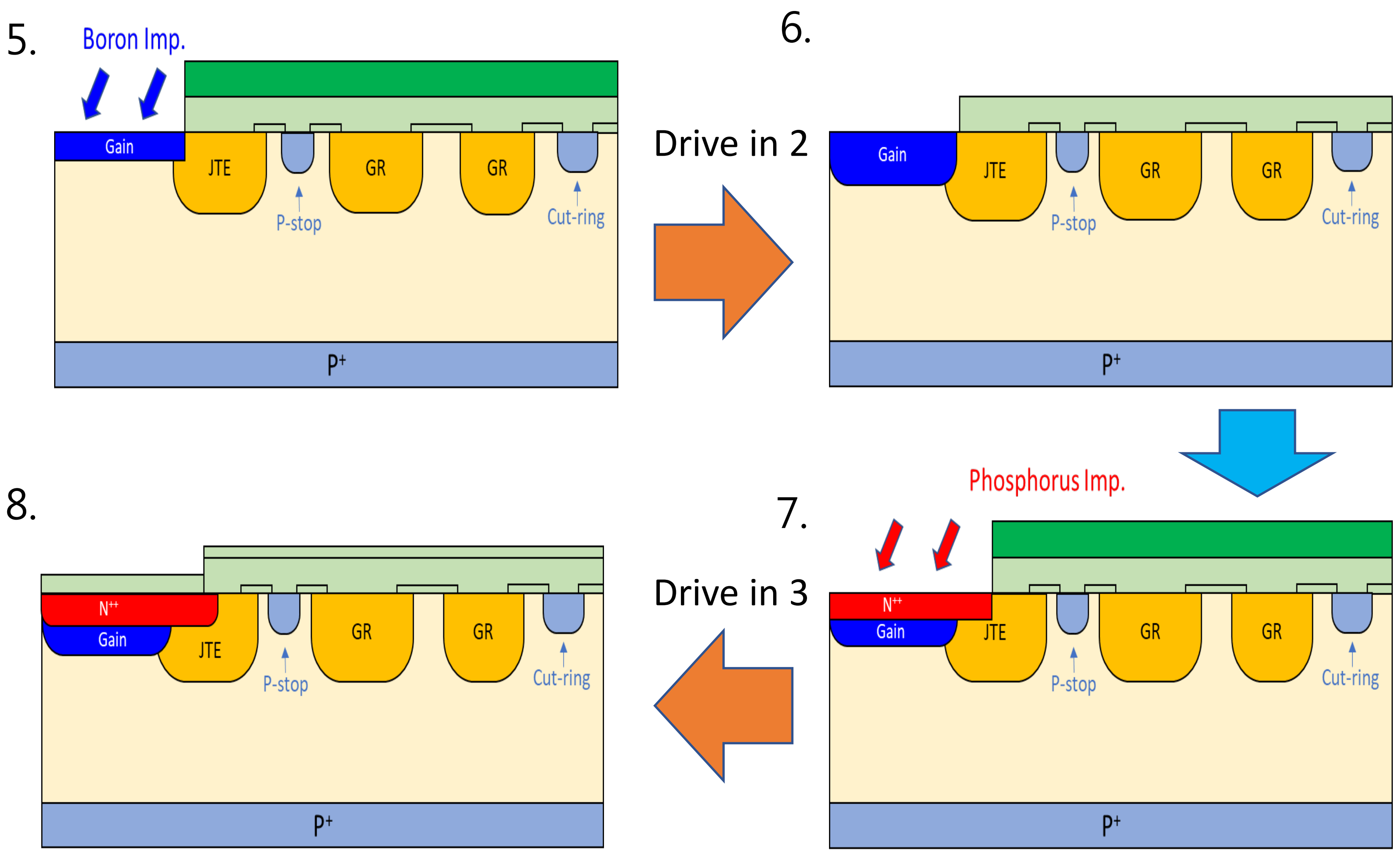
Ref. Design and fabrication of an optimum peripheral region for low gain avalanche detectors; NIMA, Volume 821, 11 June 2016, Pages 93-100

Ref. Technology developments and first measurements of Low Gain Avalanche Detectors (LGAD) for high energy physics applications; NIMA, Volume 765, 21 November 2014, Pages 12-16

LGAD Process

1	Backside imp.
2	JTE&GR imp.
3	P-stop imp.
4	Drive in 1 (長3000A Oxide)
5	Gain layer imp.
6	Drive in 2
7	N^{++} imp.
8	Drive in 3
9	PECVD 0.5um oxide
10	Contact etch
11	Front Metal dep.
12	Front Metal etch
13	alloy
14	Passivation dep.
15	Passivation etch
16	Back Metal dep.
17	alloy

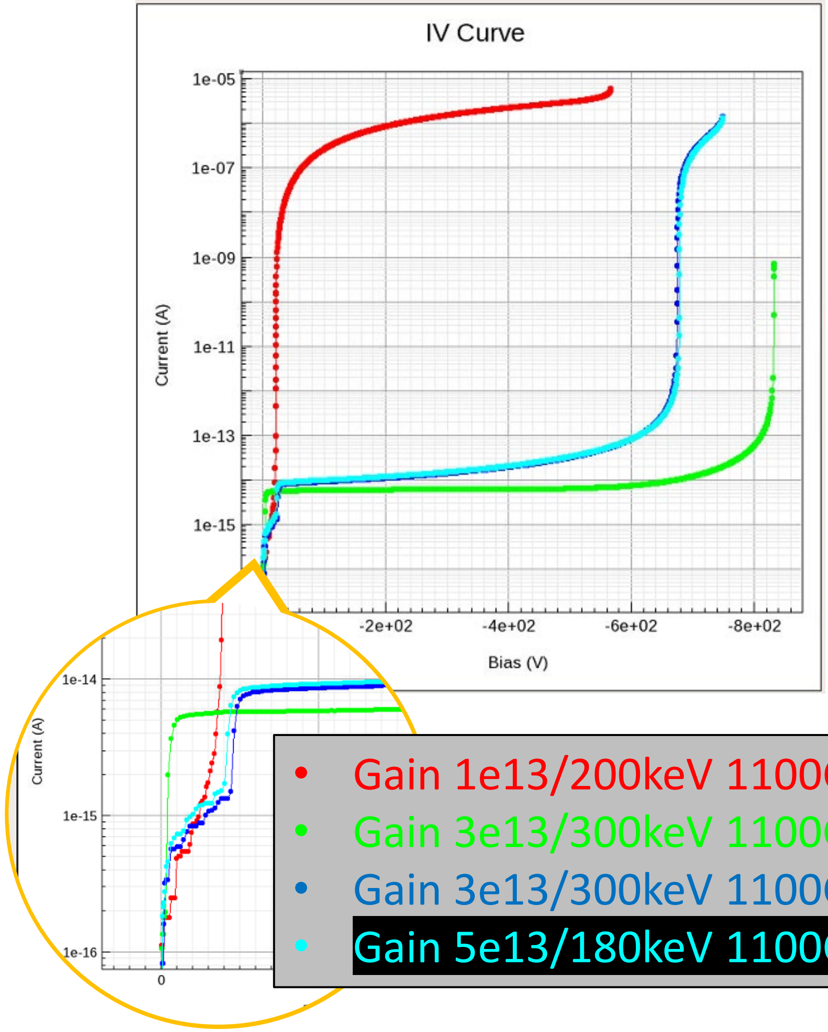
- 5-8 steps that most influential the gain feature

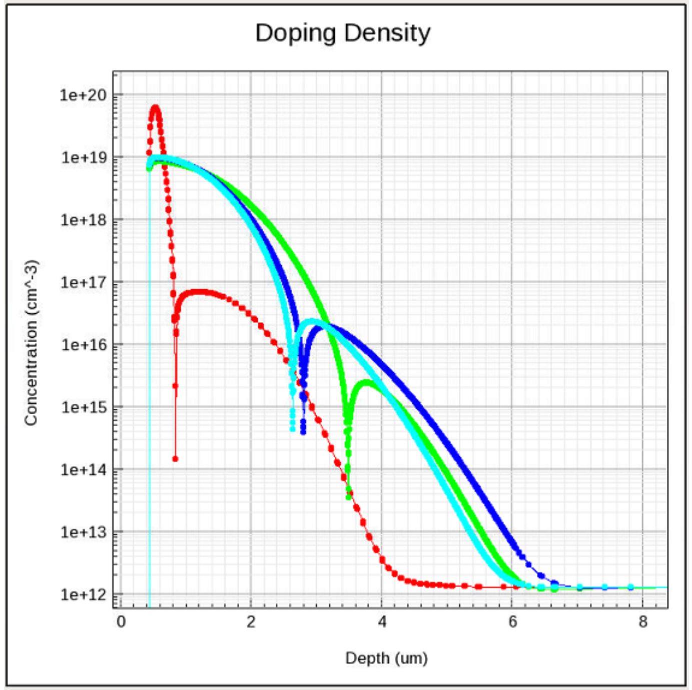


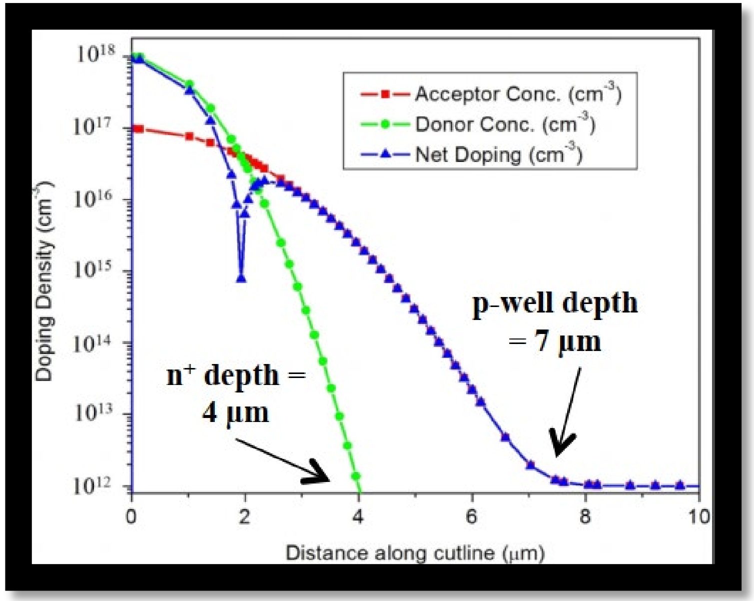
Ref. Development of a technology for the fabrication of Low-Gain Avalanche Diodes at BNL; NIMA, Volume 934, 1 August 2019, Pages 52-57

LGAD Process parameter decision by TCAD simulation

- Various gain layer and N^{++} process parameters
- The suitable parameter: Gain 5e13/180keV 1100C/200min N^{++} 1e15/100keV 1100C/200min



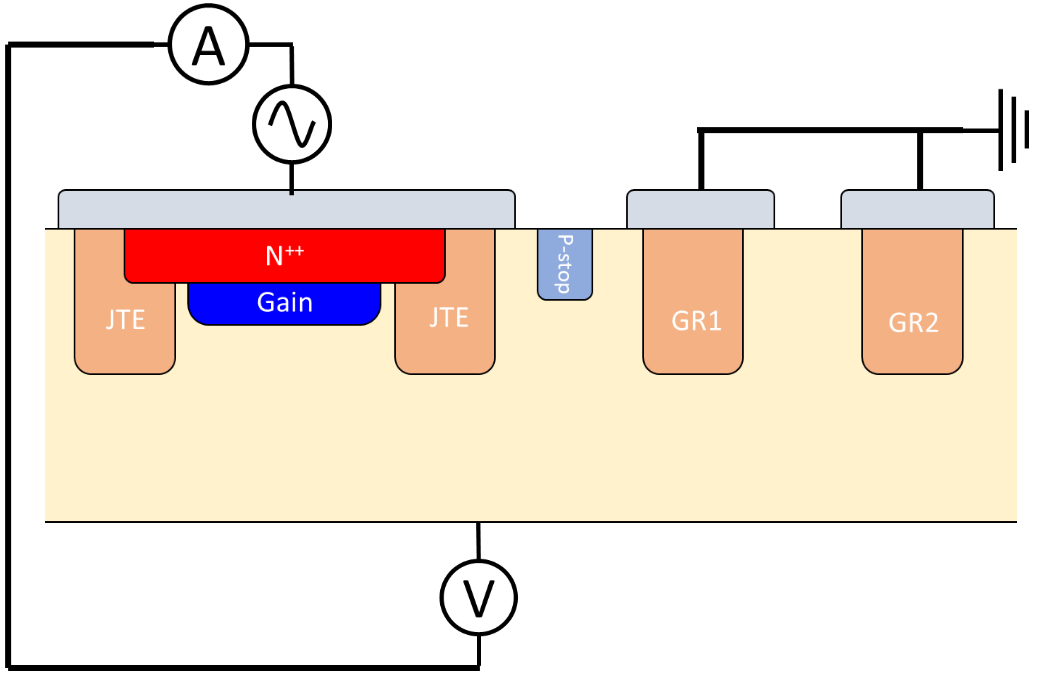




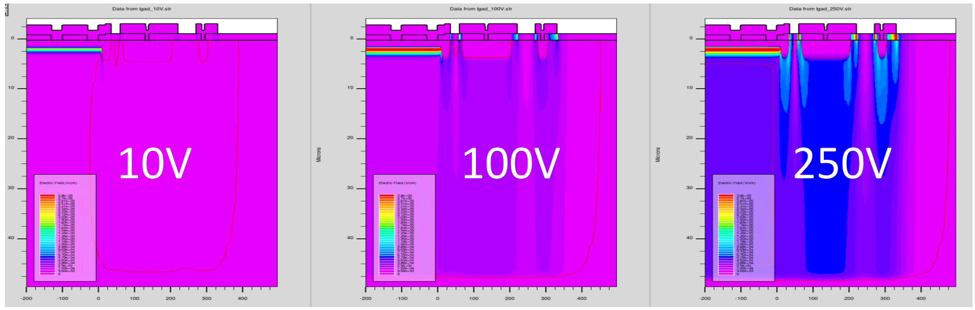
- Gain 1e13/200keV 1100C/140min N^{++} 1e15/80keV 900C/30min
- Gain 3e13/300keV 1100C/100min N^{++} 1e15/120keV 1100C/300min
- Gain 3e13/300keV 1100C/300min N^{++} 1e15/120keV 1100C/200min
- Gain 5e13/180keV 1100C/200min N^{++} 1e15/100keV 1100C/200min

Ref. TCAD simulation of Low Gain Avalanche Detectors; NIMA, Volume 836, 11 November 2016, Pages 113-121

LGAD CV & IV characteristics



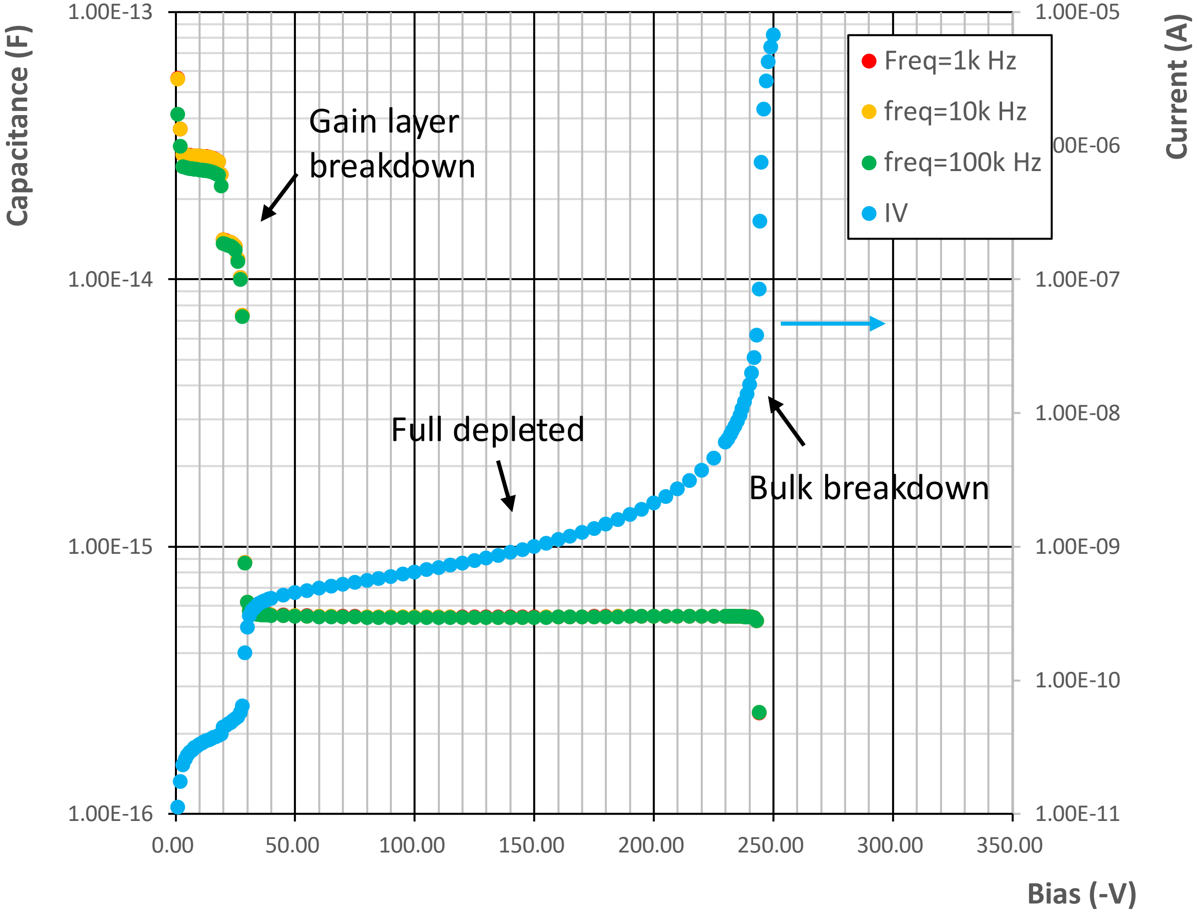
Electric Field



Boron : 5.0E13 cm^{-2}

Phosphorus : 2.0E14 cm^{-2}

Size : 500um*50um

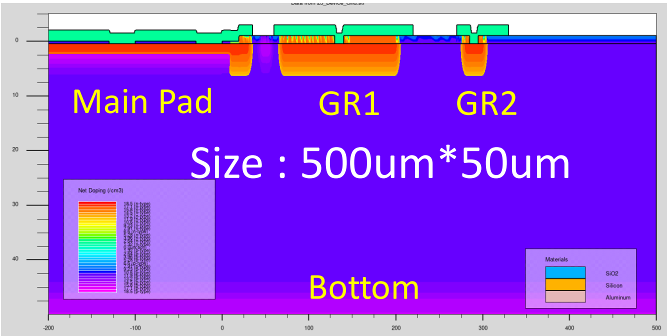


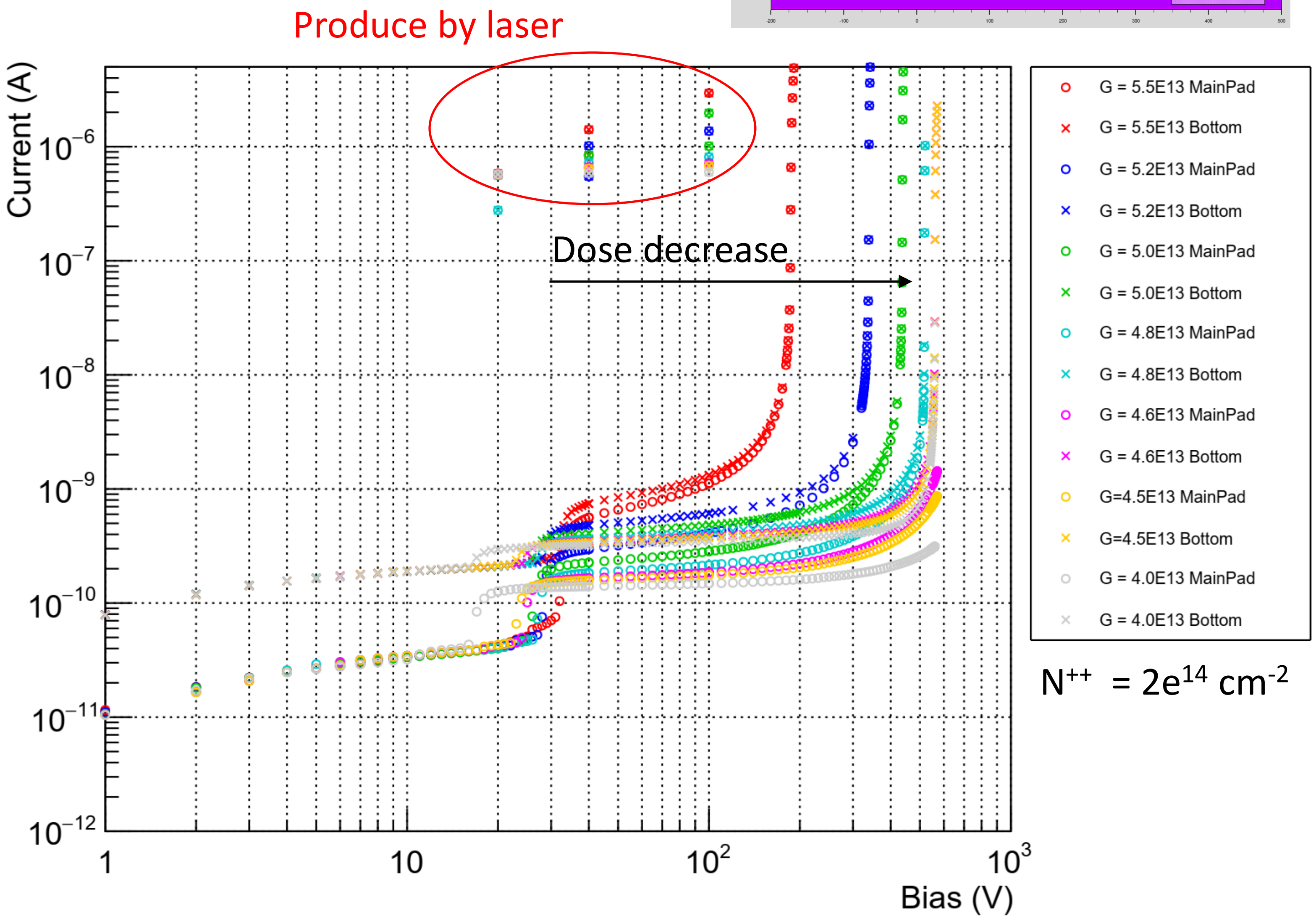
Various of gain layer dosages (GR grounding)

Gain layer dose(cm^{-2})	V_B(V)	BD location	Gain (at 100V)
$5.5E^{13}$	186	Main Pad	4.91
$5.2E^{13}$	337	Main Pad	2.28
$5.0E^{13}$	435	Main Pad	1.68
$4.8E^{13}$	517	Main Pad	1.35
$4.6E^{13}$	560	GR2	1.18
$4.5E^{13}$	560	GR2	1.13
$4.0E^{13}$	560	GR2	1.00

Gain = $I_{measurement}/I_{photocurrent}$

- The higher the gain layer dosage, the higher the gain, but the lower the breakdown voltage
- The breakdown occurs around the guard ring edge at the low gain layer dosage

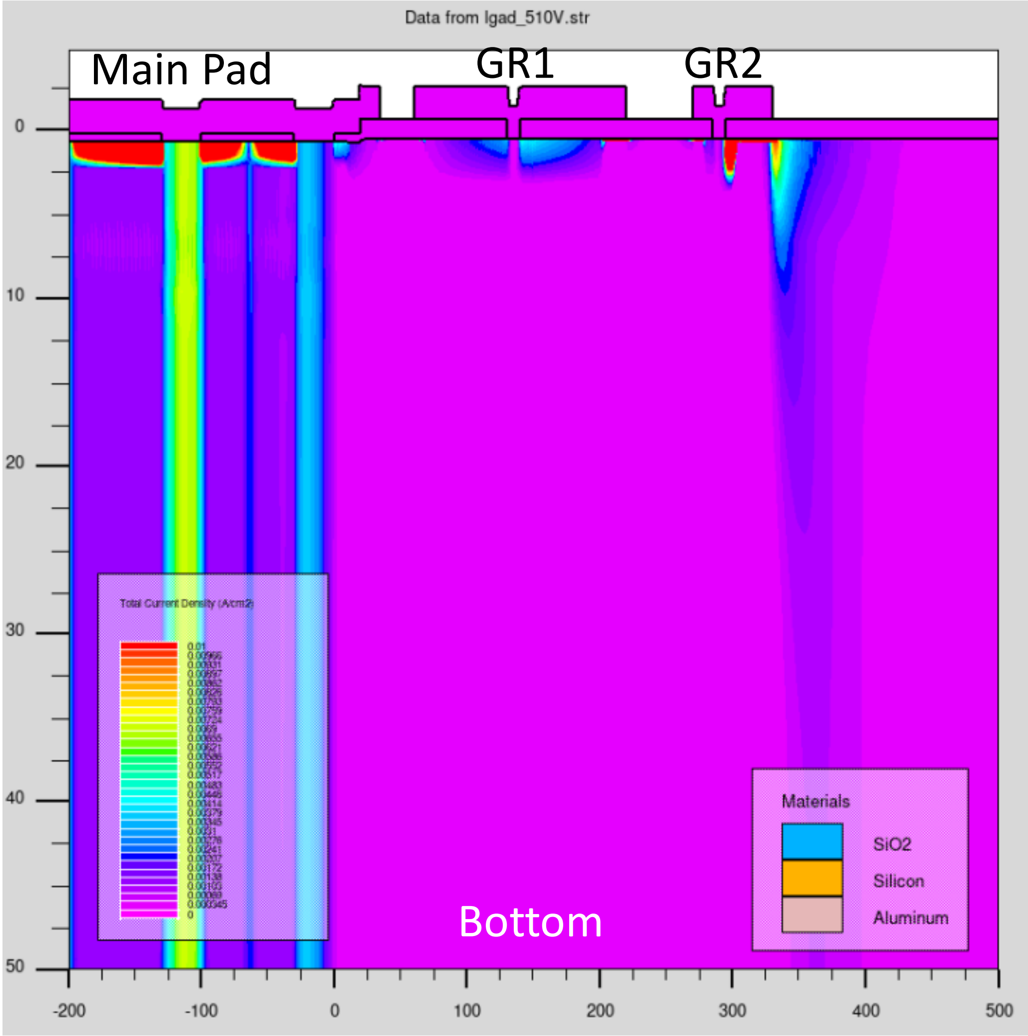




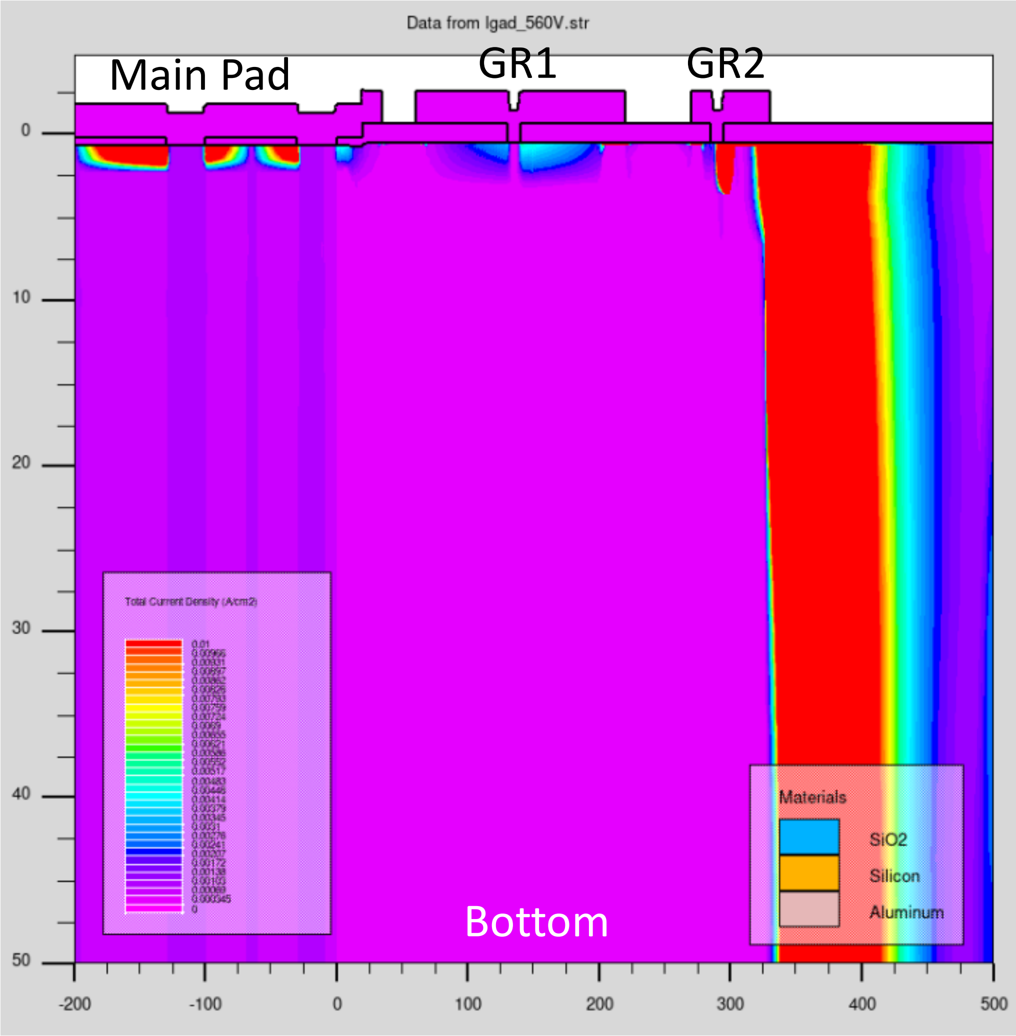
$N^{++} = 2e^{14}\ cm^{-2}$

Before BD: Current Density (Max : 0.01A/cm^2)

Gain layer dose = 4.8E13cm^{-2}

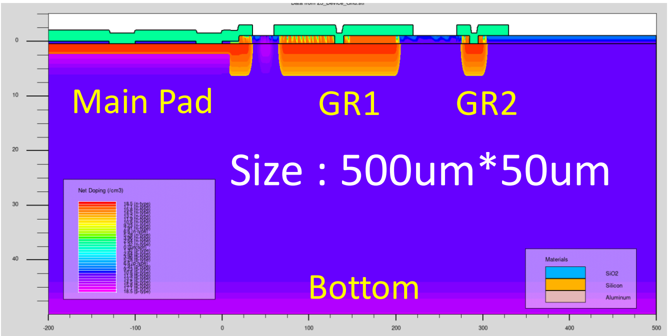


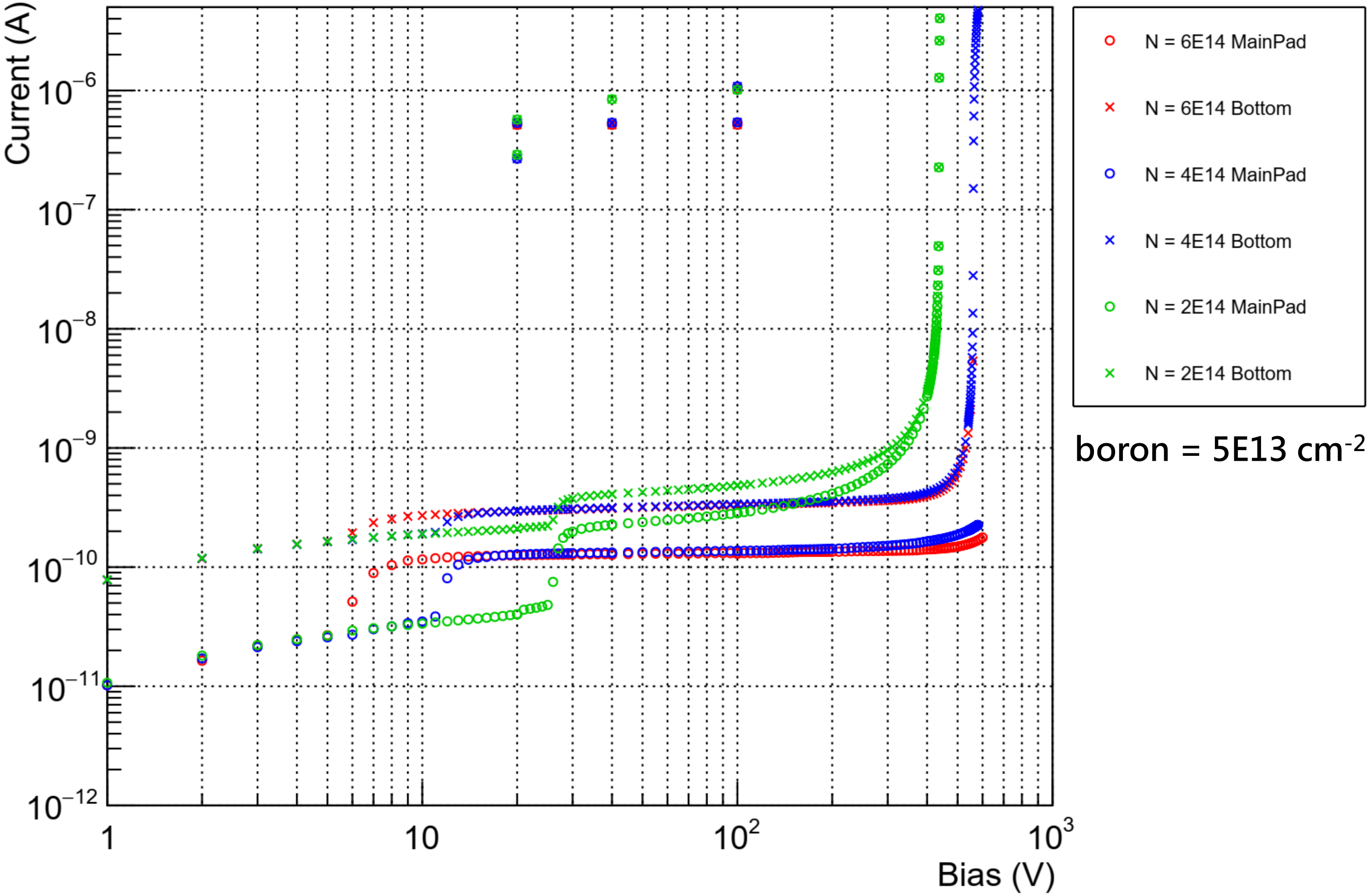
Gain layer dose = 4.6E13cm^{-2}



Dosage of N⁺⁺

- The higher the dosages of N⁺⁺, the lower effective of p-type concentration, the lower the gain, but the higher the breakdown voltage





boron = 5E13 cm^{-2}

N++ dose	V_B(V)	BD location	Gain 1 at 100V	Gain 2 at 100V
$6.0E^{14}$	600	GR2	0.86	1.08
$4.0E^{14}$	557	GR2	0.89	1.13
$2.0E^{14}$	435	Main Pad	1.68	2.12

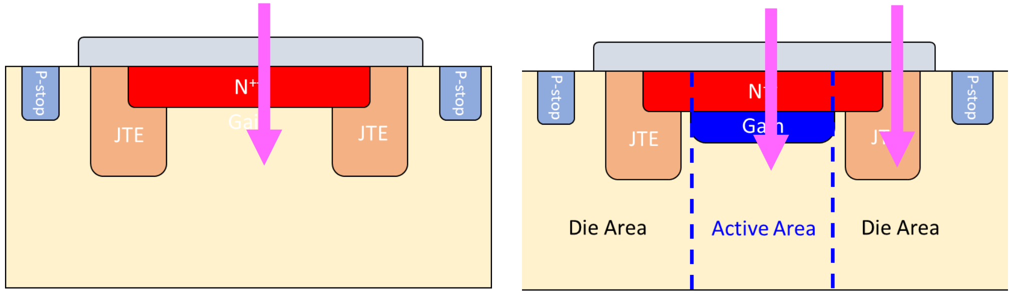
Gain = $I_{measurement}/I_{photocurrent}$

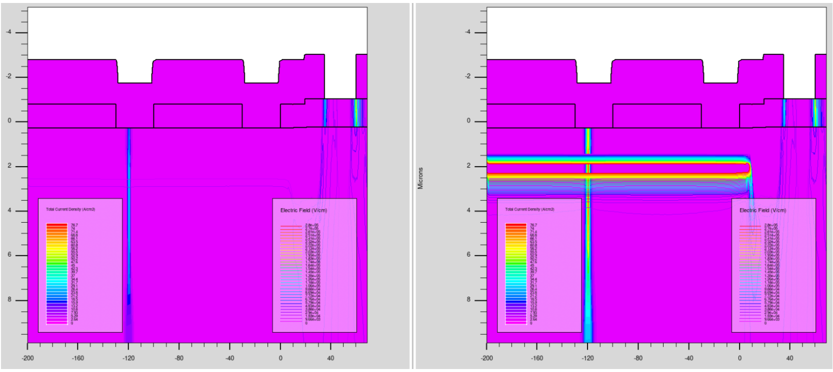
Gain measurement

1. $\text{Gain} = I_{\text{measurement}} / I_{\text{photocurrent}}$

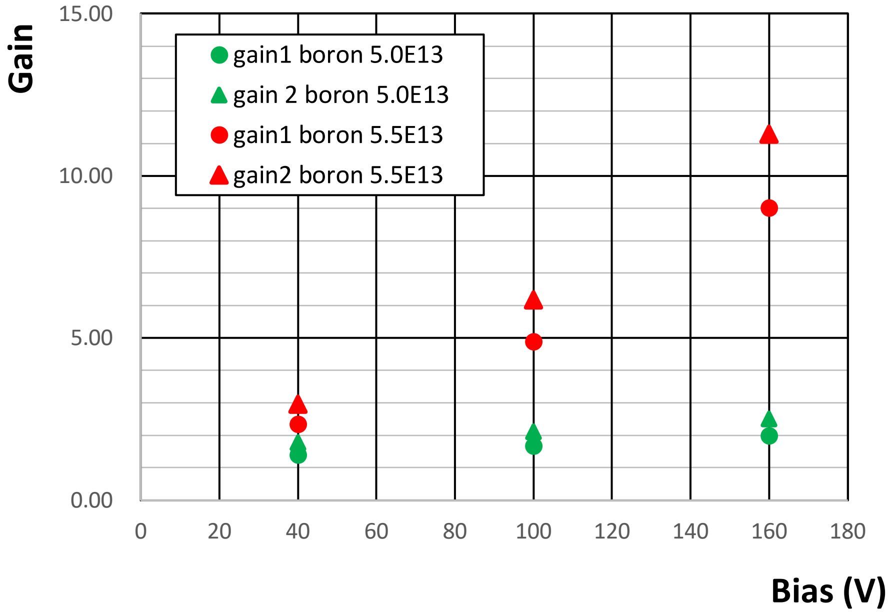
2. $\text{Gain} = I_{\text{active area}} / I_{\text{dead area}}$

3. $\text{Gain} = I_{\text{LGAD}} / I_{\text{PN diode}}$





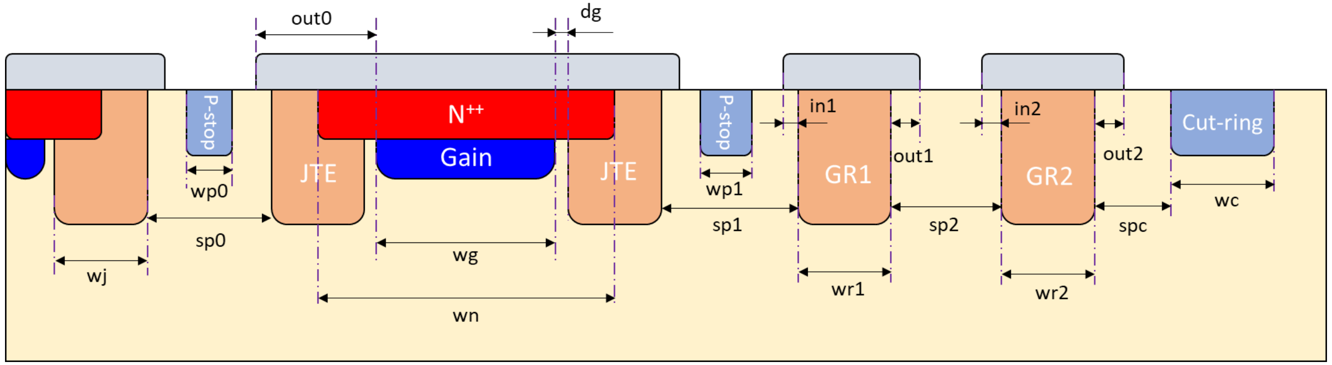
Gain layer dose(cm^{-2})	BD voltage, V_B(V)	Gain 1 (at 100V)	Gain 2 (at 100V)	Gain2 (at 40V)	Gain 3 (at 100V)	Gain3 (at 40V)
5.5E13	186	4.91	6.18	2.97	5.59	2.68
5.0E13	435	1.68	2.12	1.77	1.91	1.60
4.5E13	560	1.13	1.26	1.22	1.29	1.22
4.0E13	560	1.00	1.22	1.22	1.13	1.13

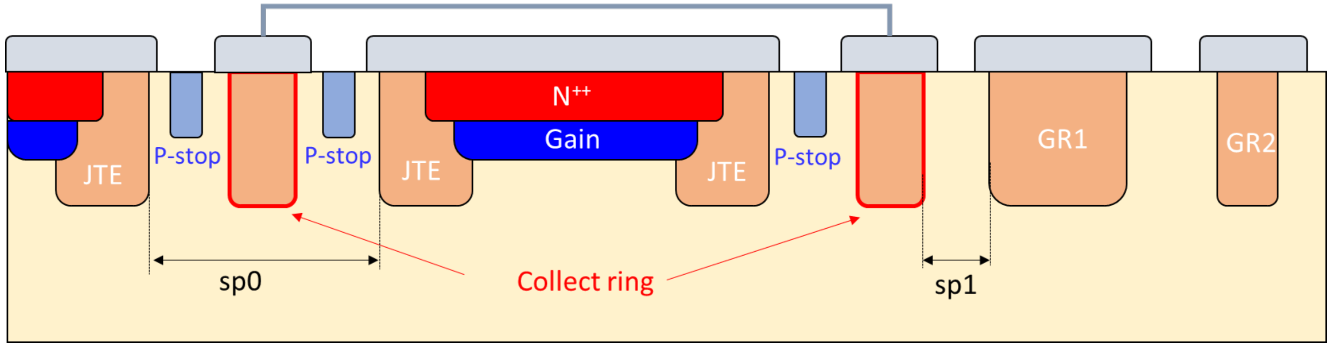


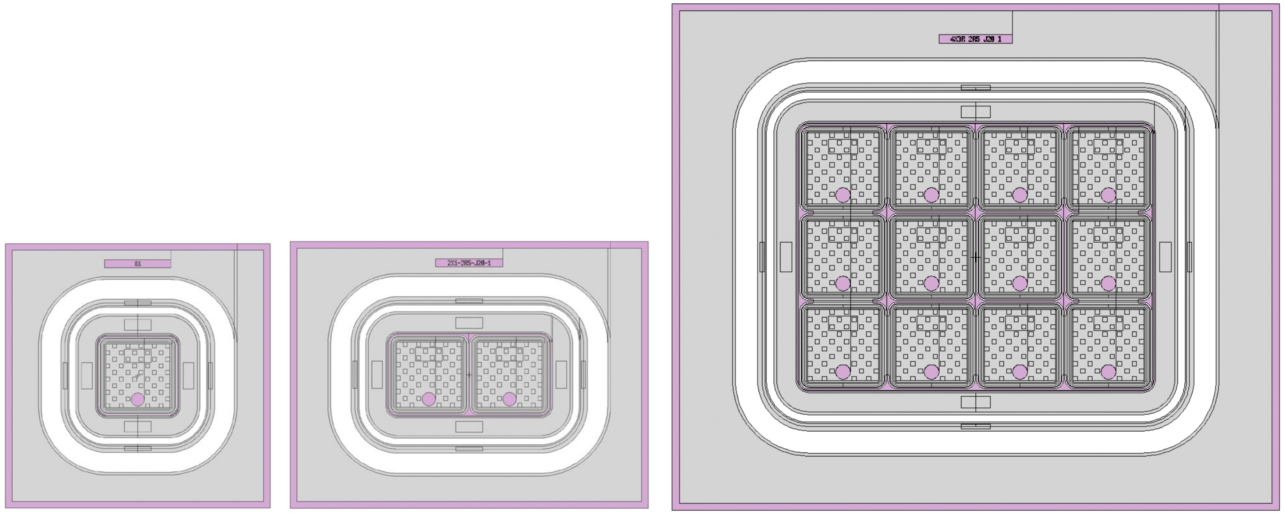
Ref. Gain estimation of RT-APD devices by means of TCAD numerical simulations; IEEE, April 2011, 11931234
Ref. Study of interpad-gap of HPK 3.1 production LGADs with Transient Current Technique; NIMA, Volume 979, 1 November 2020, 164494
Ref. A novel detector for low-energy photon detection with fast response; IEEE(NSS/MIC), 2018, pages, 1-4, 18972980

Layout design

- 1X1 LGAD structure, width of JTE (wj), location (dg), width of gain layer and guard ring design
    - Area : 500*500 µm^2 ~ 2*2mm^2
    - wj : 20~40 µm
    - wp : 5~20 µm
    - dg : 0~10 µm
    - GR : 2/3 rings

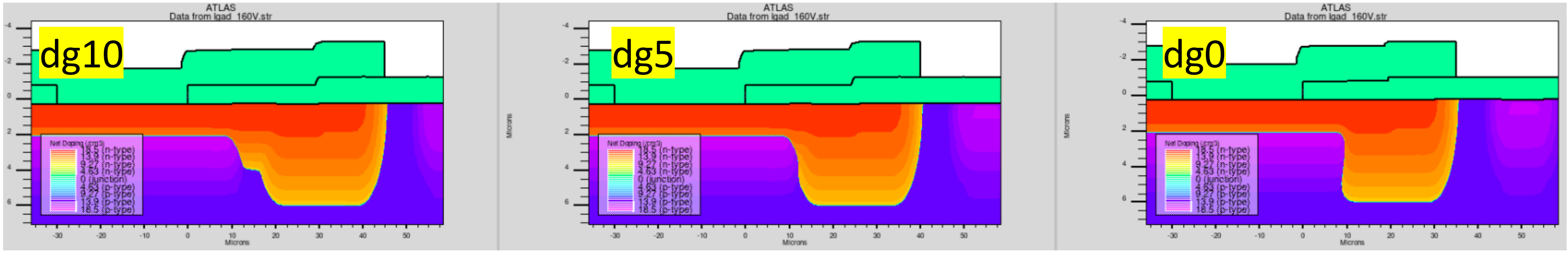


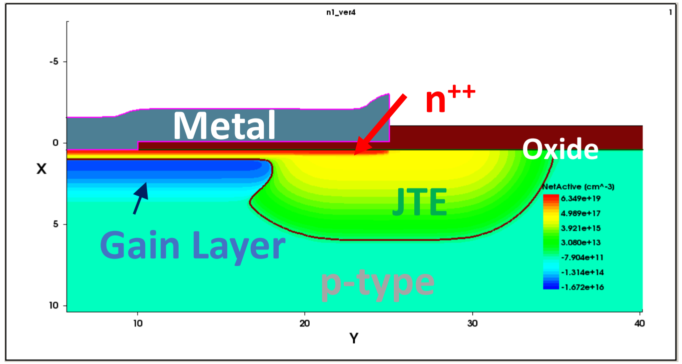


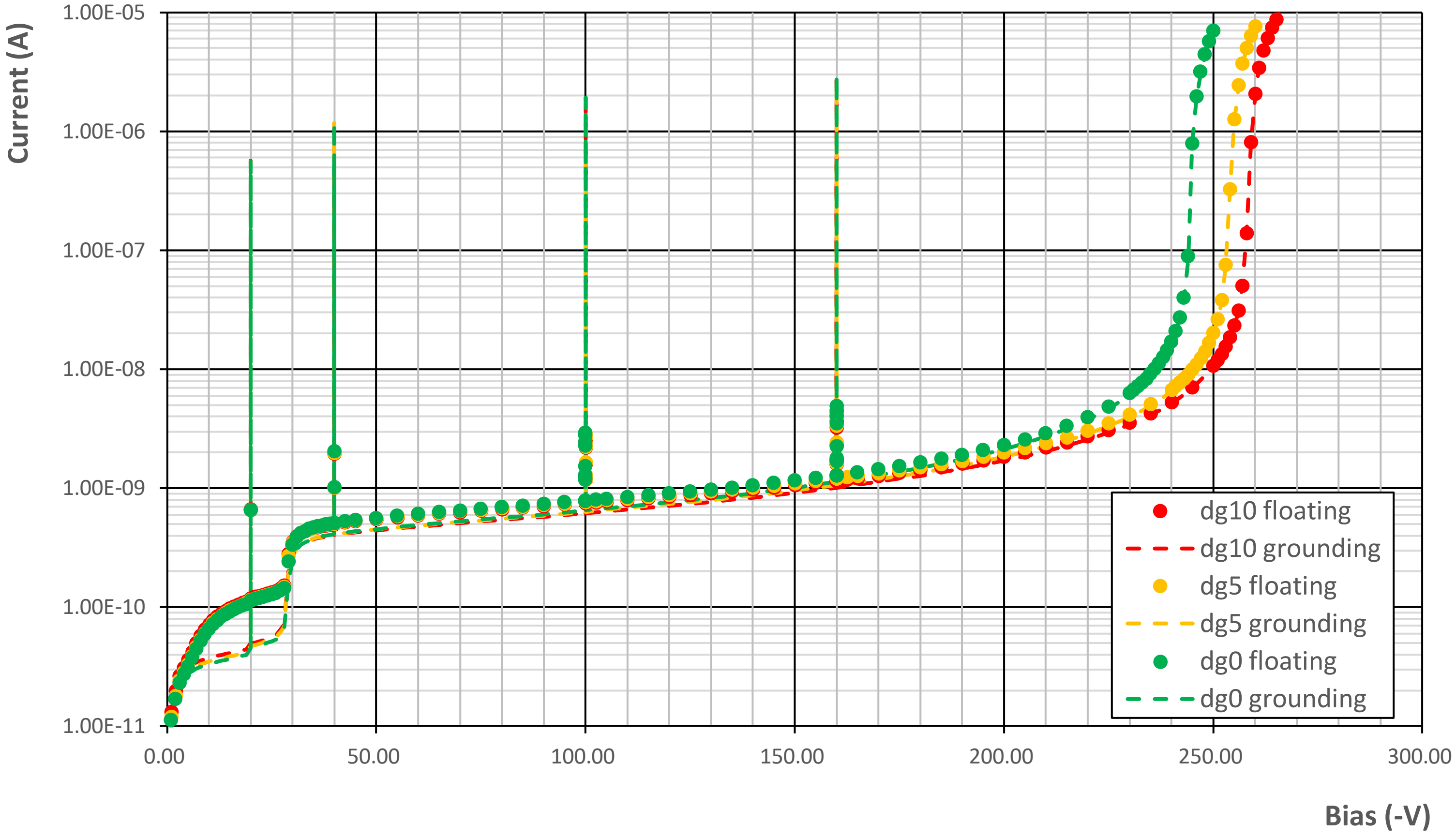


Ref. Design and fabrication of Low Gain Avalanche Detectors (LGAD): a TCAD simulation study; JINST 15, March 2020, C03008
Ref. A novel detector for low-energy photon detection with fast response; IEEE(NSS/MIC), 2018, pages, 1-4, 18972980
Ref. The Effect of a Collector Ring on Low Gain Avalanche Detector for High Energy Physics Application; IEEE(NSS/MIC), 2019, 18972980
Ref. Ke Ming Chou Huang, TCAD simulation of silicon detector; https://hdl.handle.net/11296/ncj457

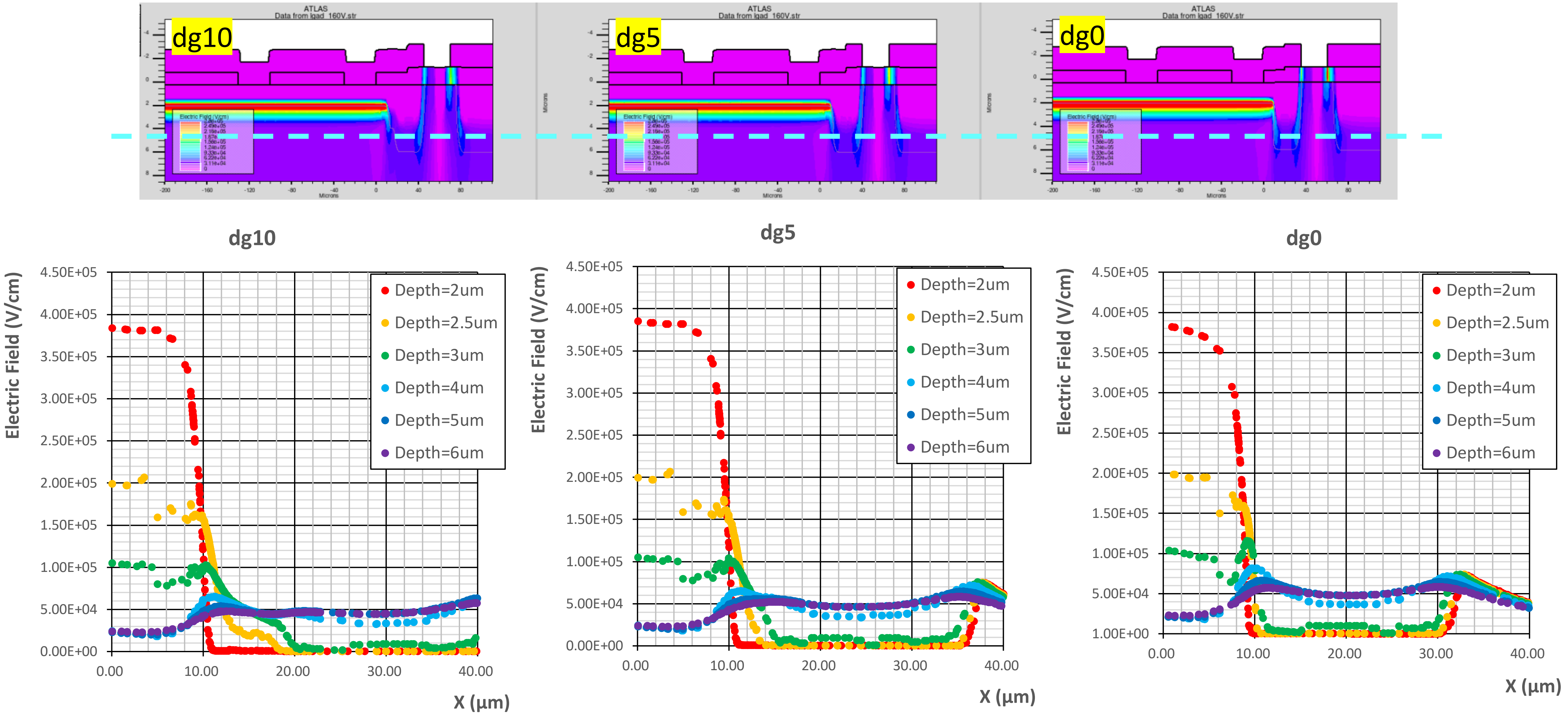
Various of dg



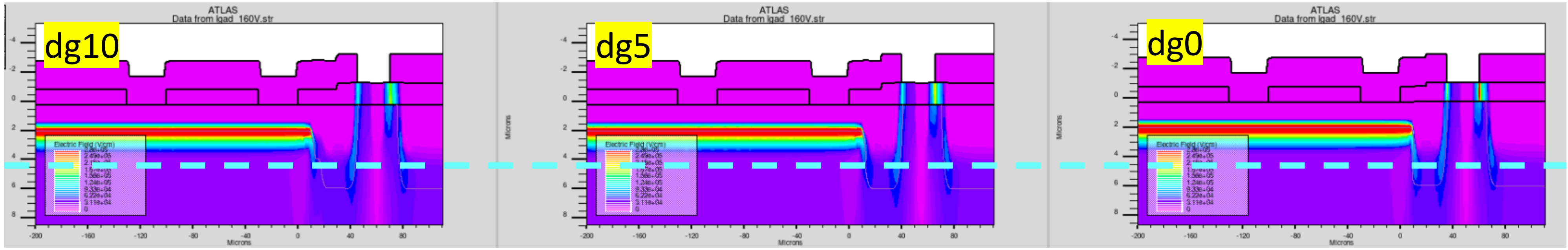


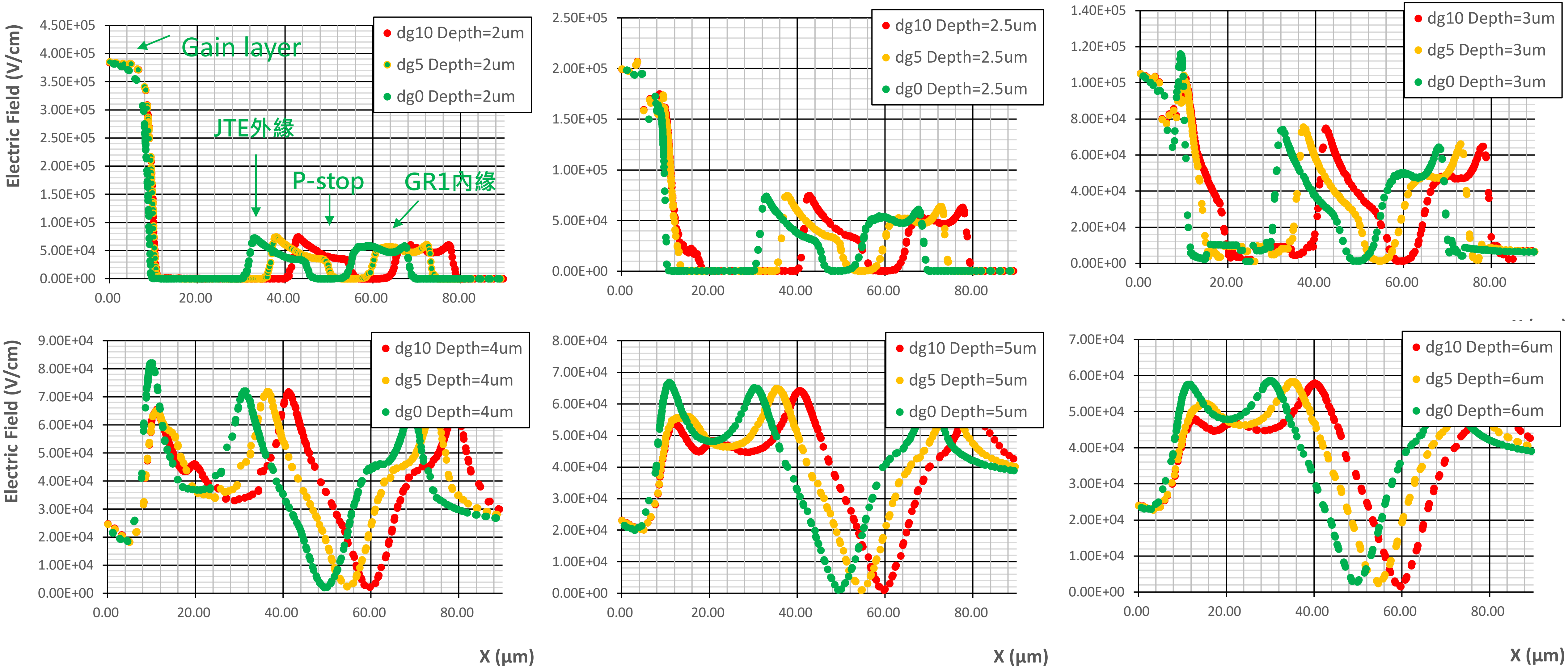


Dg-horizontal electric field

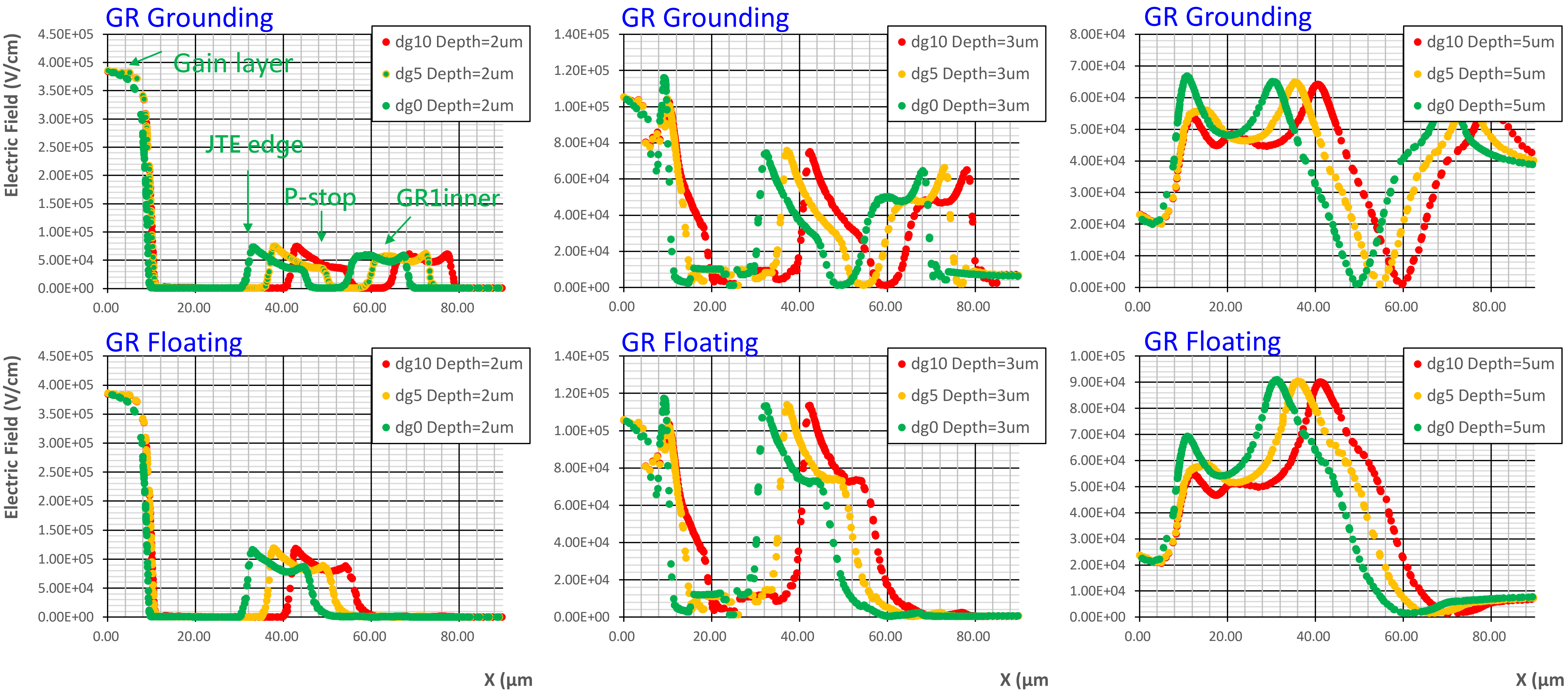


Dg- horizontal electric field

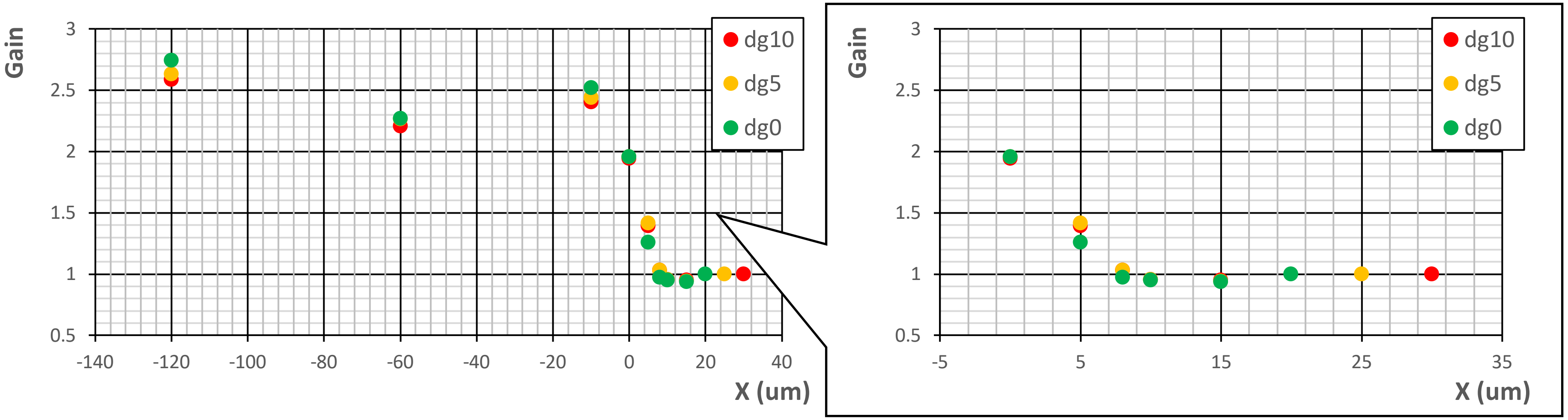


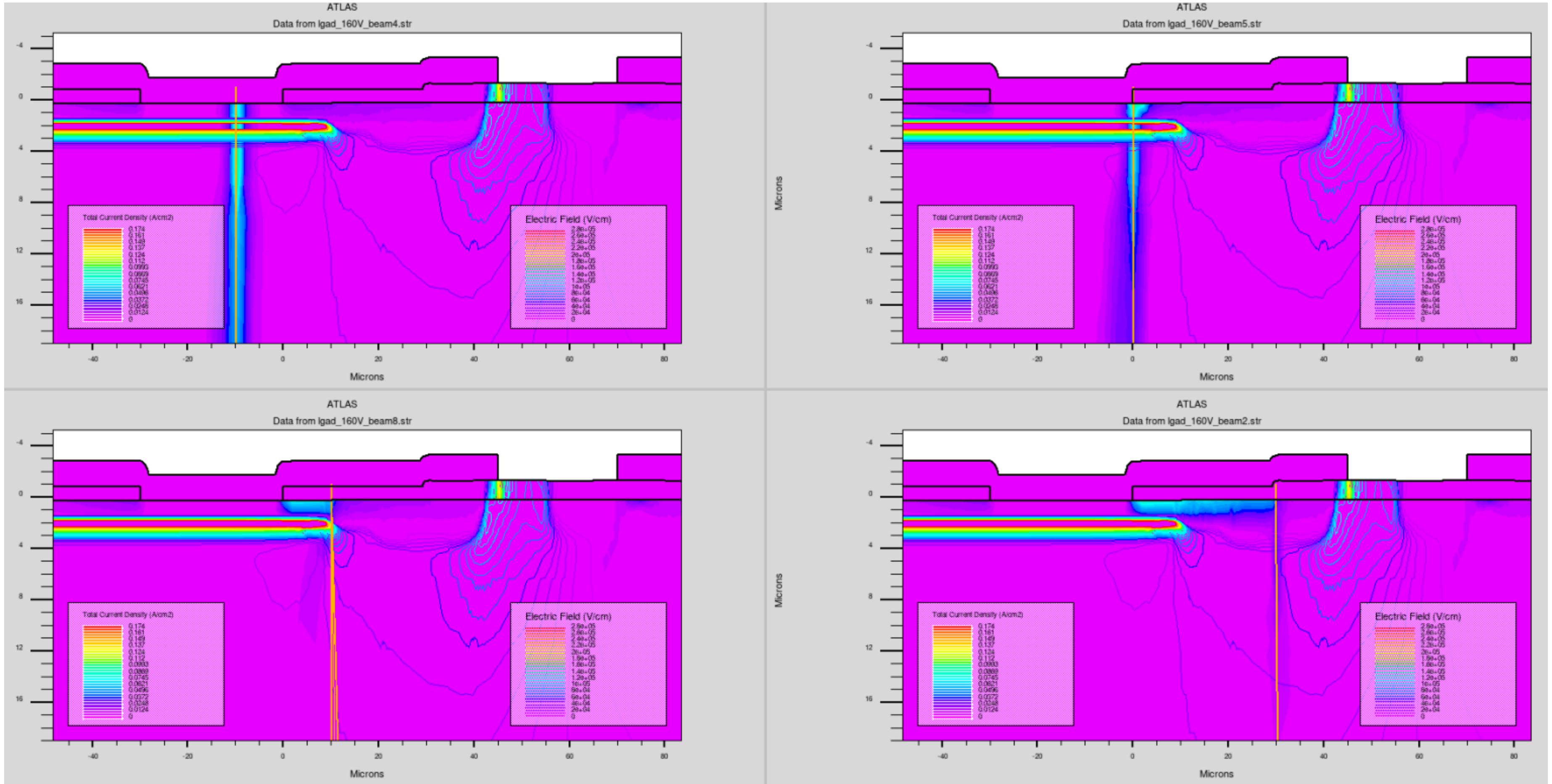


Dg- horizontal electric field



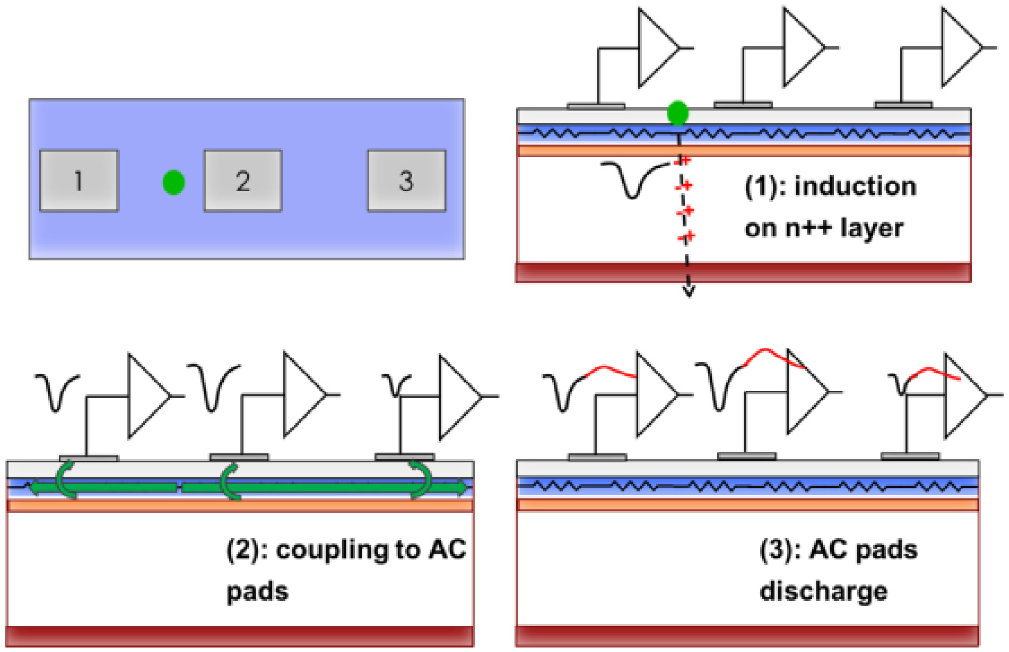
The gain value with various location

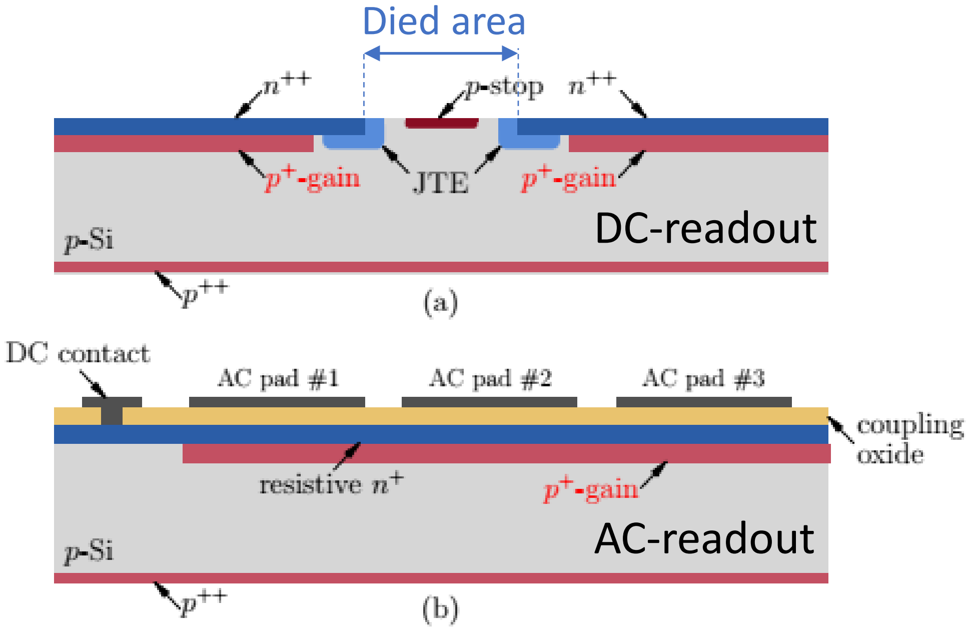


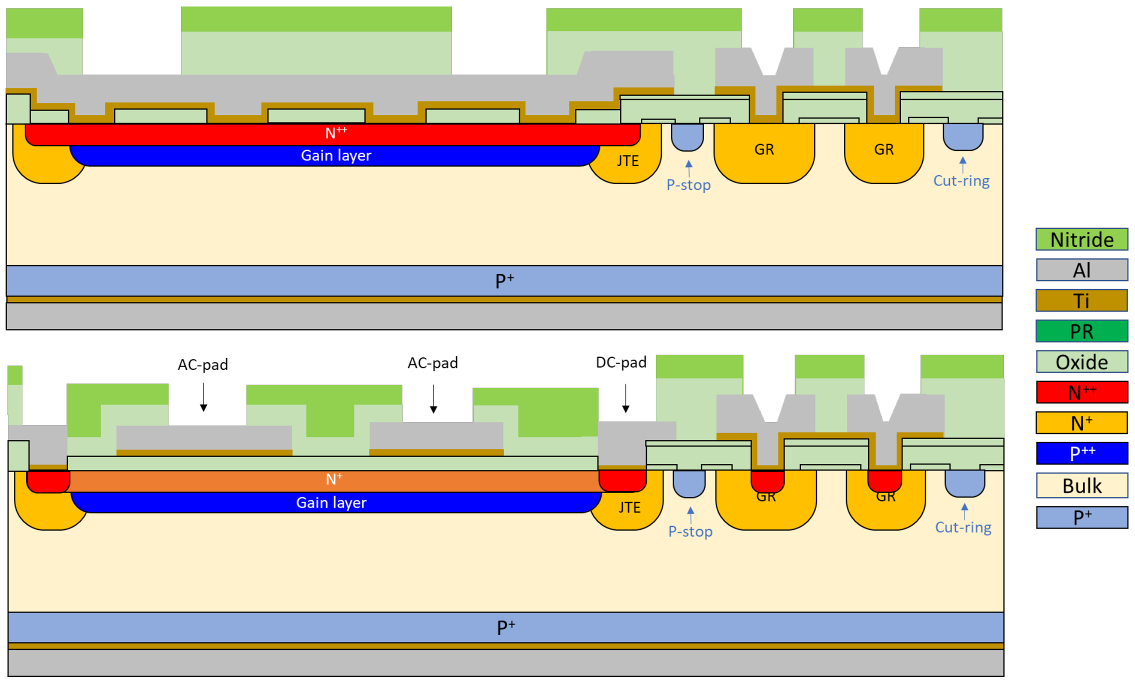


Future plans: AC-LGAD

- Almost 100% Fill Factor can be
- The signal is collected on the n++ electrode
- The metal AC pads act as capacitors, they are charged by the signal
- AC-PAD LGAD by change three masks of the DC LGAD masks :1. metal, 2. contact, 3. passivation







Ref. First demonstration of 200, 100, and 50 μm pitch Resistive AC-Coupled Silicon Detectors (RSD) with 100% fill-factor for 4D particle tracking; IEEE Electron Device Letters PP(99):1-1, September 2019

Ref. LGAD designs for Future Particle Trackers; NIMA, volume 979, 2020, 164383

Thank you for your attention !!