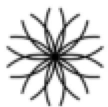

CHiP 高能與強場物理研究中心
CENTER FOR HIGH ENERGY AND HIGH FIELD PHYSICS

中央研究院物理研究所
INSTITUTE OF PHYSICS, ACADEMIA SINICA

LGAD R&D in Taiwan

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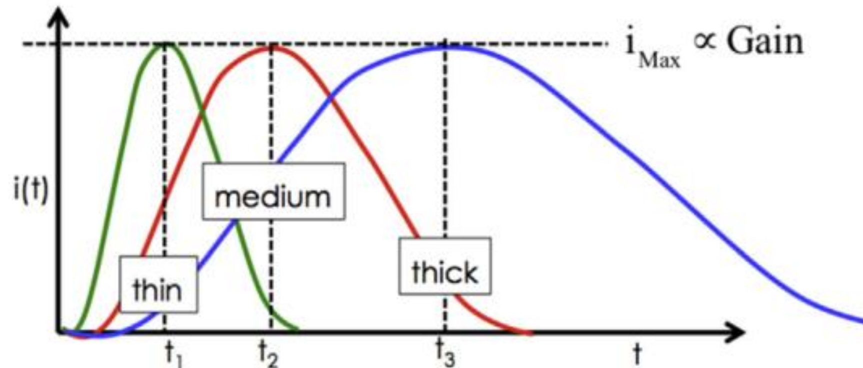
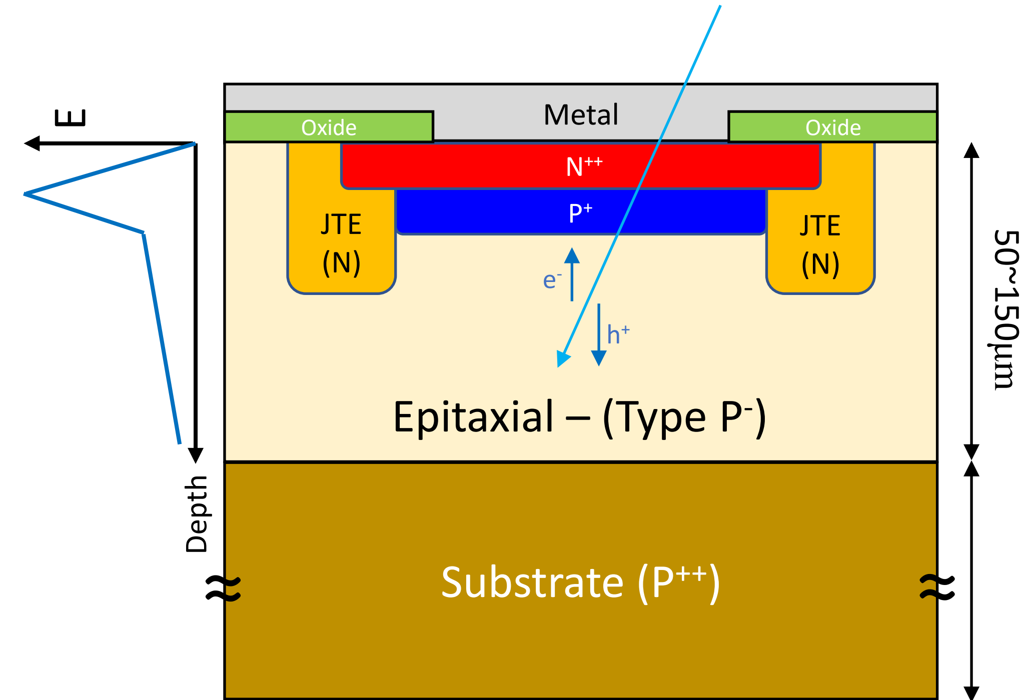
Institute of Physics, Academia Sinica[3]

Low Gain Avalanche Diode

- **Ultra-fast Silicon Detector**
  - High time resolution (~30ps)
  - Higher doped p^+ gain layer
  - Thinner bulk

$$\frac{dI}{dt} \propto \frac{G}{d}$$



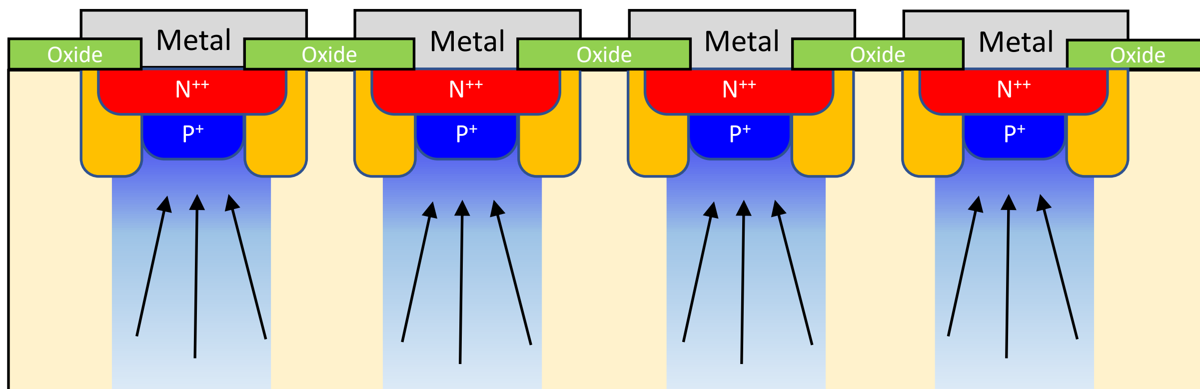


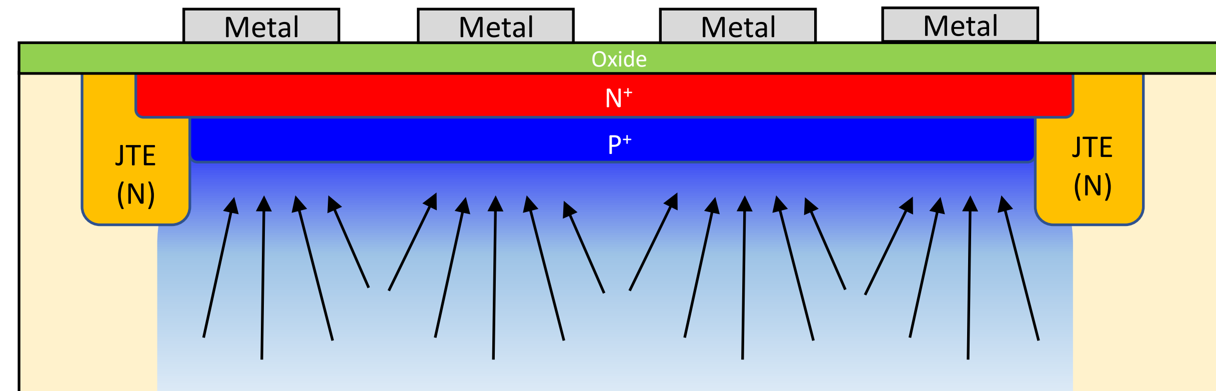
[1] : N. Cartiglia, et al., http://dx.doi.org/10.1016/j.nima.2015.04.025i

DC & AC Readout

- **DC-LGAD**
  - Simple structure
  - Lager signal
  - Lower p^+ doping
  - Higher n^{++} doping
  - Lower fill factor

- **AC-LGAD**
  - 100% fill factor
  - Higher spacing resolution
  - Consistent and accurate n^+ sheet resistance
  - Higher p^+ doping



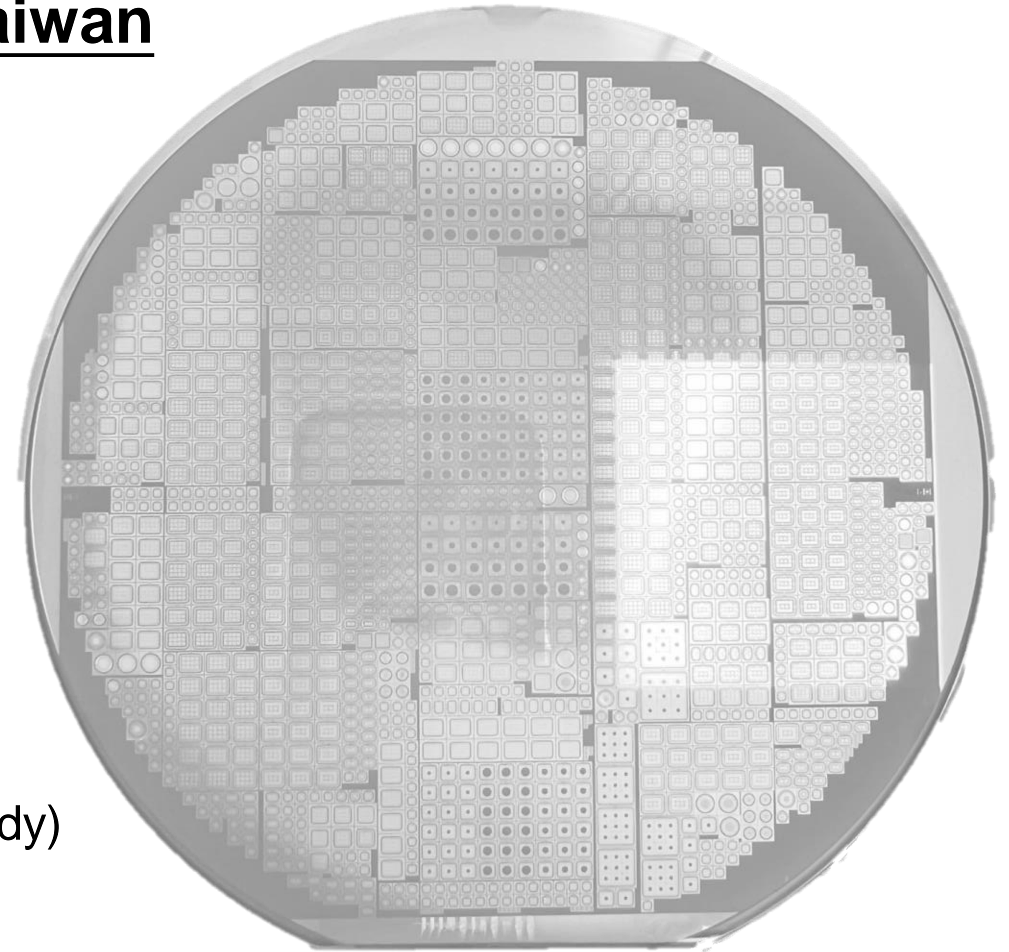


R&D Status in NCU

Find a Production line for Silicon Senor in Taiwan

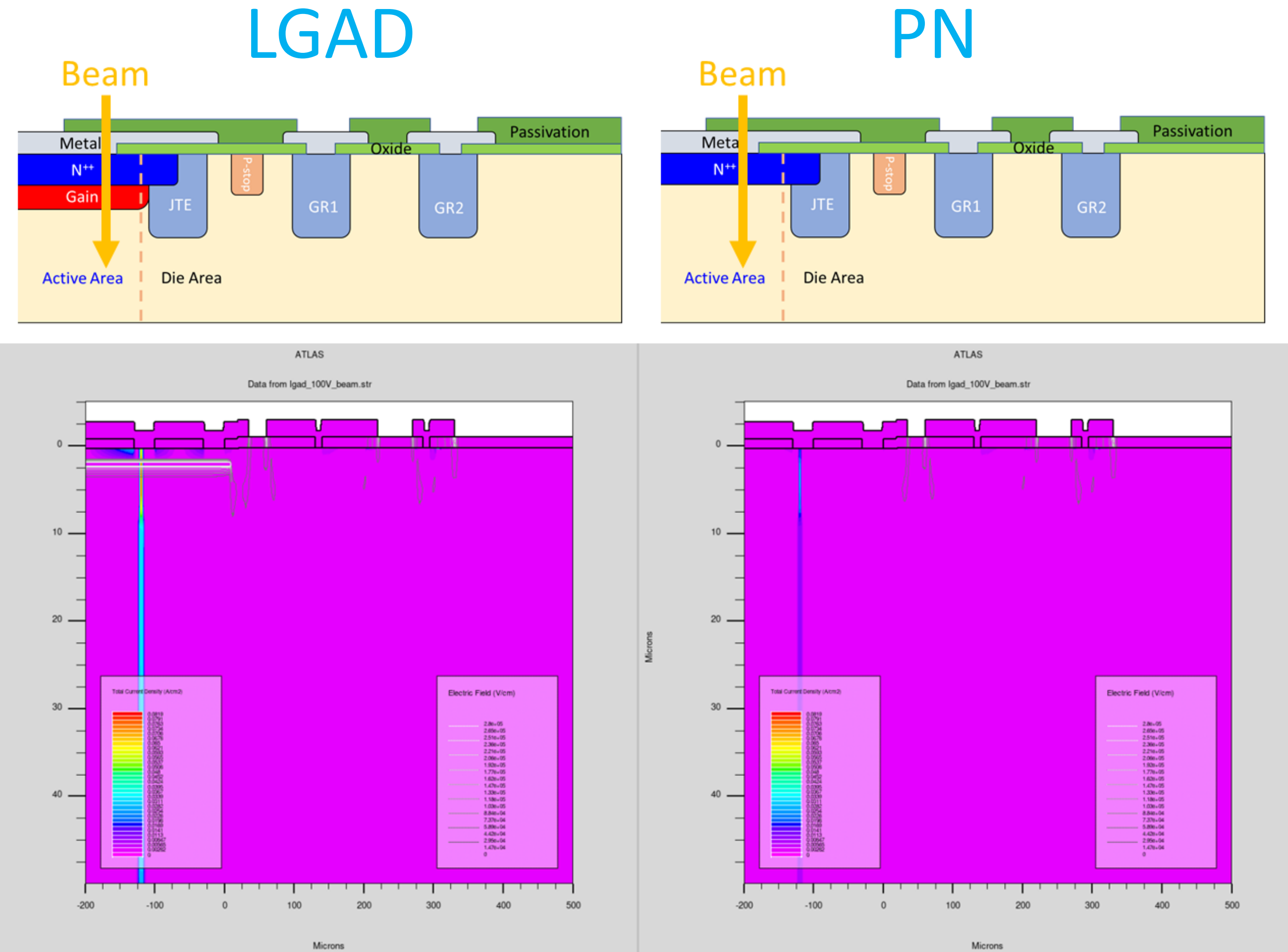
- **Silivaco (+Synonpsys)TCAD Simulation**
  - Process flow
  - Implant dose
  - Temperature and time of diffusion
  - Gain
  - Structure

- **Manufacture Testing**
  - Mask design
  - Taiwan Semiconductor Research Institute (TSRI) (for study)
  - 台亞 (TASC), 鼎元, etc. (for manufacture)



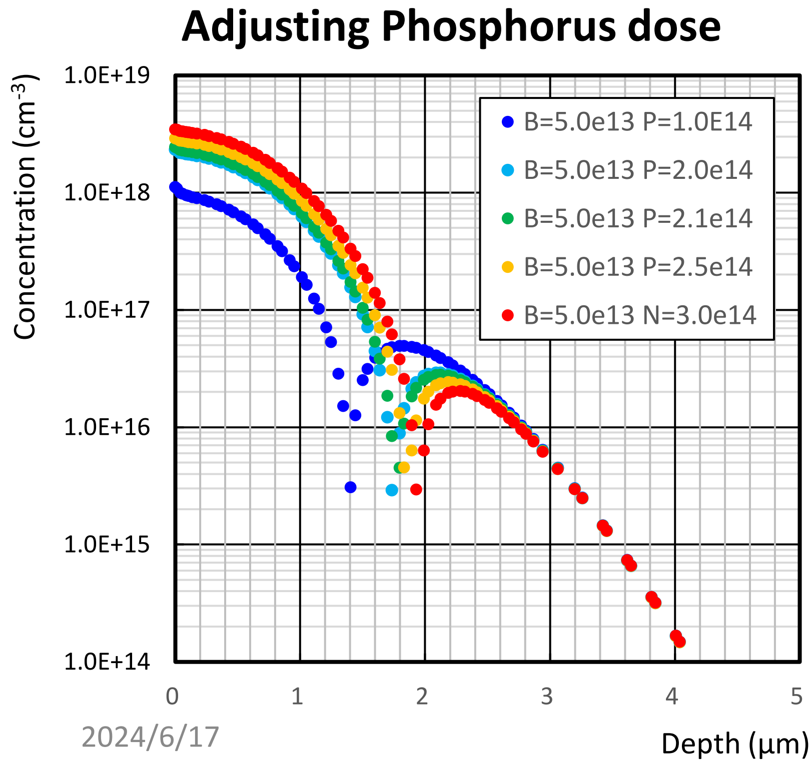
TCAD Simulation

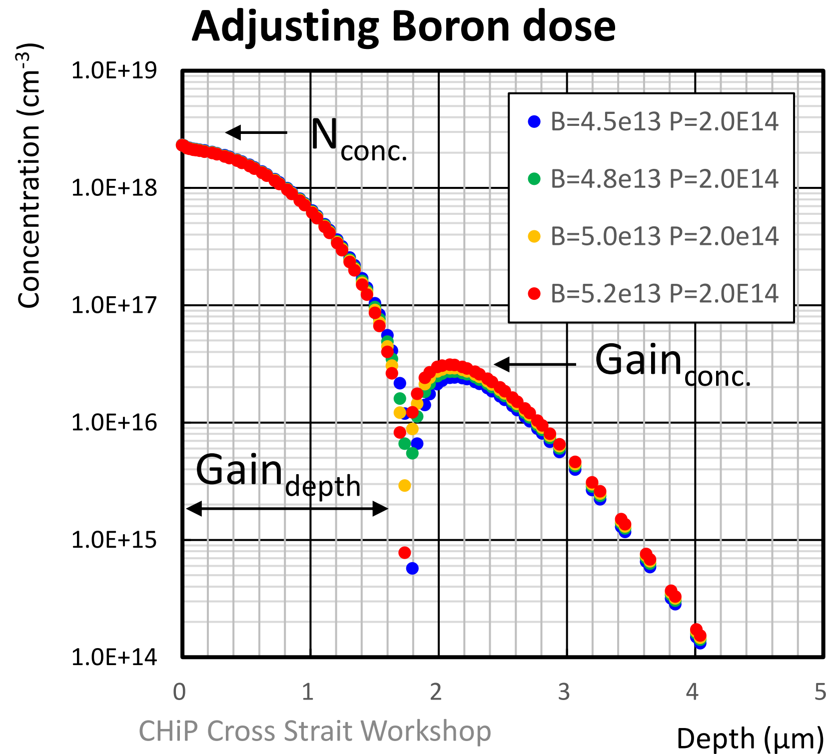
- Simulation space :
- (W) 700 μm x (H) 50 μm
- Guard rings are grounded
- Define gain with the ratio of additional current between LGAD and PN structure
- $Gain = \frac{I_{light}^{LGAD} - I_{dark}^{LGAD}}{I_{light}^{PN} - I_{dark}^{PN}}$

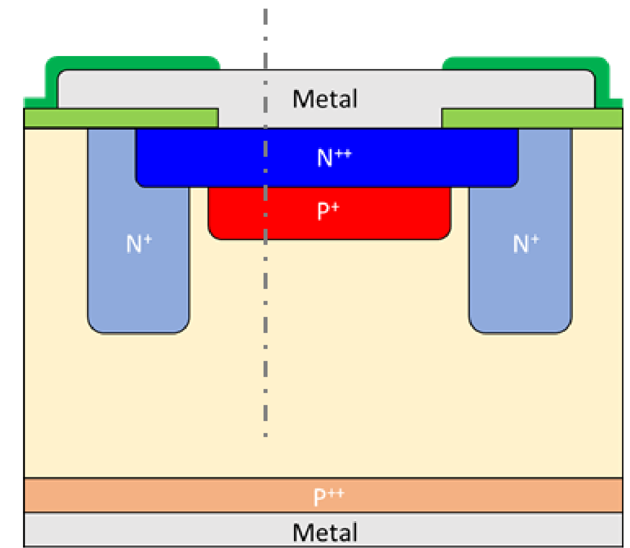


Concentration Profile Simulation

Phosphorus : affect $N_{conc.}$, $Gain_{conc.}$, $Gain_{depth}$
Boron : affect $Gain_{conc.}$

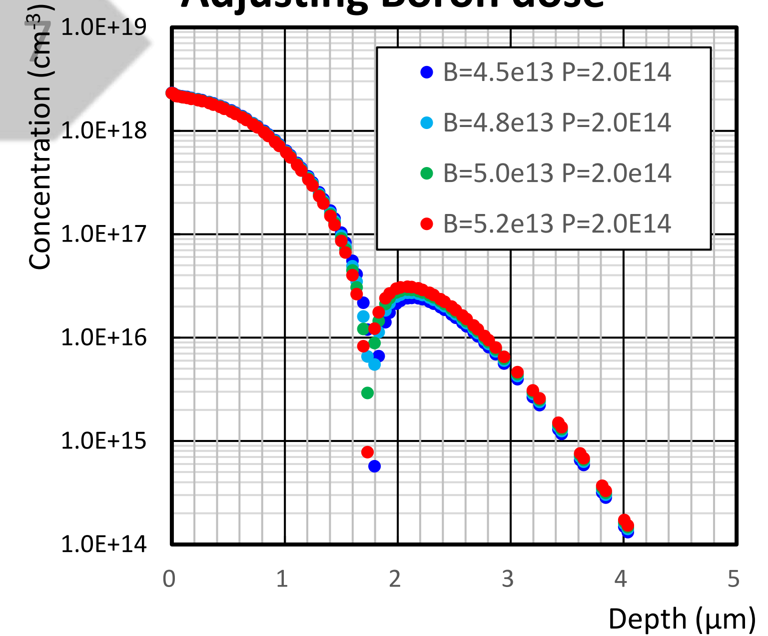




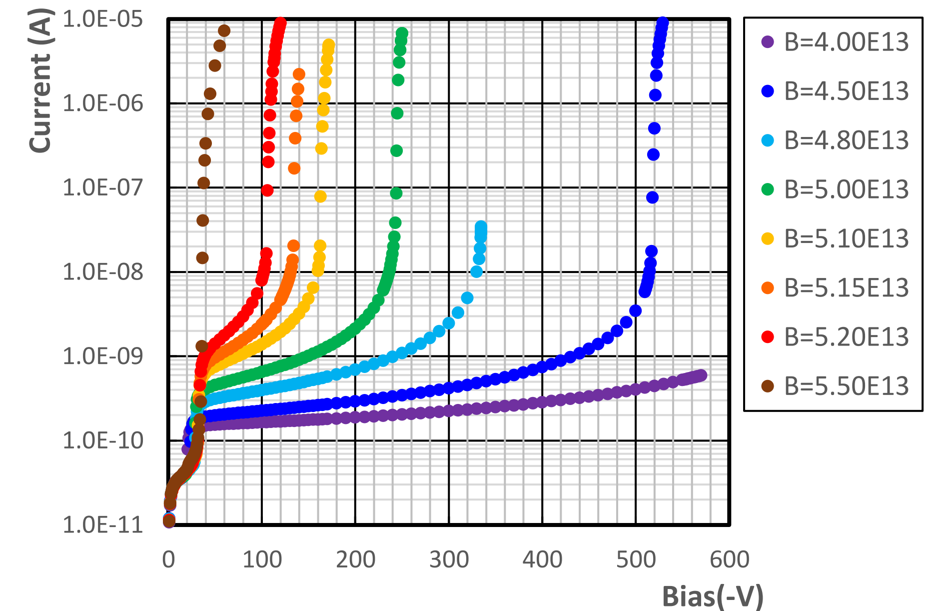


Implant Dose Simulation

- Boron dose : 4.8E13 ~ 5.2E13 cm-2
- Phosphorus dose : 2.0E14 ~ 2.5E14 cm-2

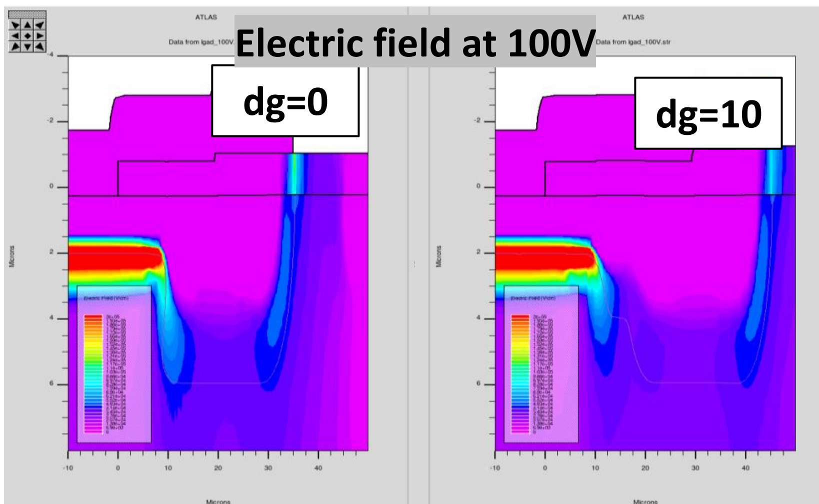


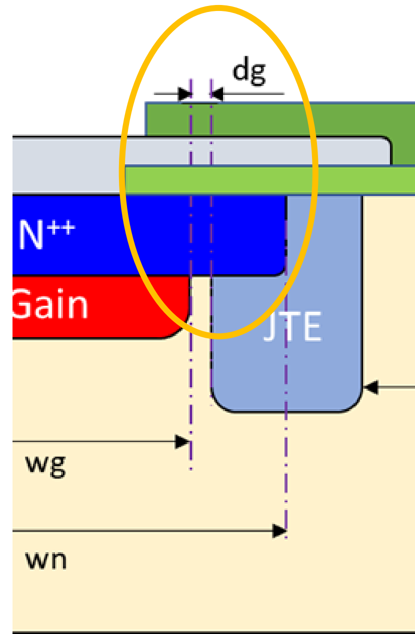
B dose(cm^{-2})	V_B	Gain (100V)	$N_b(cm^{-3})$	E_{gain}(V/cm) (100V)
5.50E13	37	-	3.4E16	4.3E5
5.20E13	106	49.34	3.1E16	4.0E5
5.15E13	131	15.02	3.1E16	4.0E5
5.10E13	163	8.90	3.0E16	3.9E5
5.00E13	244	4.45	2.9E16	3.7E5
4.80E13	335	2.62	2.7E16	3.5E5
4.50E13	518	1.65	2.4E16	3.1E5
4.00E13	>560	0.96	2.0E16	2.6E5

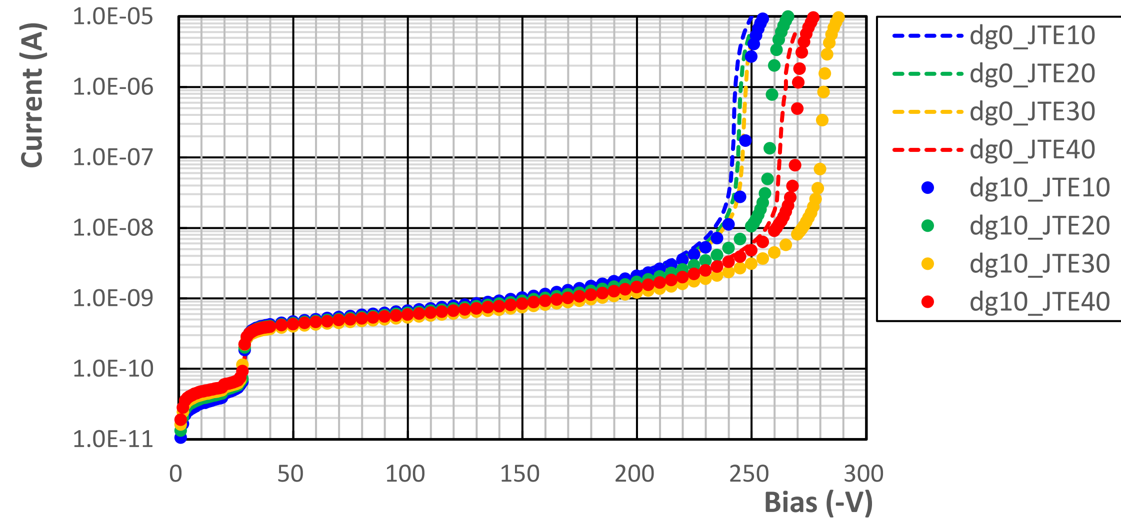


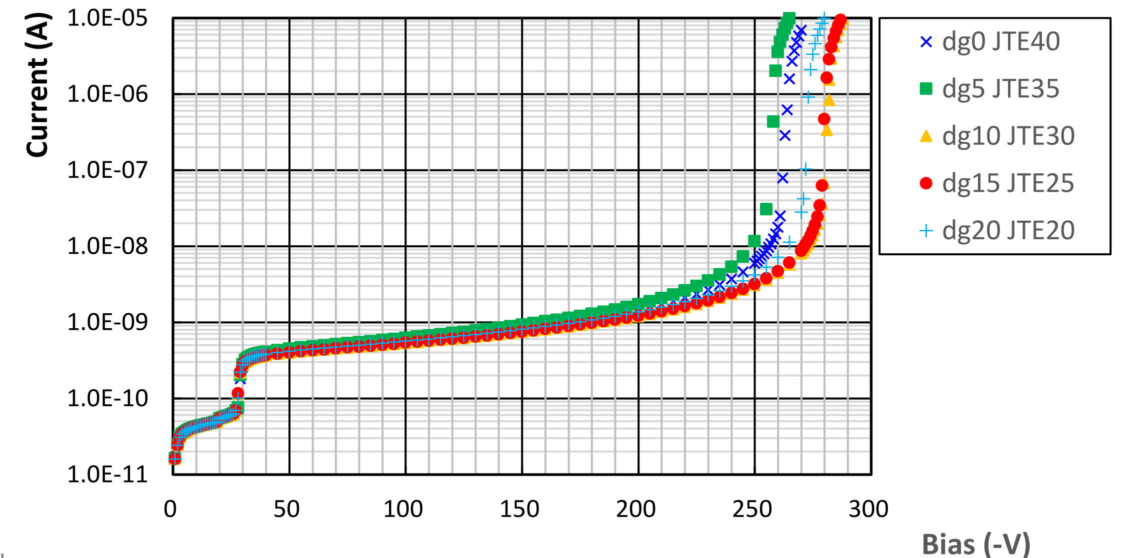
Edge of Gain Electric Field

- Adjust the inner edge shape of JTE.
- Change the protruding electric field.
- In same JTE width, all dg=10μm has higher breakdown voltage.



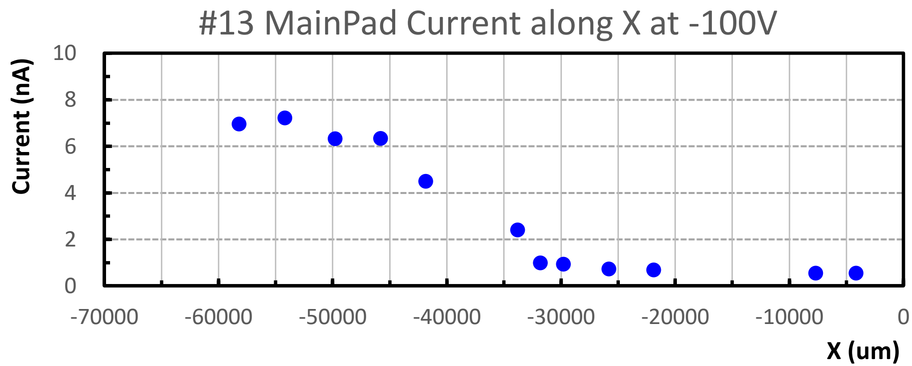


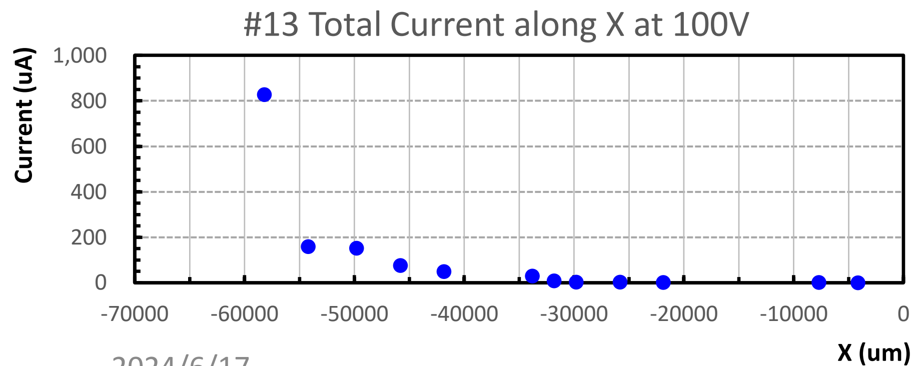


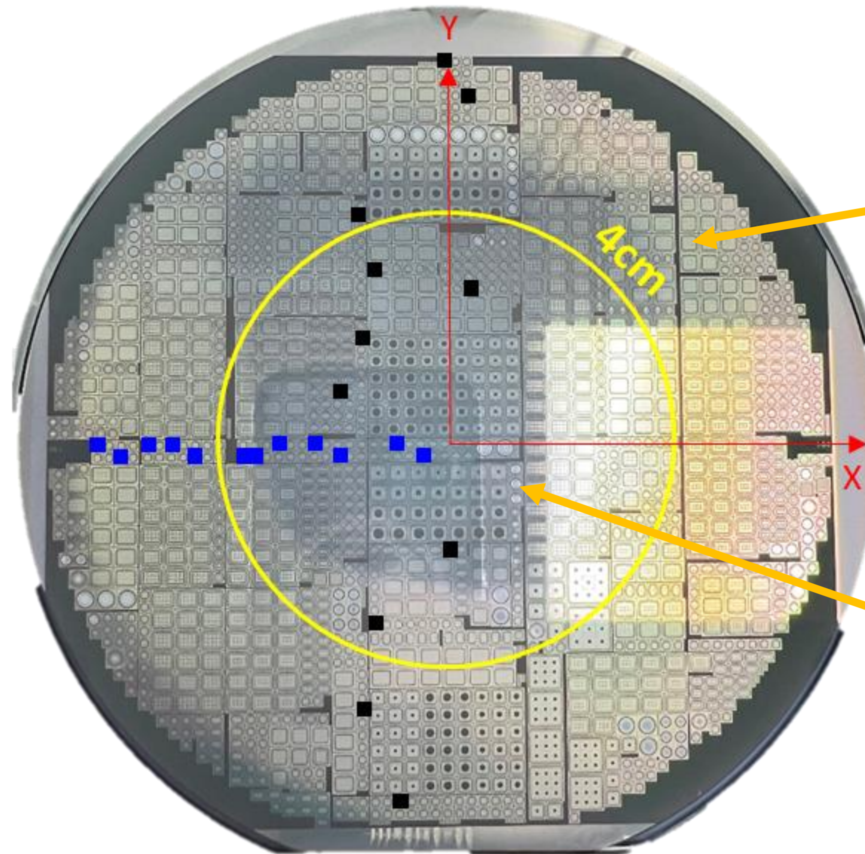


First Prototype Manufacture

- Cell size : 500μm x 500μm ~ 2mm x 2mm
- LGAD、PN、MOS、GCD







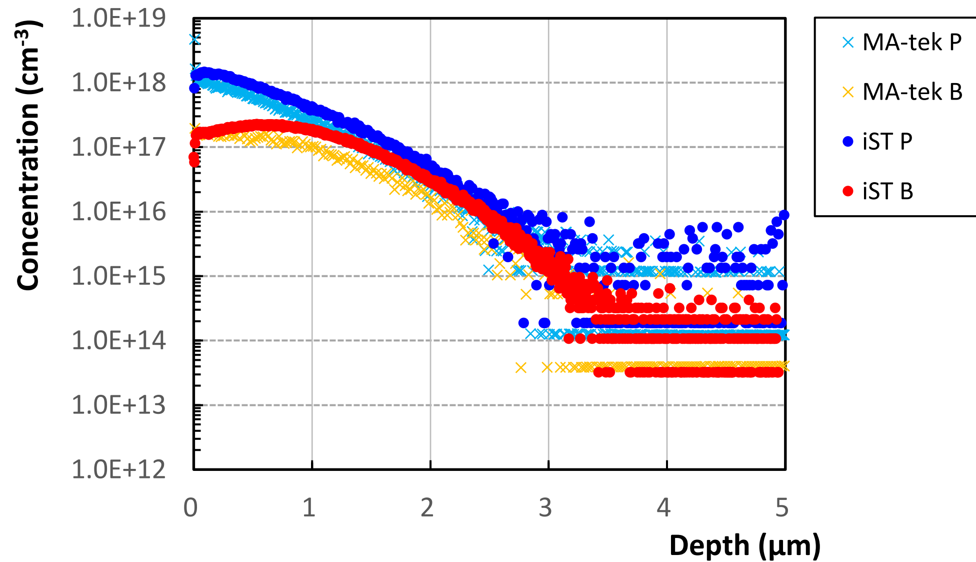
Outer Region

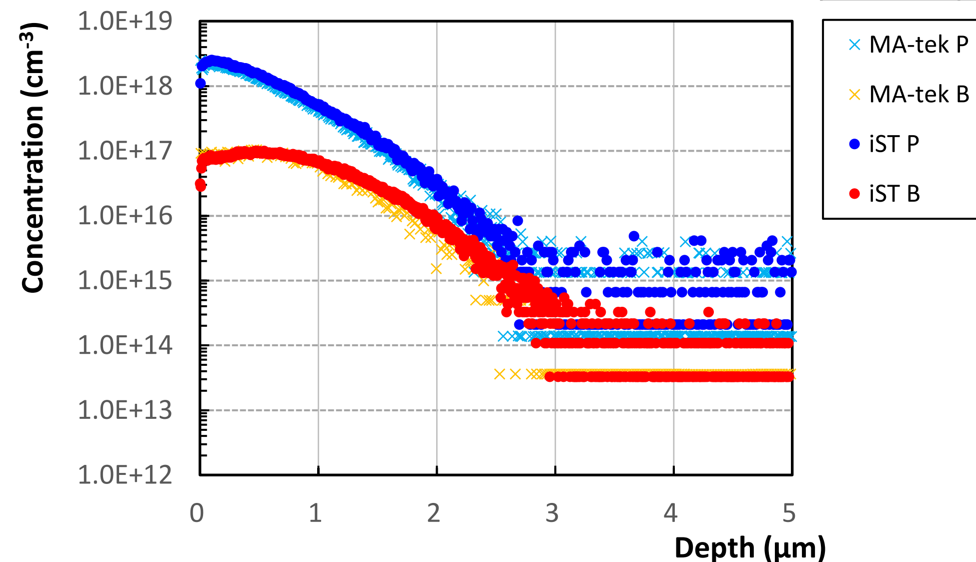
Center Region

SIMS Result

Step	Process
1	Back side B Imp.
2	JTE & GR Imp.
3	P-stop Imp.
4	Drive in 1
5	Gain layer Imp.
6	Drive in 2
7	N^{++} Imp.
8	Drive in 3
9	Deposit oxide
10	Contact etch
11	Metal deposit & etch
12	Passivation deposit & etch

Wafer	Gain Layer(I04) B Imp.	Drive in 2 (D02)	N++(I05) P Imp.	Drive in 3 (D03)
#15	2.0E+14	1100℃ / 400min	2.00E+14	1100℃ / 200min
#21	5.5E+13			1100℃ / 30min





SIMS Comparison

- Wafer #1 and #10 are produced before modification and do the SIMS measurement by TSRI
- Wafer #15 and #21 are measured in iST and MA-tek.
- The measuring dose is much lower than the implant dose.

	Wafer	#1	#10	#15		#21	
Process	B dose (cm^{-2})	4.5E13	5.5E13	2.0E14		5.5E13	
	Drive in 2 (min)	200	200	400		400	
	P dose (cm^{-2})	2.0E14	4.0E14	2.0E14		2.0E14	
	Drive in 3 (min)	200	200	200		30	
SIMS Result	SIMS Company	TSRI	TSRI	MA-tek	iST	MA-tek	iST
	B Max Conc. (cm^{-3})	2.05E17	2.44E17	1.74E17	2.13E17	1.04E17	9.87E16
	P Max Conc. (cm^{-3})	1.39E18	2.92E18	1.64E18	1.47E18	2.30E18	2.49E18
	B Depth (μm) (= 1E16cm^{-3})	1.84	1.88	2.23	2.50	1.79	1.96
	P Depth (μm) (= 1E16cm^{-3})	2.21	2.32	2.51	2.63	2.32	2.30
	B Area (cm^{-2})	1.60E13	1.91E13	1.92E13	3.02E13	1.07E13	1.17E13
	P Area (cm^{-2})	1.20E14	2.39E14	7.30E13	1.12E14	1.44E14	1.67E14
	$\frac{B\ SIMS\ Dose}{B\ Imp.Dose}$	35.6%	34.7%	9.6%	15.1%	19.5%	21.2%
	$\frac{P\ SIMS\ Dose}{P\ Imp.Dose}$	60.0%	59.7%	36.5%	55.8%	72.0%	83.4%

The Future Plan

- Students will go to TSRI to operate the machines and compare each step with the simulation.
- For next manufacture, we will change to study the AC-LGAD. We had started to simulate the characteristics of AC-LGAD, such as sheet resistance and signal transfer.
- Discuss production possibilities of AC-LGAD with companies for EIC.

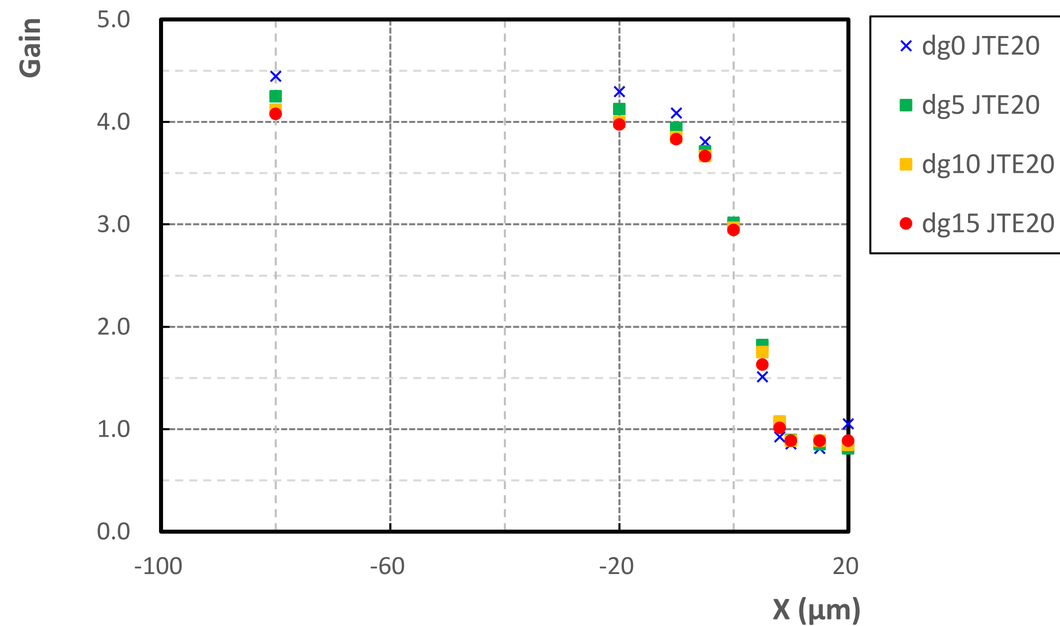
Summary

- For produce LGAD in Taiwan, we use the TCAD simulation to study the process flow and structure. The first round of DC-LGAD wafers are produced by TSRI to verify the simulation, but there are no gain layer structure in SIMS result.
- Base on comparison the SIMS measurement of different wafers, the impurity concentration didn’t much to the process flow. It maybe caused by equipment issues.
- Keep process study in TSRI with operating machine by ourself.
- EIC’s AC-LGAD will be made by a suitable manufacturer.

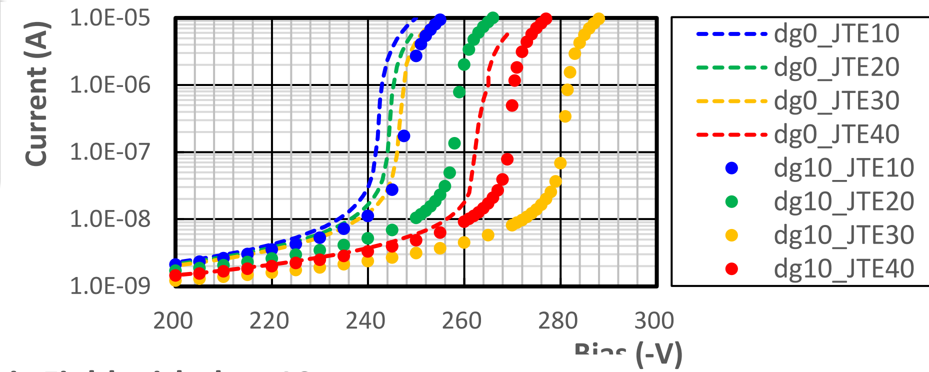
Thank you for your attention!

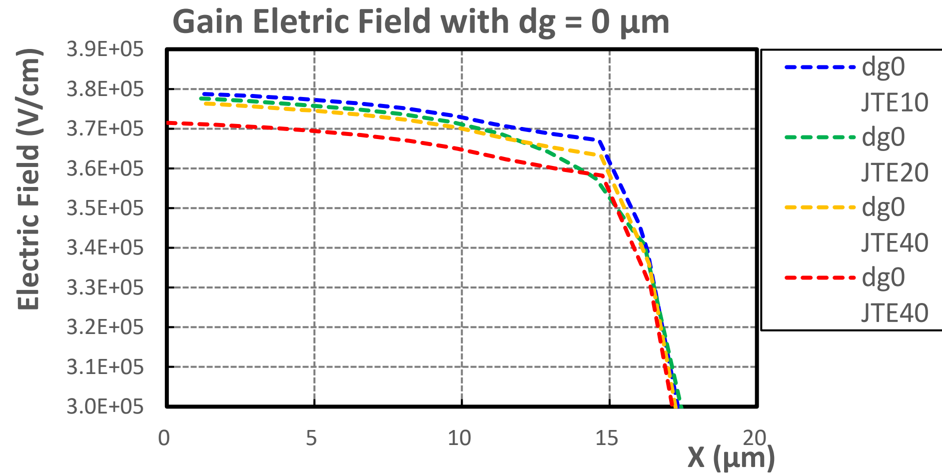
Gain(x)

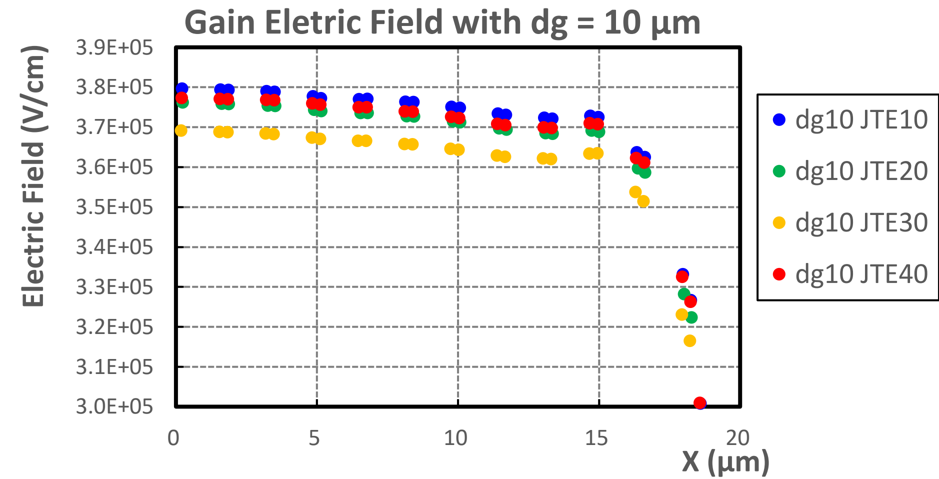
- Different dg keep the same boundary of active area.
- Based on the different dg, the gain is lower about 0.2~0.5.

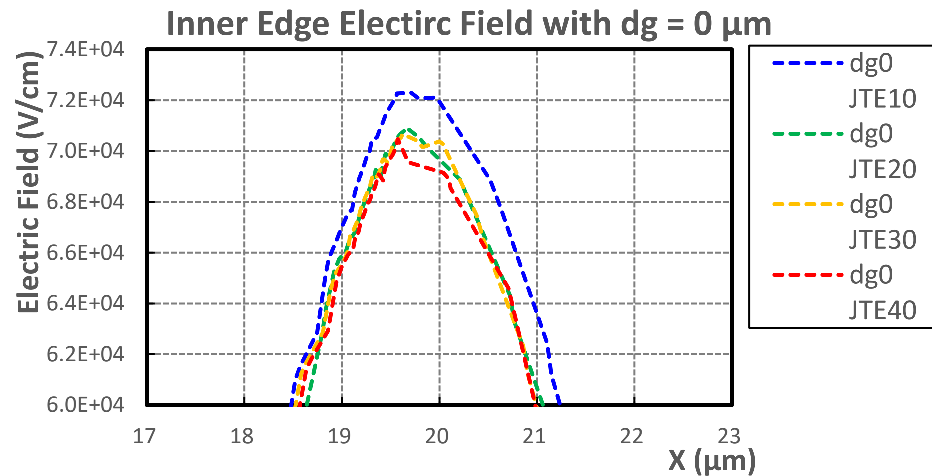


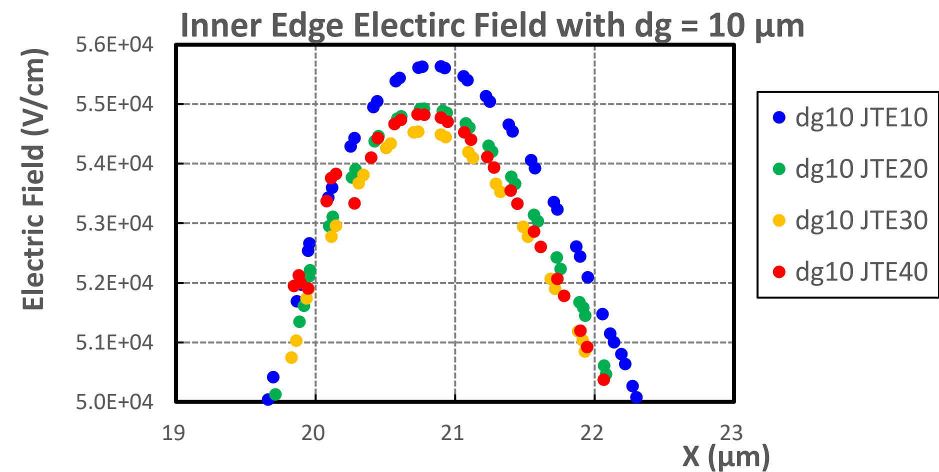
Horizontal Electric Field





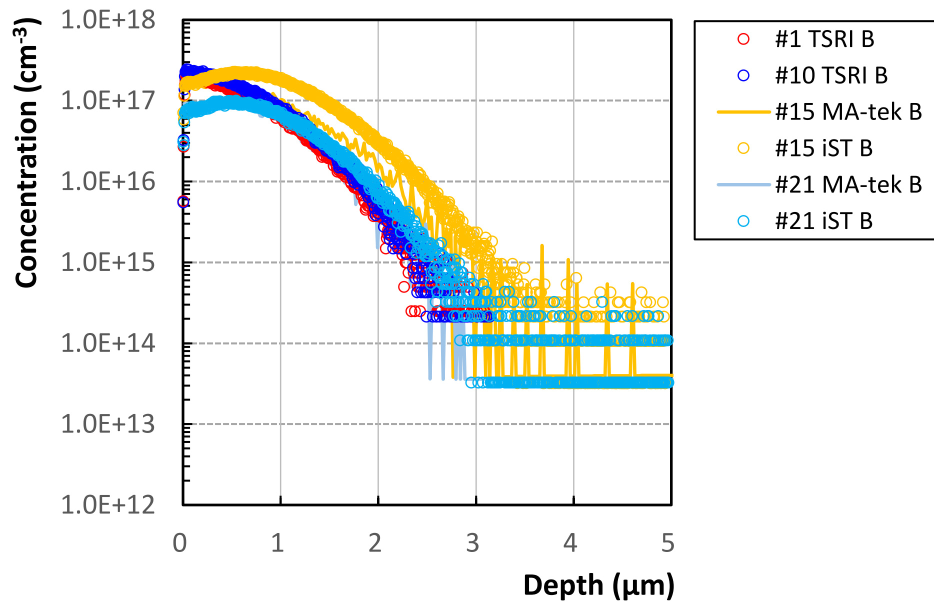


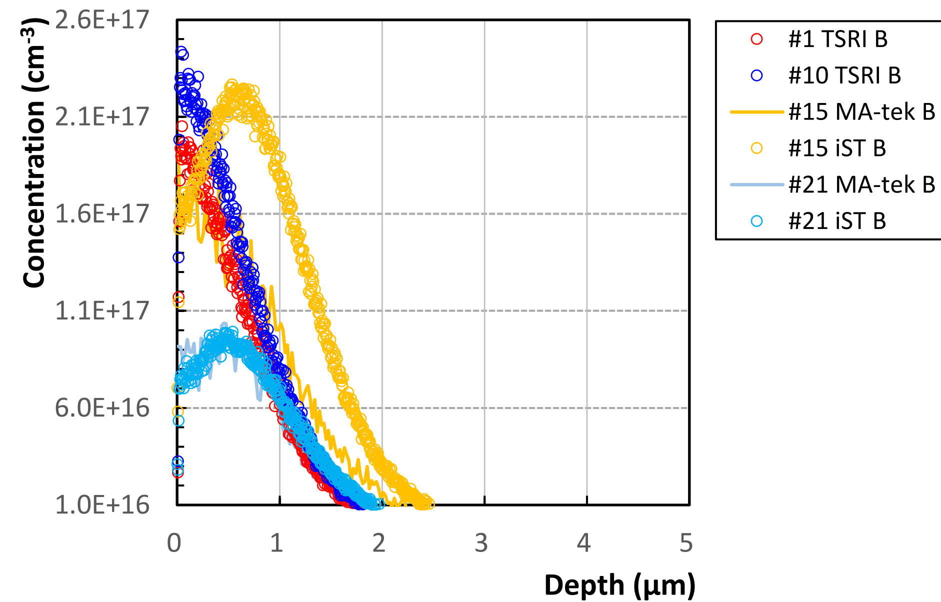




Boron SIMS

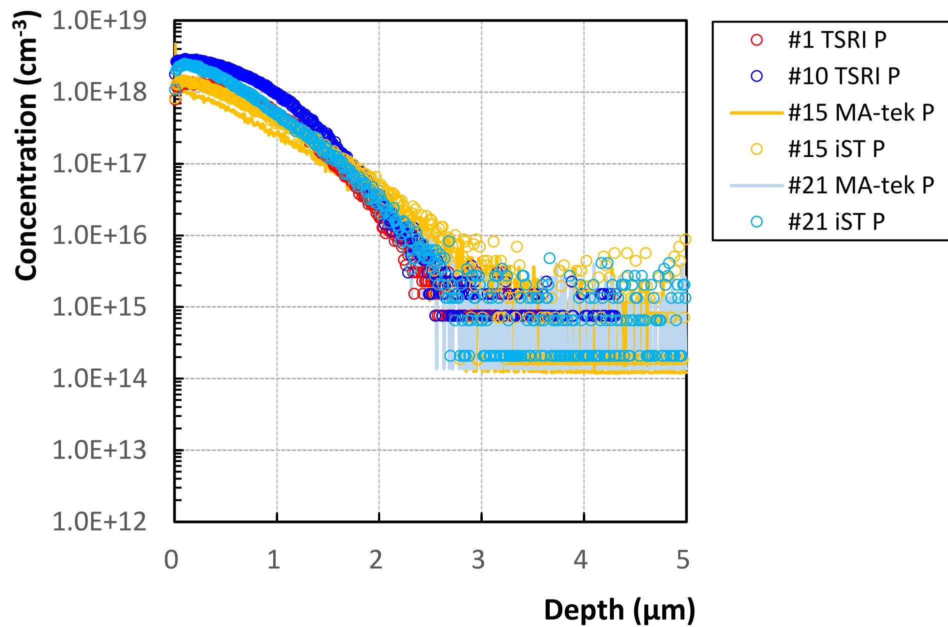
Wafer(#)	B Imp (cm^{-2})	Drive in 2	P Imp (cm^{-2})	Drive in 3	Company	B Max Conc. (cm^{-3})	Depth (µm) (Conc. = 1E16)	$\frac{SIMS\ Dose}{Imp.\ Dose}$
1	4.5E+13	200min	2.0E+14	200min	TSRI	2.05E17	1.84	35.6%
10	5.5E+13	200min	4.0E+14	200min	TSRI	2.44E17	1.88	34.7%
15	2.0E+14	400min	2.0E+14	200min	MA-tek	1.74E17	2.23	9.6%
					iST	2.13E17	2.50	15.1%
21	5.5E+13	400min	2.0E+14	30min	MA-tek	1.04E17	1.79	19.5%
					iST	9.87E16	1.96	21.2%

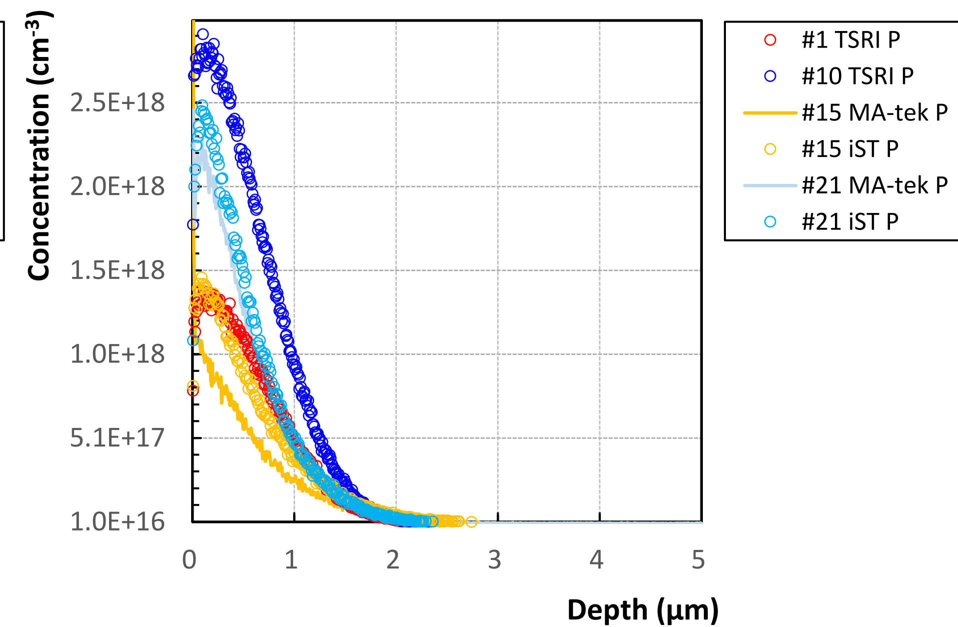




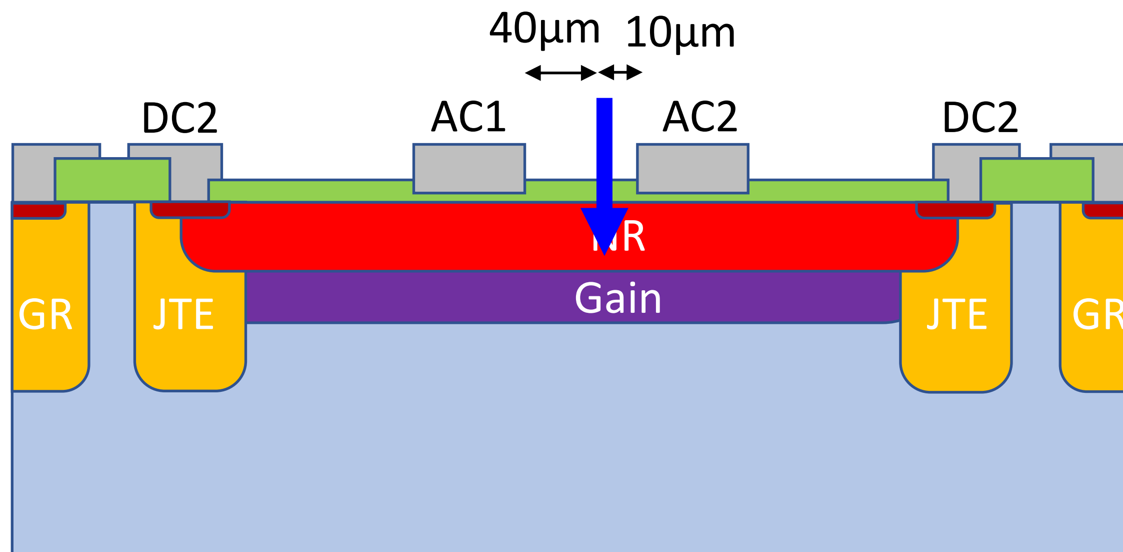
Phosphorus SIMS

Wafer(#)	B Imp (cm^{-2})	Drive in 2	P Imp (cm^{-2})	Drive in 3	Company	P Max Conc. (cm^{-3})	Depth (μm) (Conc. = 1E16)	$\frac{SIMS\ Dose}{Imp.\ Dose}$
1	4.5E+13	200min	2.0E+14	200min	TSRI	1.39E18	2.21	60.0%
10	5.5E+13	200min	4.0E+14	200min	TSRI	2.92E18	2.32	59.7%
15	2.0E+14	400min	2.0E+14	200min	MA-tek	1.64E18	2.51	36.5%
					iST	1.47E18	2.63	55.8%
21	5.5E+13	400min	2.0E+14	30min	MA-tek	2.30E18	2.32	72.0%
					iST	2.49E18	2.30	83.4%





Signal Simulation



在靠近右邊電極(AC2)處產生約10MIP的訊號

- 粒子路徑：(-140,-3)~ (-140,10)
- 訊號大小： 800 e-h/μm
  = 1.28×10^{-4} pC/μm
- (在Ref中提到1MIP約80 e-h/μm)
- 訊號時間 : 100ps~200ps
- Bias : 200V
- Gain ~4.8