KNU KYUNGPOOK NATIONAL UNIVERSITY

SPDAK 2022

3rd School for Particle Detectors and Applications at KNU
Semiconductor Detector Lab.

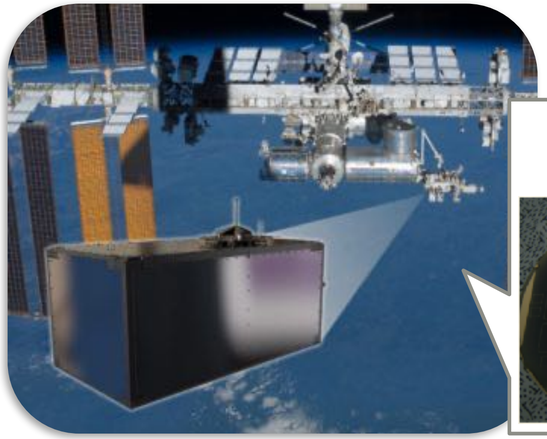
Jongmin Baek **KNU**

Contents

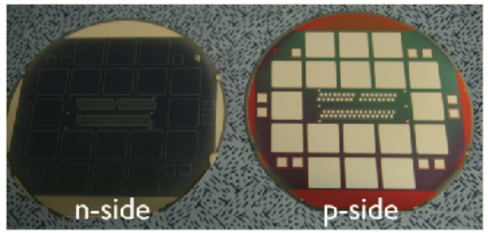
I. Current/Previous Projects

하전 입자, 광자 등 입자 검출 → 이미징, 입자 궤적 및 버텍스 측정

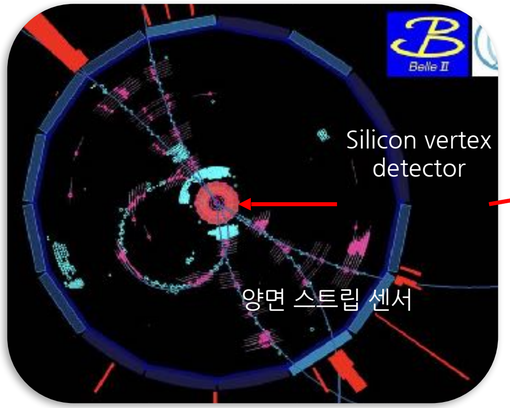
천체 물리학
:우주선 측정

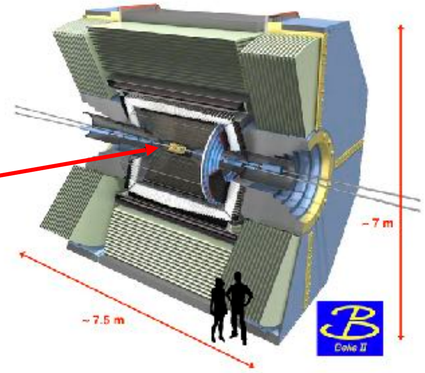


패드 광센서

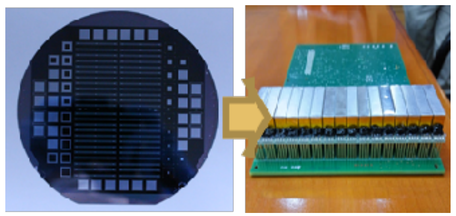


고에너지 물리학
:궤적/버텍스 관측





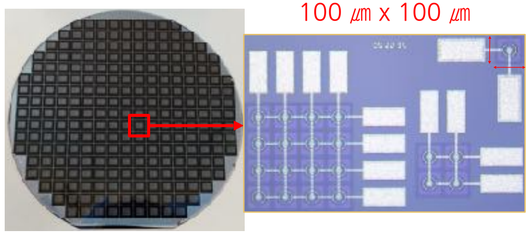
항만용 X-ray 컨테이너 검색기



어레이 광센서

의학용 이미지 센서

Mammography



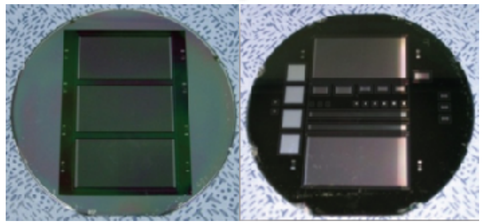
JFET 픽셀 센서

II. History of Sensor R&D

2002

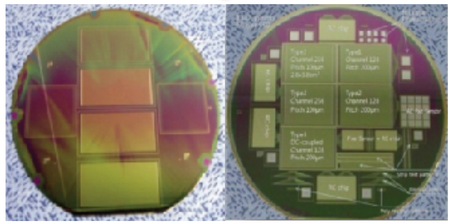
DC-coupled 4x4 pads sensor
CREAM SCD sensor

2003 2005



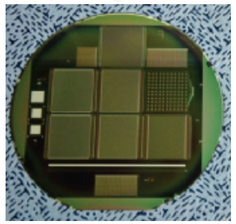
DC-coupled
Single/Double-sided strip sensor

2007



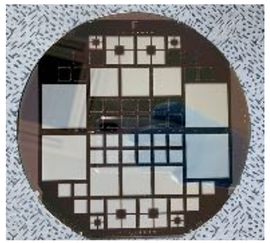
DC/AC-coupled strip sensor
tracker, University of Maryland

2009 2011



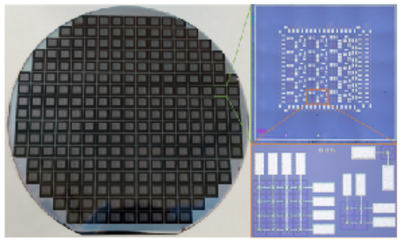
AC-coupled
Single/Double-sided strip sensor

~ 2019



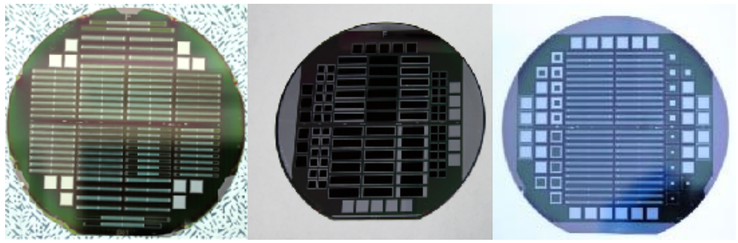
PIN photodiode sensor for
X-ray detection

2017



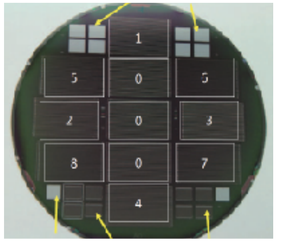
JFET pixel array sensor for
imaging

2015



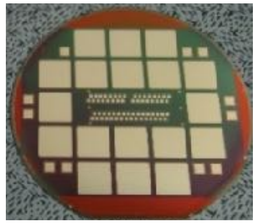
DC/AC-coupled
Single/Double-sided photo sensor

2014



AC-coupled
Single-sided strip sensor

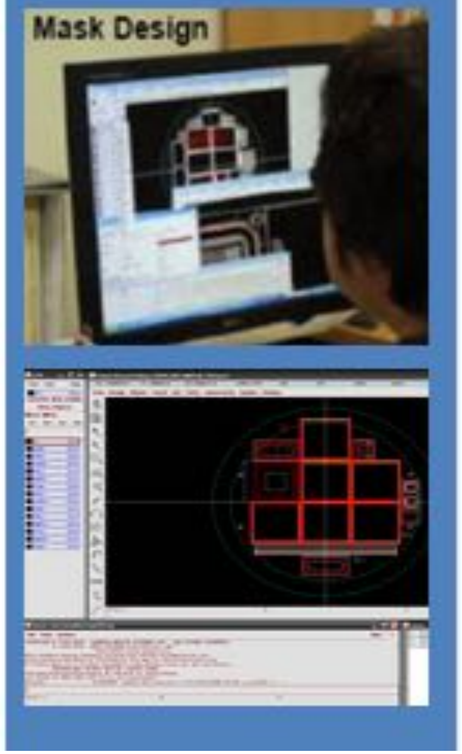
2012

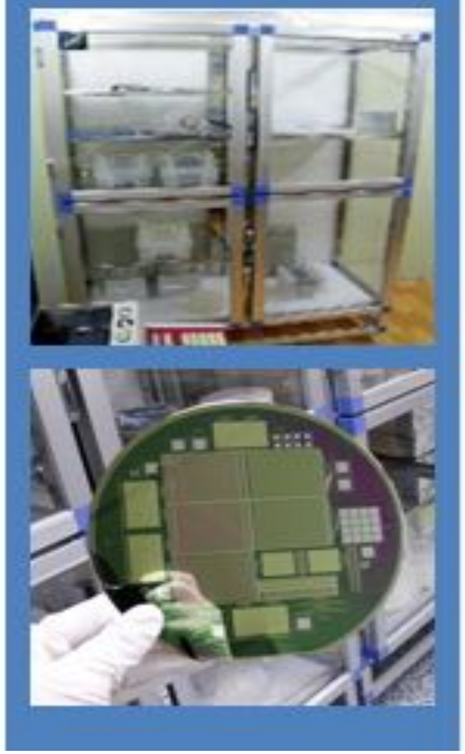


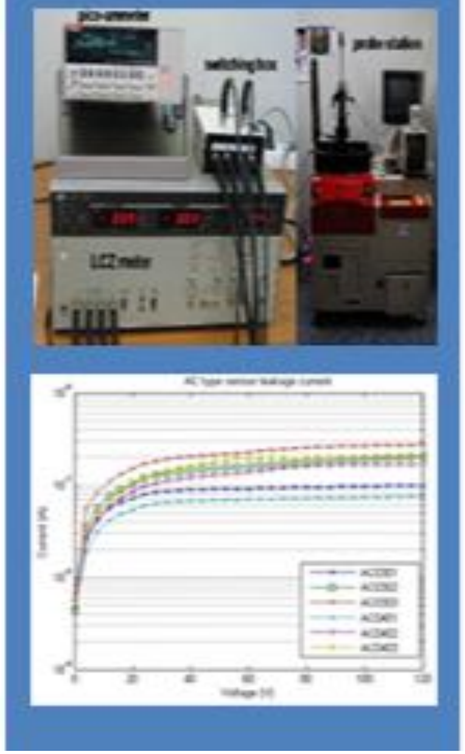
Large area photodiode
for ISS-CREAM experiment

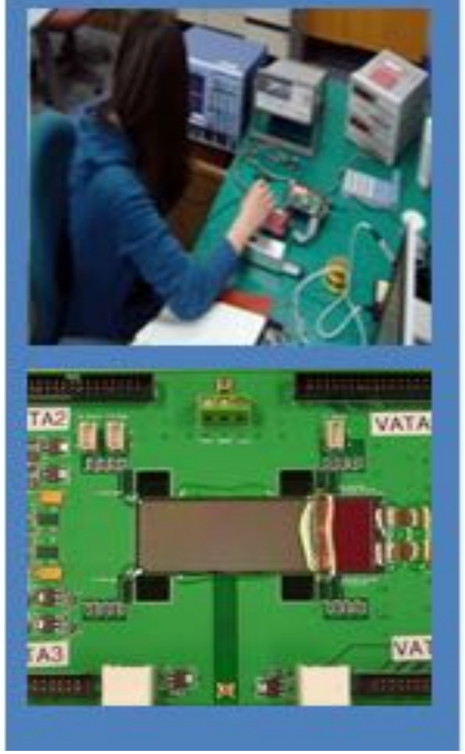
III. Sensor R&D

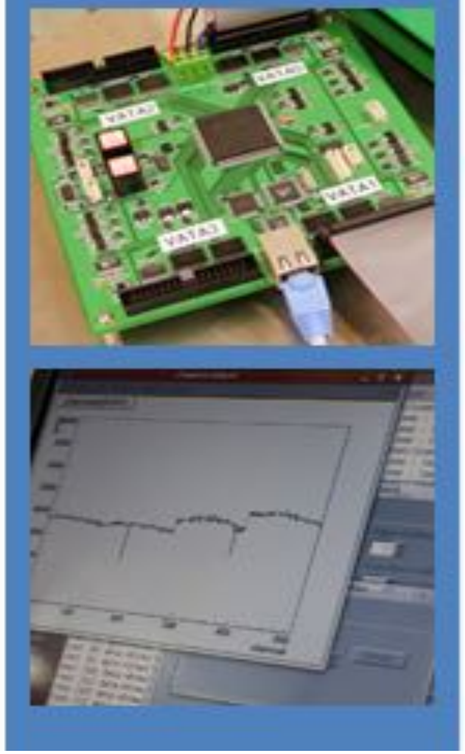
Design & Simulation → Manufacture → Electrical Characteristics → Signal Processing → Signal Analysis









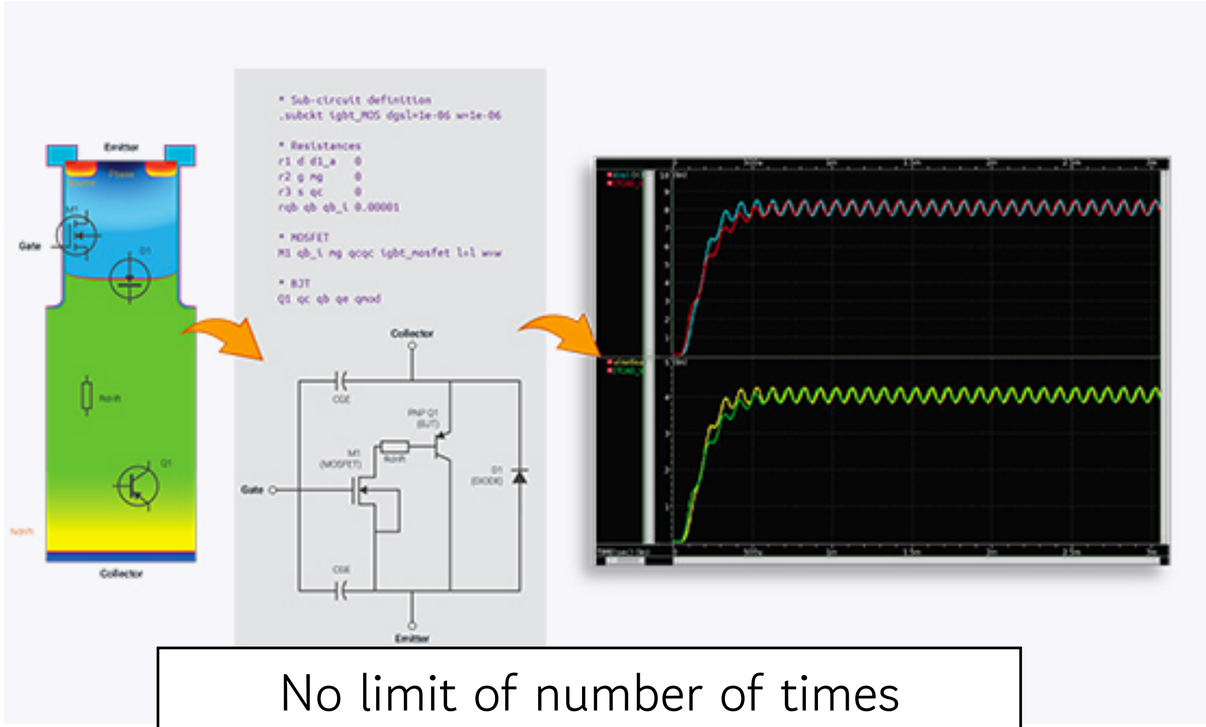


III. Sensor R&D

i. TCAD Simulation

"TCAD" ➟ Technology CAD

High Cost → limit of number of times
Hard to try various parameters



No limit of number of times
Can simulate under various conditions

III. Sensor R&D

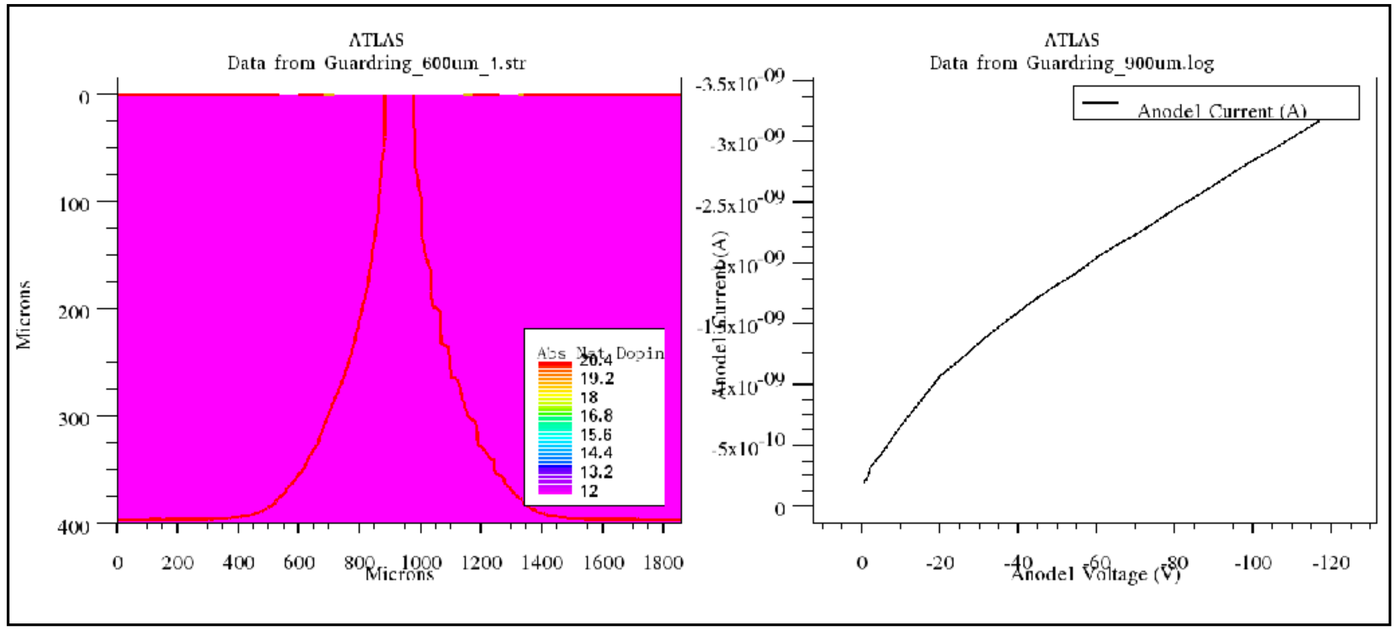
i. TCAD Simulation

Silvaco TCAD

```
go atlas

mesh infile=structure1-2.str

model srh auger conmob fldmob bgn bbt.std
impact selb
#output e.field

#solve
solve init
solve vcathode=0 outf=solve_cathode


load infile=solve_cathode
log outf=diode_iv_100.log
solve name=drain vdrain=0 vfinal=-100 vstep=-5

save outf=structure1-3-100V.str
tonyplot structure1-3-100V.str
tonyplot diode_iv_100V.log
```

generate sensor structure

apply bias voltage



DeckBuild code example for making .str file.

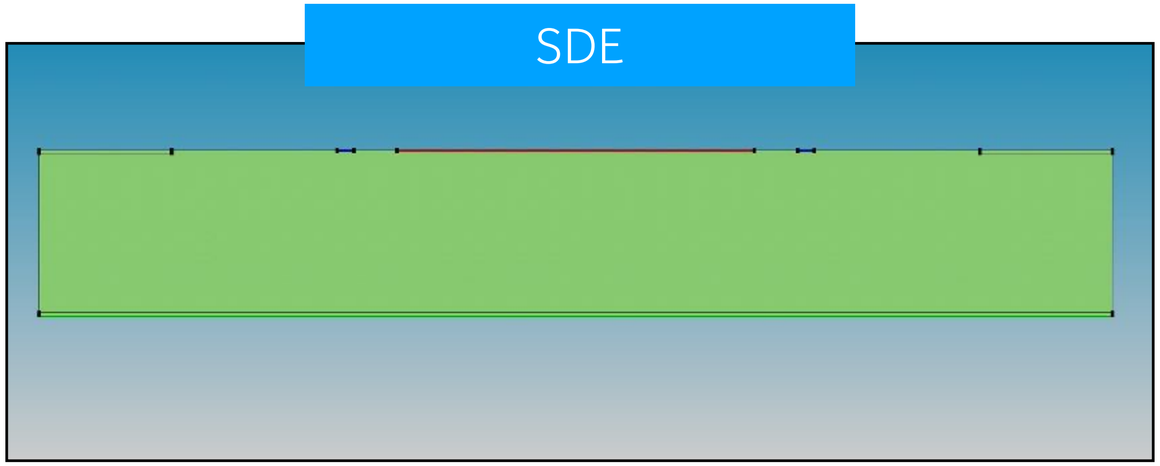
Simulation result example of **TonyPlot**.

- **DeckBuild** simulation for building sensor structure and setting mesh properties.
- **DeckBuild** allows users to build, debug Silvaco TCAD simulation.
- **TonyPlot** allows visualization of all outputted TCAD simulation results.

III. Sensor R&D

i. TCAD Simulation

Synopsys TCAD



Example of sensor structure draw with **SDE**.

SDevice

Apply bias voltage or measurement conditions

Sentaurus TCAD

Sentaurus Workbench

SProcess
- Process simulator
- Structure generation
- Mask-based process simulation

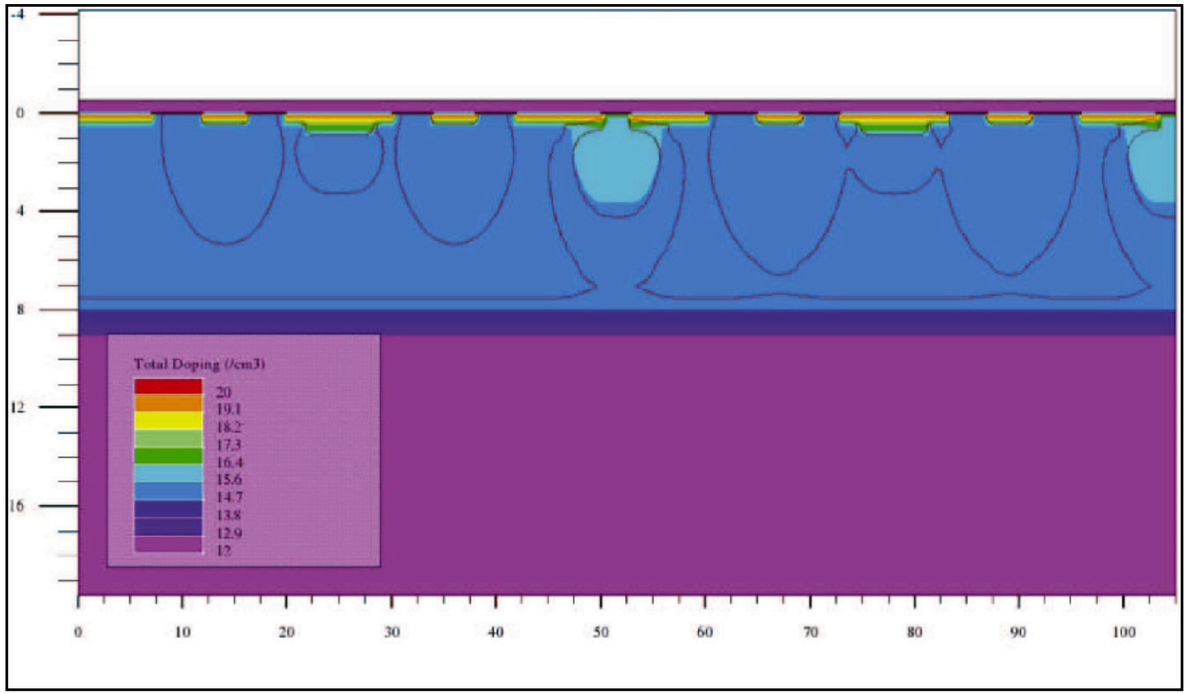
SDE
- Process simulator
- GUI framework
- Ion implantation concentration

SDevice
- Device simulator
- Apply characteristic measurement conditions

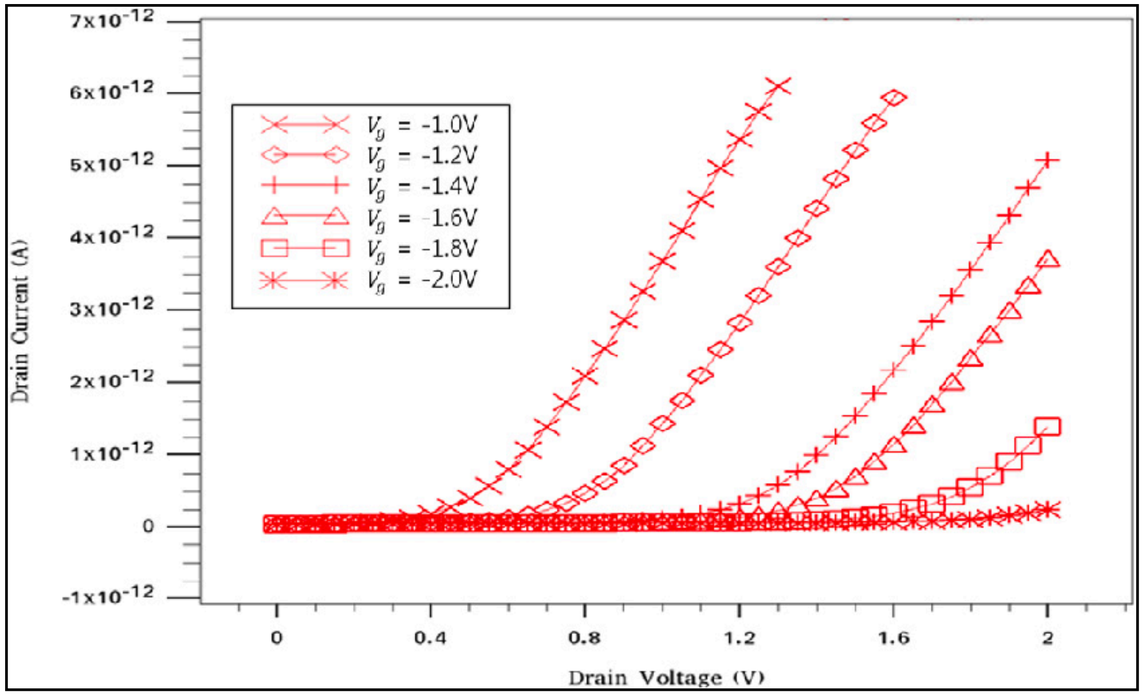
SVisual
- GUI framework
- Visualize device simulation results

III. Sensor R&D

i. TCAD Simulation



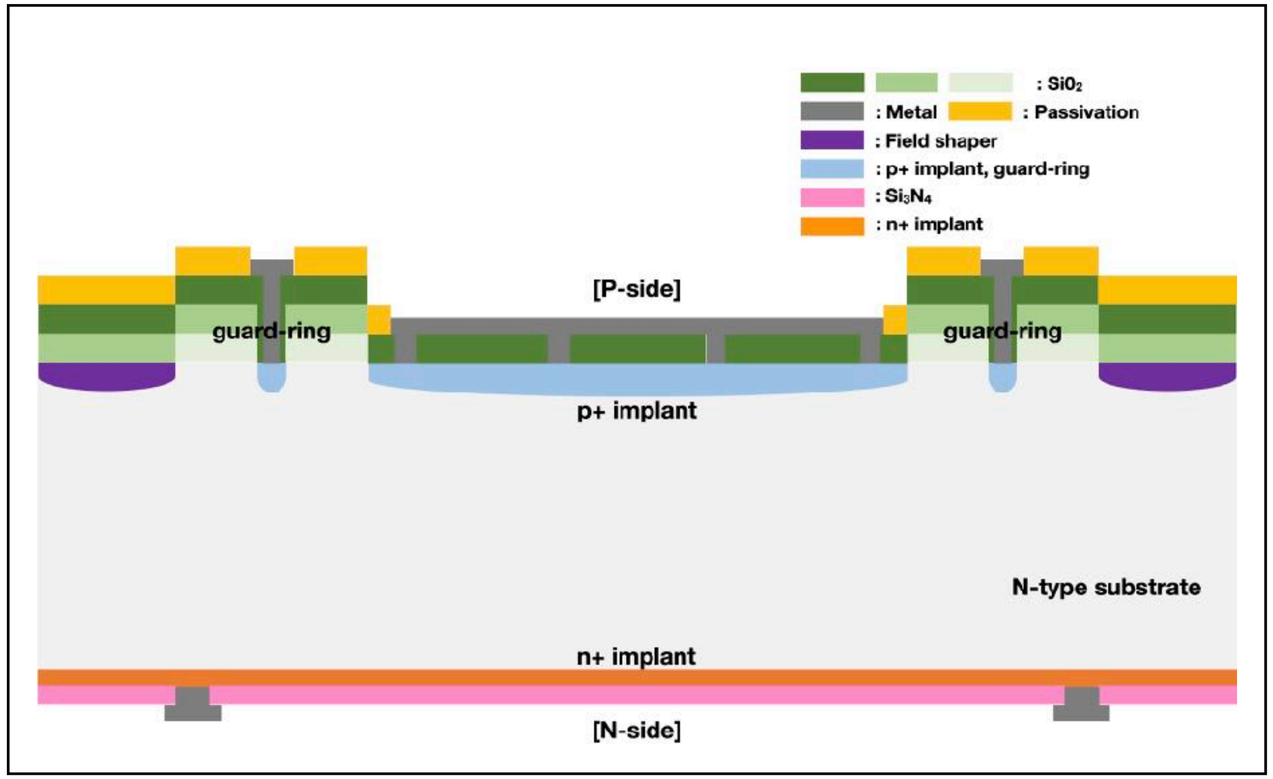
Device simulation results viewed with **SVisual.**



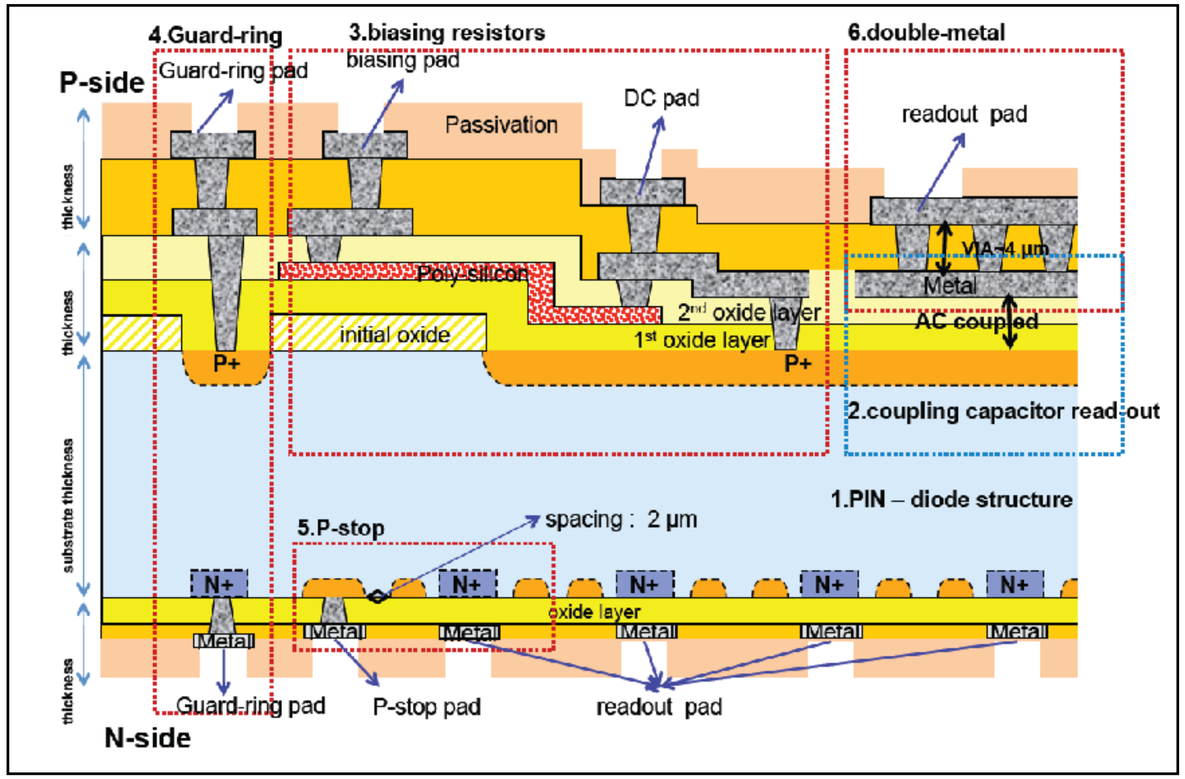
Example of IV characteristics plot visualized using **SVisual**.

III. Sensor R&D

ii. Design



A cross-sectional view of the PIN photodiode.

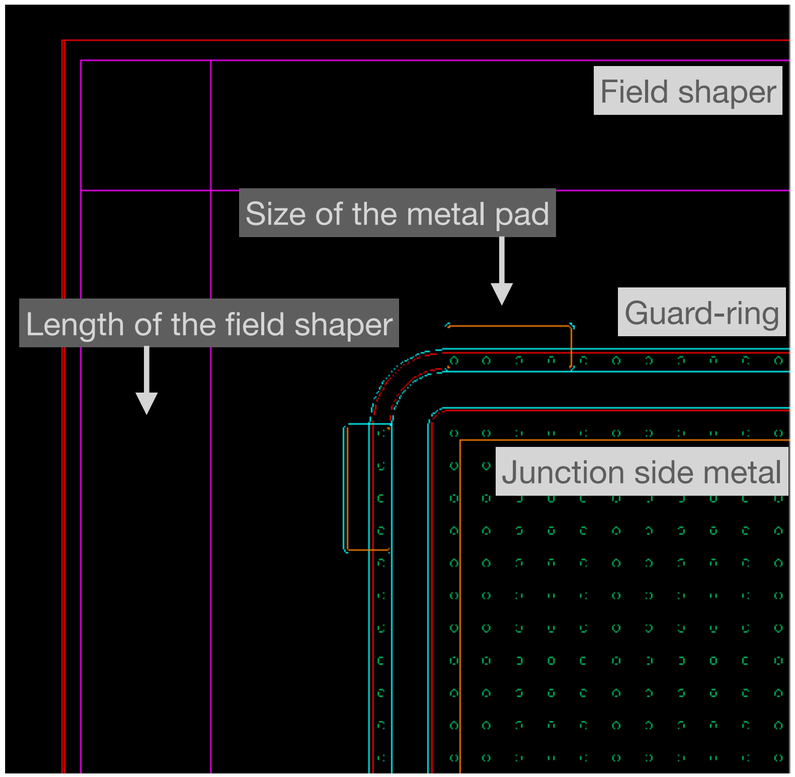


A cross sectional view of the AC coupled double sided strip sensor.

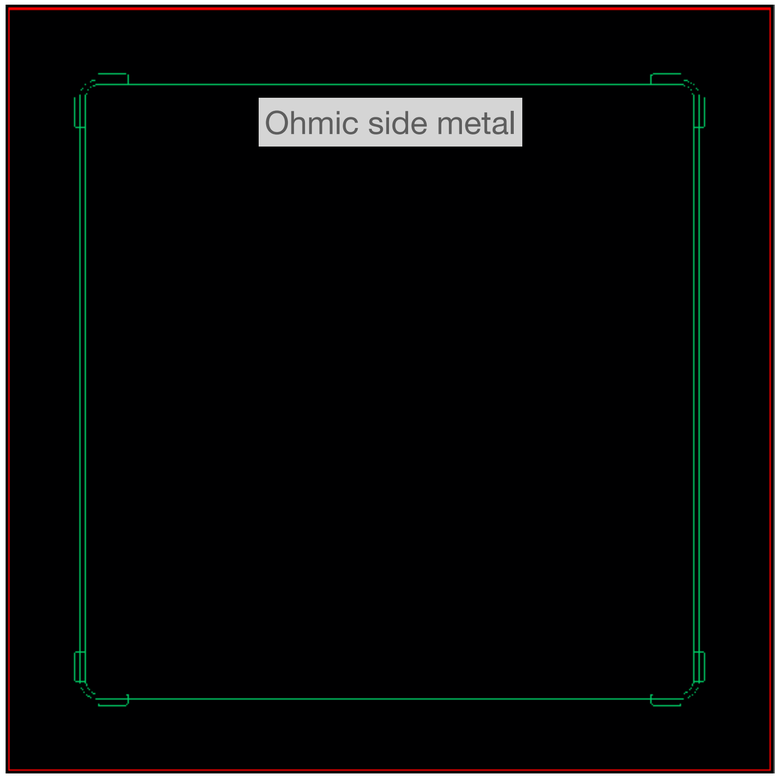
- Draw concept structure with a schematic view of the target sensor.
- Ex) PIN photodiode, strip sensor, JFET pixel sensor, *etc* …

III. Sensor R&D

iii. Photomask Design



P-side photomask view.

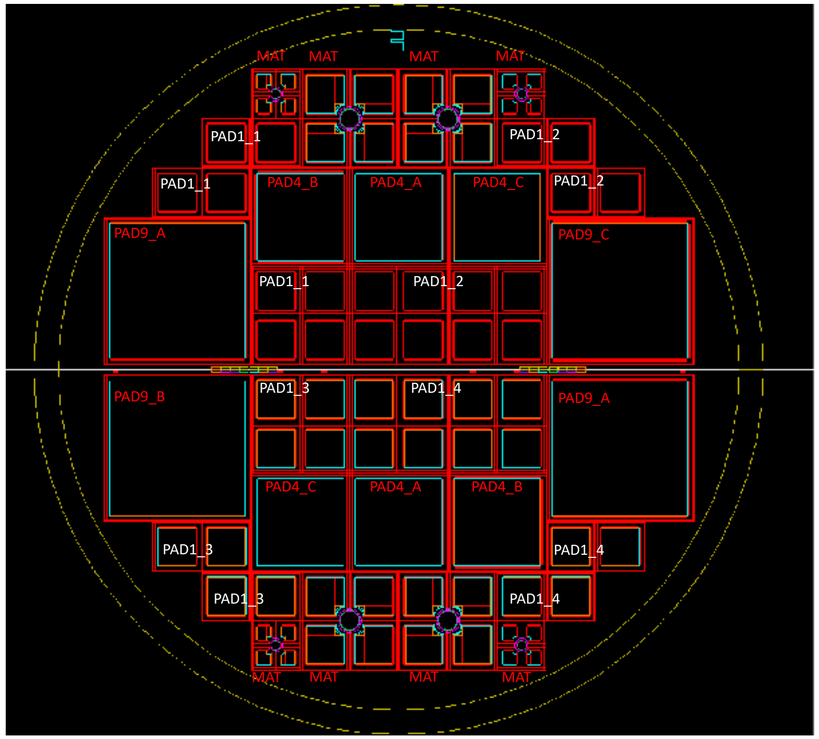


N-side photomask view.

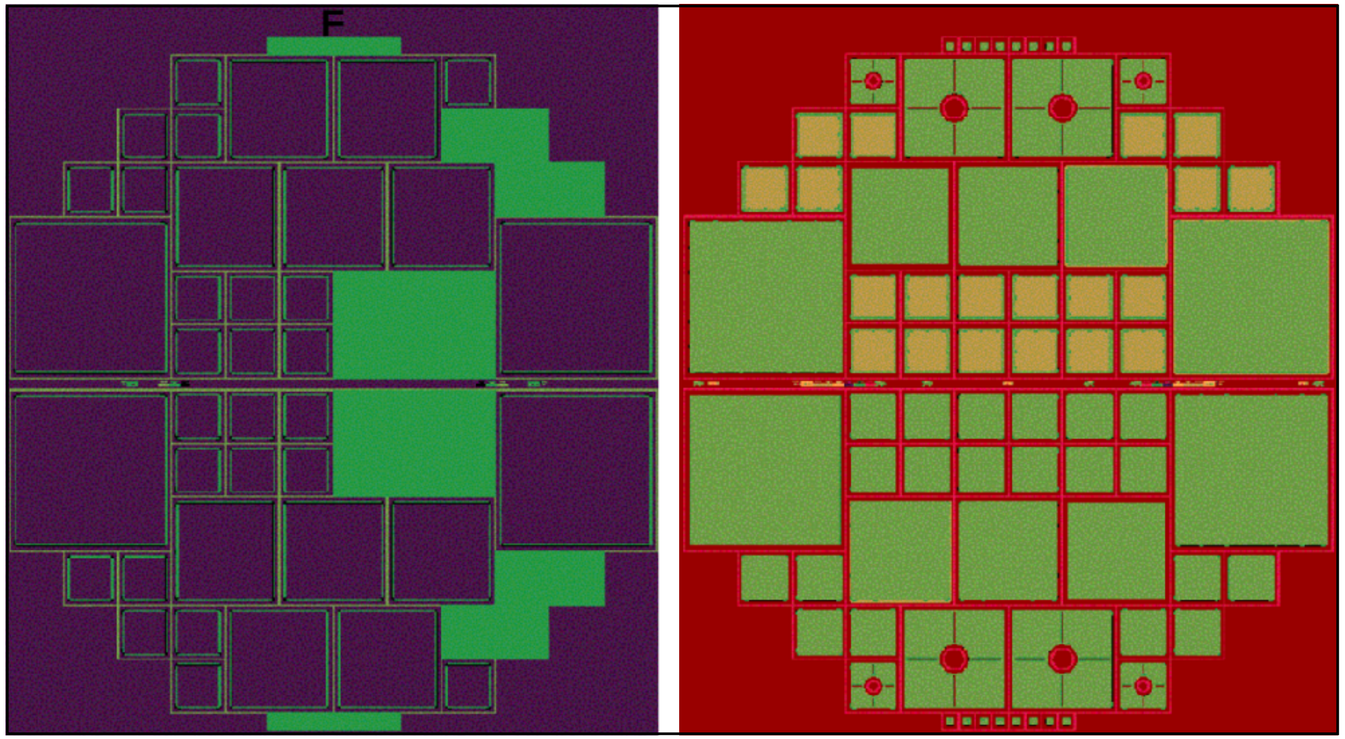
- Draw the photomask using design rule of the sensor.
- Use '**Cadence virtuoso**' as a mask design tool.

III. Sensor R&D

iii. Photomask Design



photomask_design.gds.



Photomask design view.

*Mask manufacture : PKL (Photomask Manufacture Institute, Cheonan in Korea)

III. Sensor R&D

iv. Fabrication

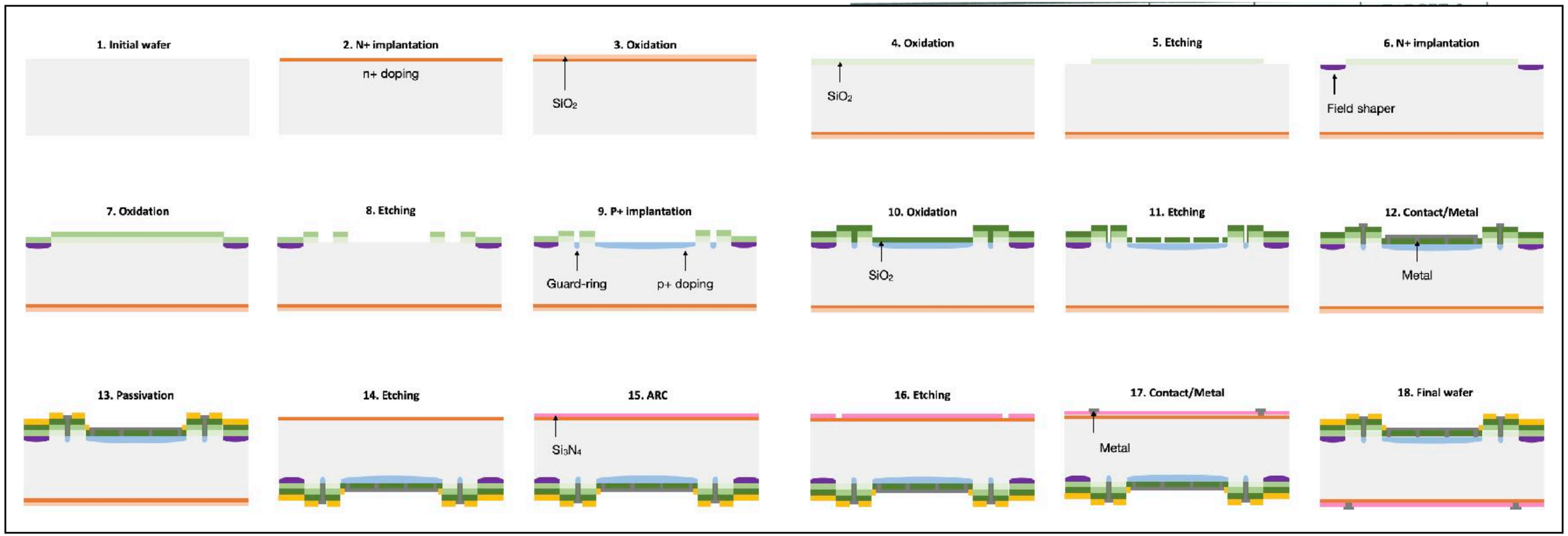
SEQ	PROCESS	P.CODE	WAFER INSTRUCT	TARGET & MEASURE
1	Wafer ID & DI Cleaning **(W/F 앞면 Bottom)**		P01 - P03	
2	Cleaning, STD1		P01 - P03	Spin dry=15min
3	Oxidation. H2/O2. 900 (Initial Oxidation)		P01 - P03	T=5500±500A **(time=350 min)**
4	Measure.Tox (Target=5500±500 A)		#P01	C 5240 B 5249 T 5215 L 5212 R 5233 Avg. 5230
5	**HMDS/ Coat/Bake (90C/90sec)** **PR(GA2, 1.63μm)** No. 2B2 (#15)		**P01 - P03**	**RPM : 4000 (앞면 PR도포)**
6	Hard Bake. (120°C/30min)		P01 - P03	Time= 30 min

SEQ	PROCESS	P.CODE	WAFER INSTRUCT	TARGET & MEASURE
159	DI Cleaning		P01 - P03	
160	Hard Bake. (120°C / 30 min)		P01 - P03	
161	Wet Etch TiW(H2O2)		P01 - P03	*T=1500A+50%* *30도, 20min*
162	Measure.**Tnit** (Target=700±50A) (Wafer 뒷면)		#P01	C 662 B 694 T 683 L 685 R 677 Avg. 680
163	Plasma Strip.PR		P01 - P03	
164	Solvent Strip.PR		P01 - P03	
165	Inspection		P01 - P03	
166	Alloy. N_2/H_2. 420°C		P01 - P03	30 min
167	Inspection		#P01	
	Fab-Out			

*Sensor manufacture : ETRI (Electronics and Telecommunications Research Institute, Daejeon in Korea)

III. Sensor R&D

iv. Fabrication

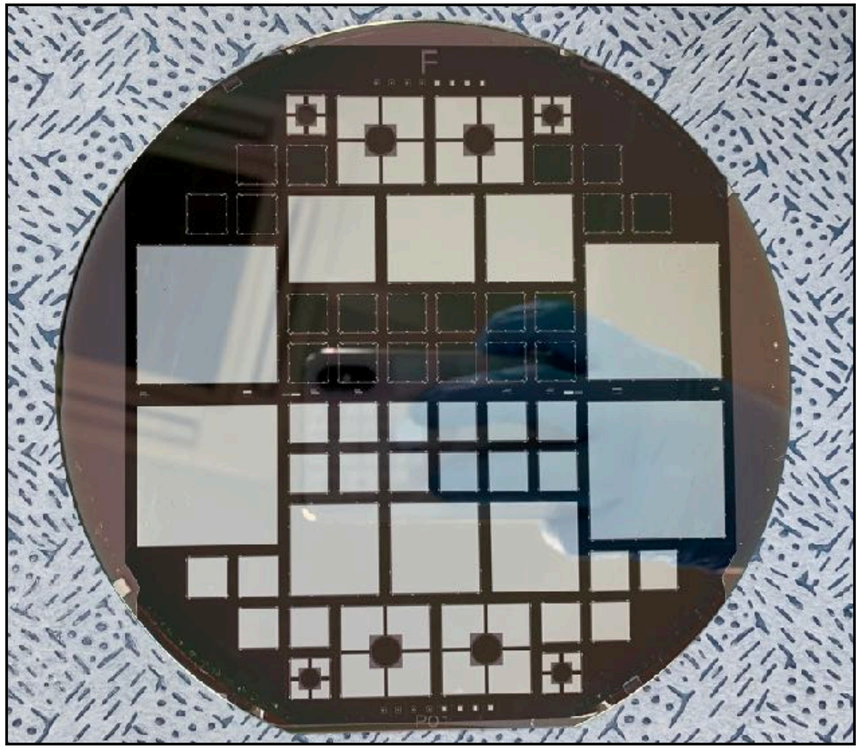


The example fabrication process flow of the PIN photodiode.

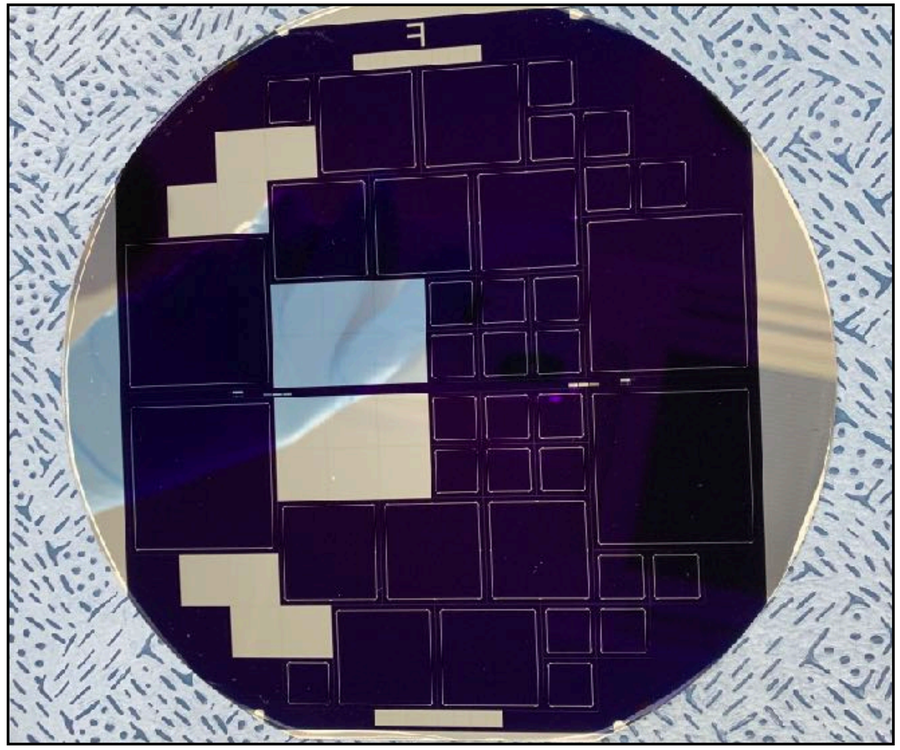
*Sensor manufacture : ETRI (Electronics and Telecommunications Research Institute, Daejeon in Korea)

III. Sensor R&D

iv. Fabrication



P-side view of the manufactured wafer.



N-side view of the manufactured wafer.

*Sensor manufacture : ETRI (Electronics and Telecommunications Research Institute, Daejeon in Korea)

III. Sensor R&D

v. Modularization (Dicing)

- **Dicing** is one of the post-process processes of switching sensors from wafers to chips.

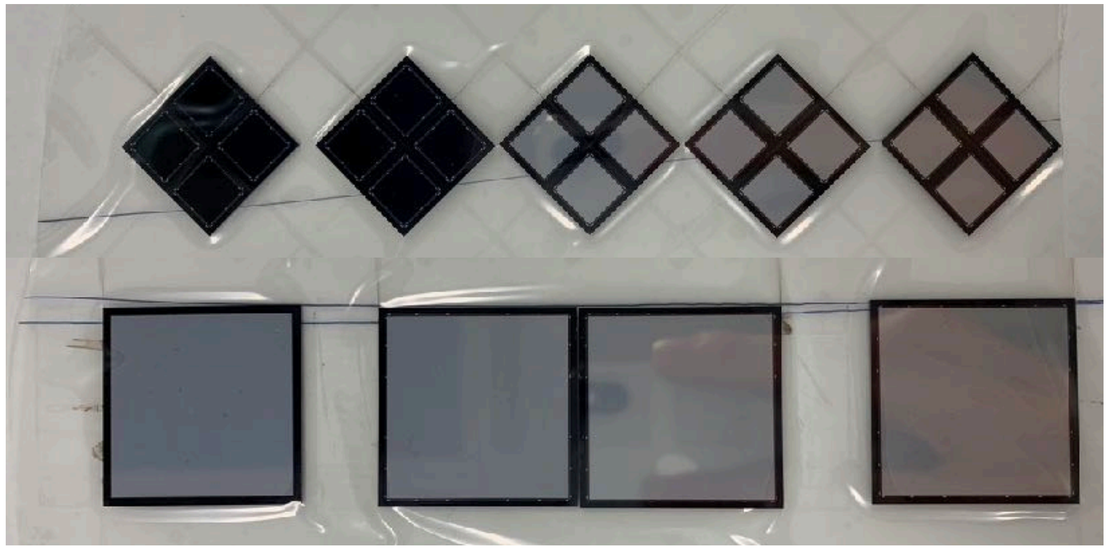
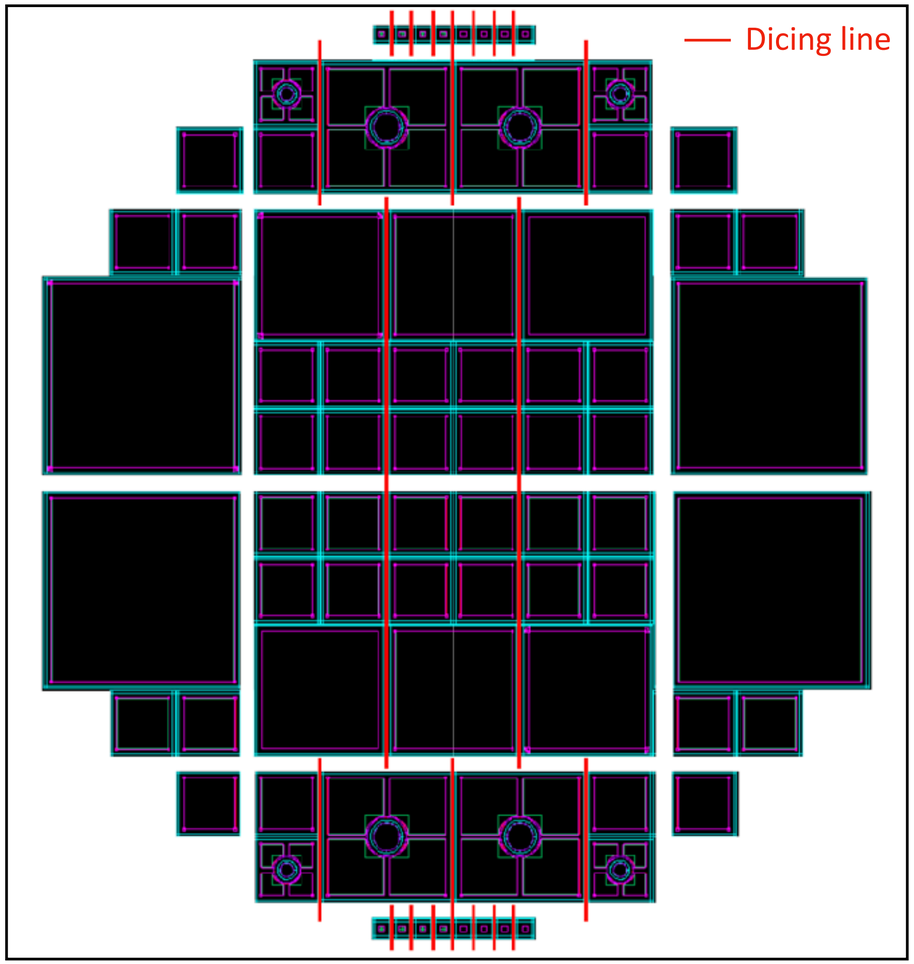


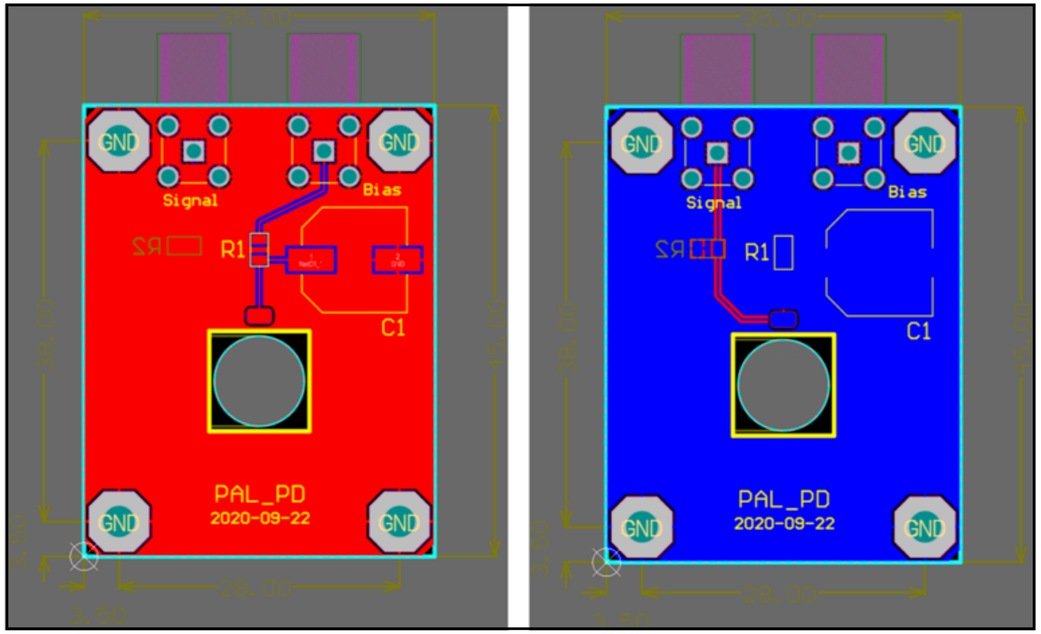
Photo of sensors after laser dicing.



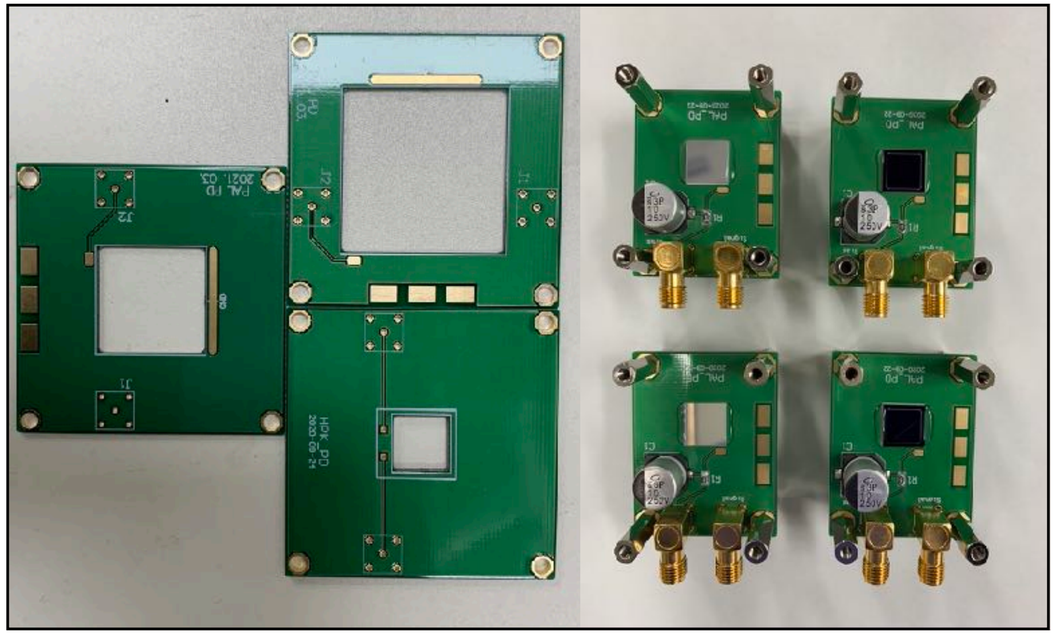
Example picture of dicing request.

III. Sensor R&D

v. Modularization (PCB - Printed Circuit Board)



Design example for PCB manufacture using **Altium designer**.



Manufactured PCB example.

*PCB manufacture : HANSAEM DIGITEC (https://www.hsdgt.com)

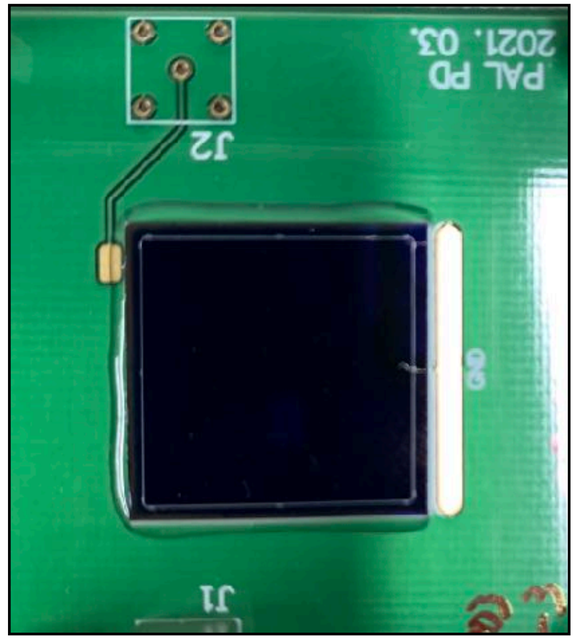
- After dicing, sensors can be bonded to PCBs and used for performance tests.
- You can do PCB design using the **Altium designer** program
- **Altium** requires additional license.

III. Sensor R&D

v. Modularization (Gluing)

Epoxy used for gluing.

Photograph of gluing machine.



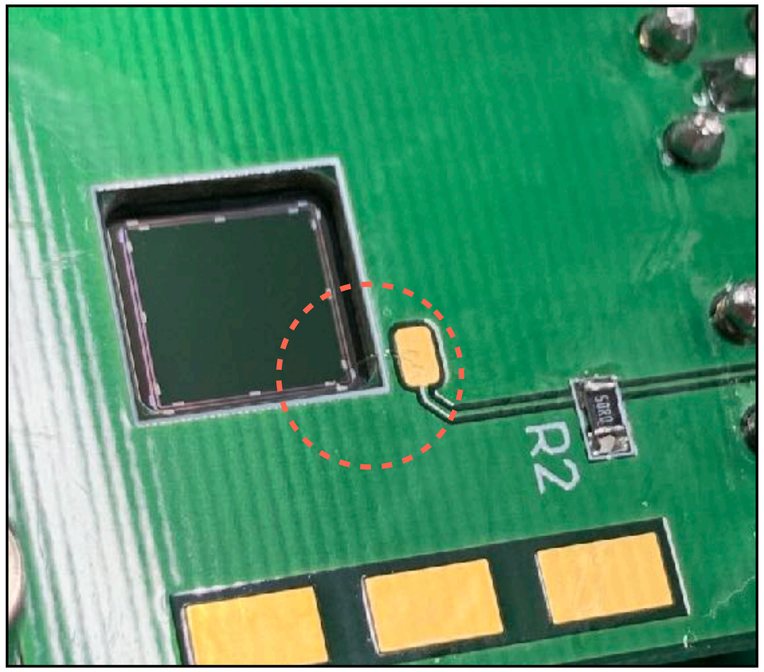
Example of gluing a sensor.

- It is recommended to use epoxy for more stable bonding in the process of bonding sensors to PCB.

III. Sensor R&D

v. Modularization (Wire Bonding)

Photograph of wire bonding machine.

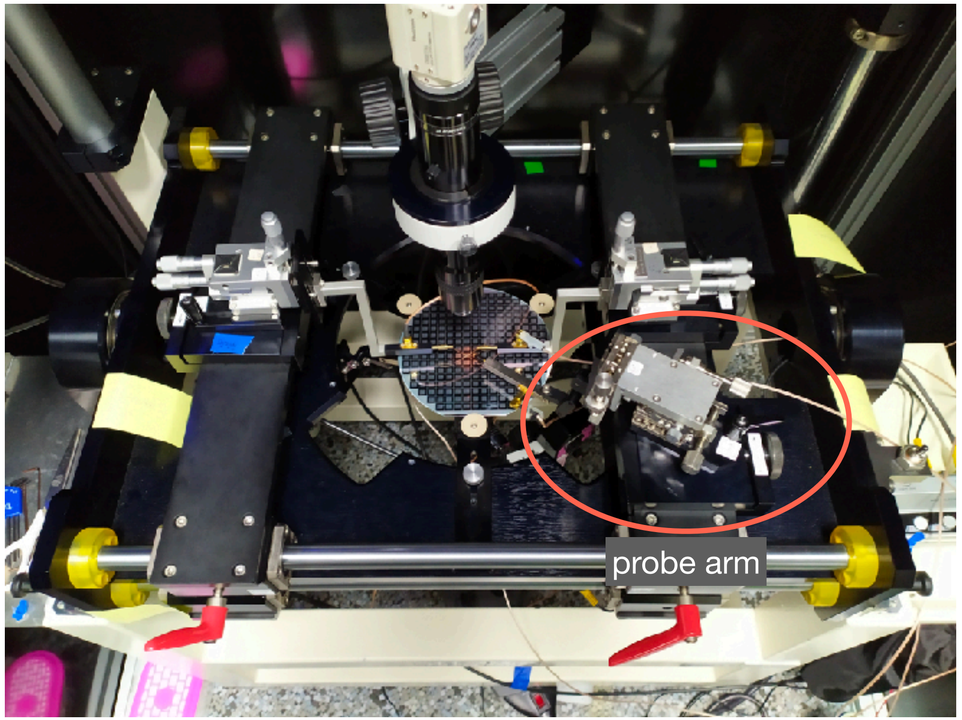


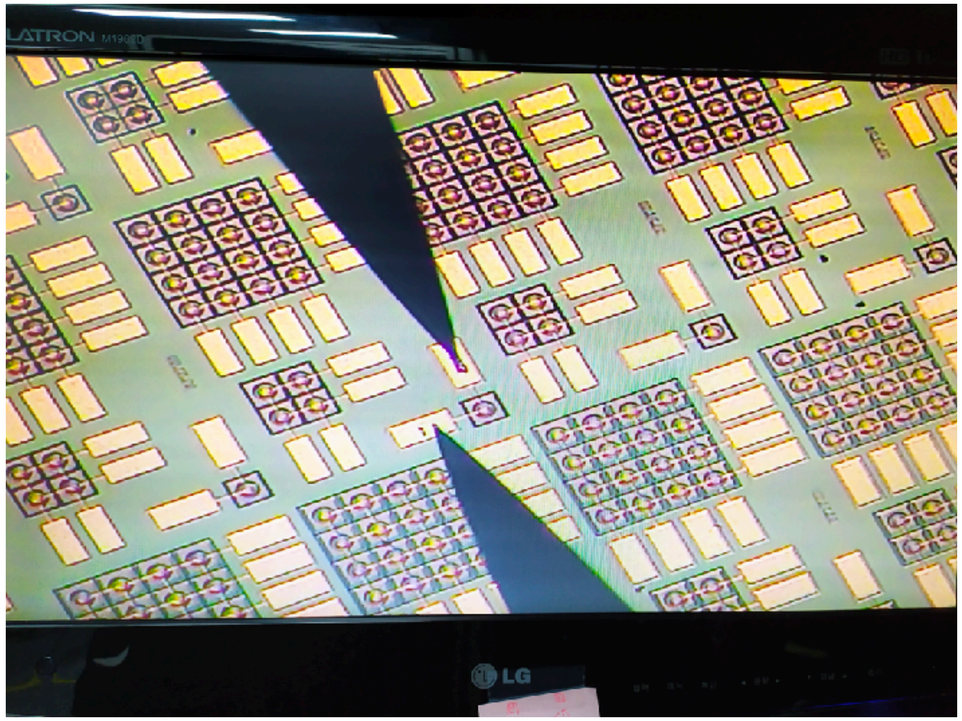
Example of wire bonding to sensor.

- Wire bonding machines typically have 'wedge' type and 'ball' type, and our lab used 'wedge' type.

III. Sensor R&D

vi. Performance Test (Electrical Characteristics)





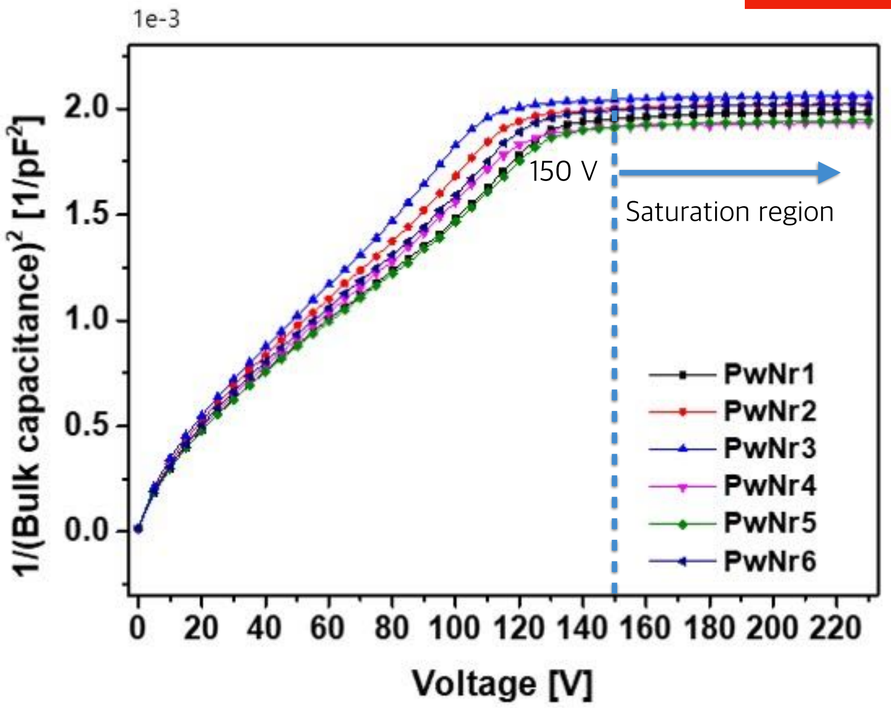
Electrical characteristics measurement view.

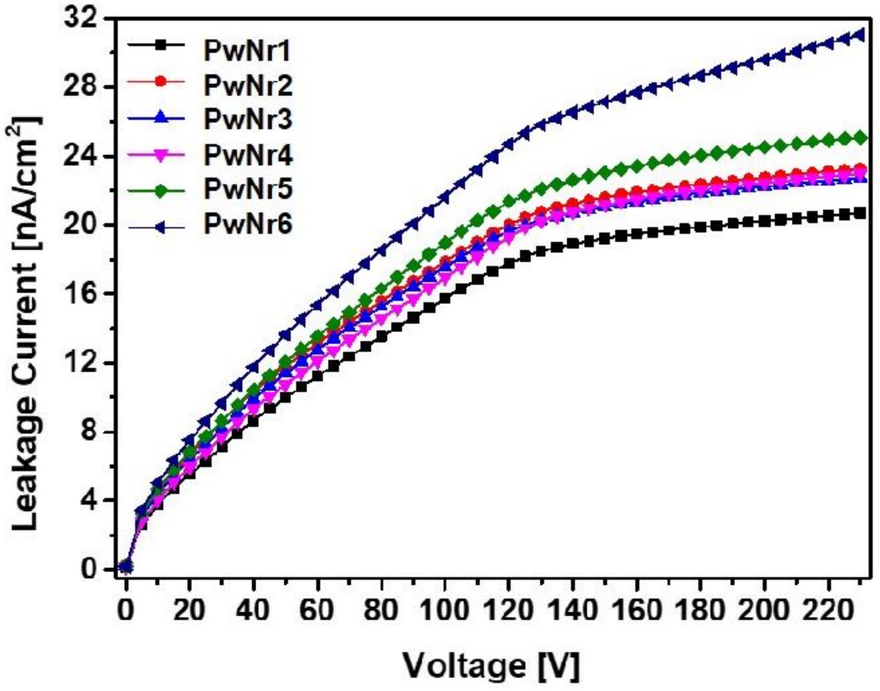
- Probe station is used to measure characteristics of wafer or chip status sensors before modularization.
- Various measurements can be attempted by increasing the number of probe arms in the probe station as needed.

III. Sensor R&D

vi. Performance Test (Electrical Characteristics)

Set Operation Voltage

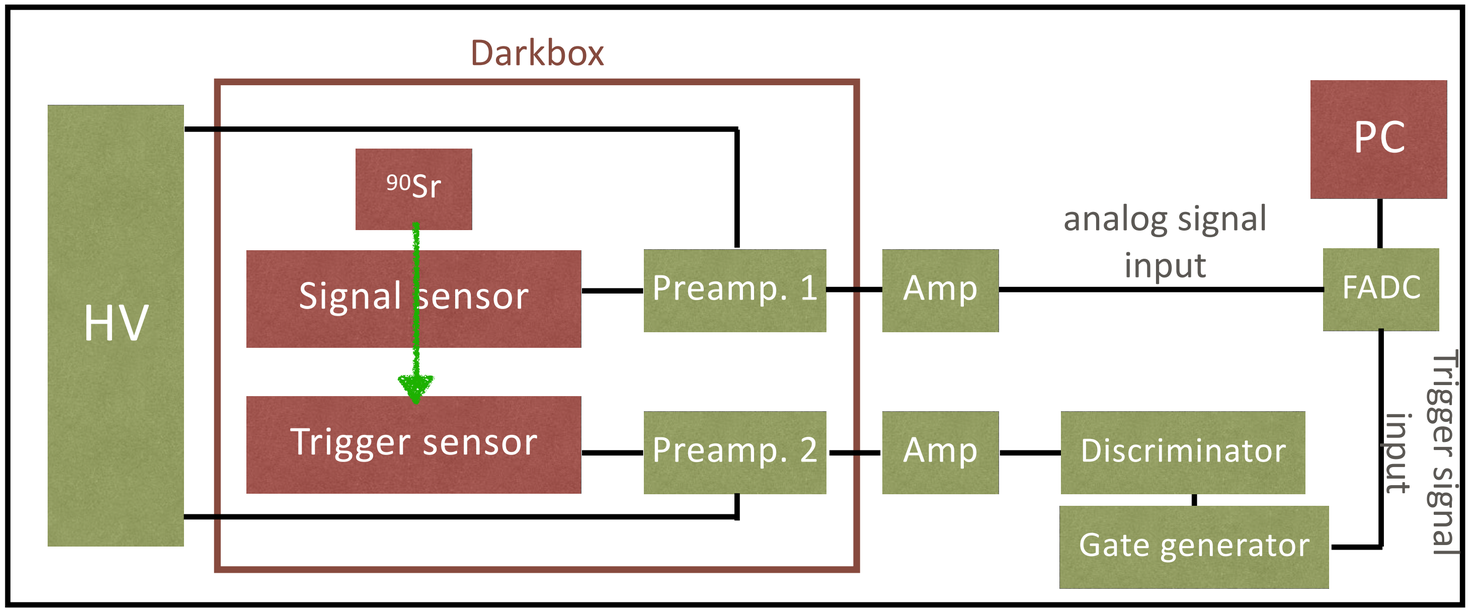




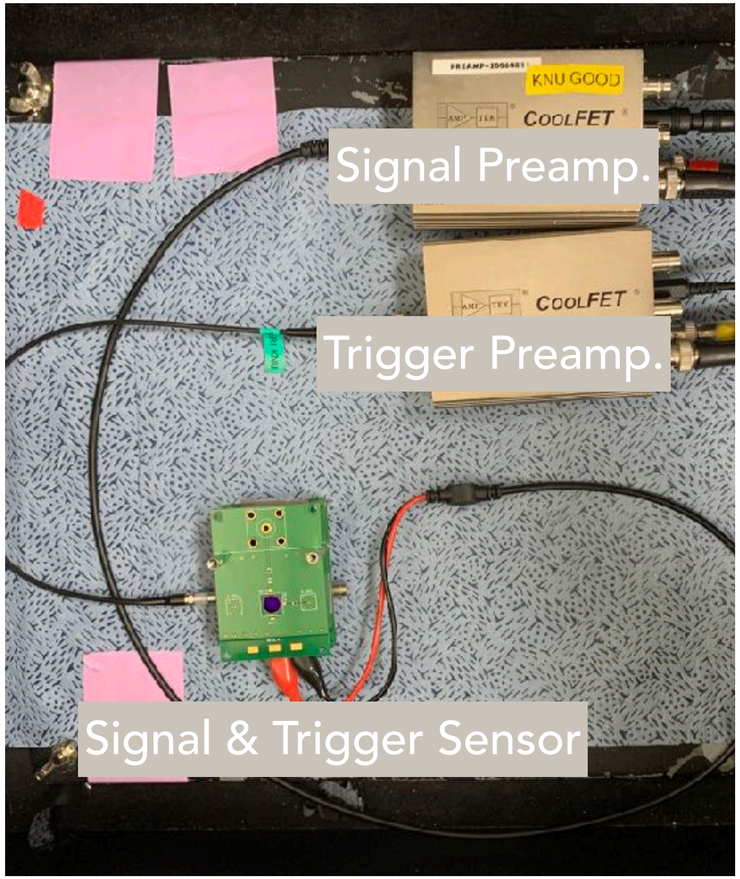
- Leakage current per unit area as a function of the reverse bias voltage shows the diode performance, simply
- The depletion voltage was determined from the capacitance measurement and an operation voltage was set well above the depletion voltage

III. Sensor R&D

vi. Performance Test (SNR)



Measurement setup diagram for the source test.

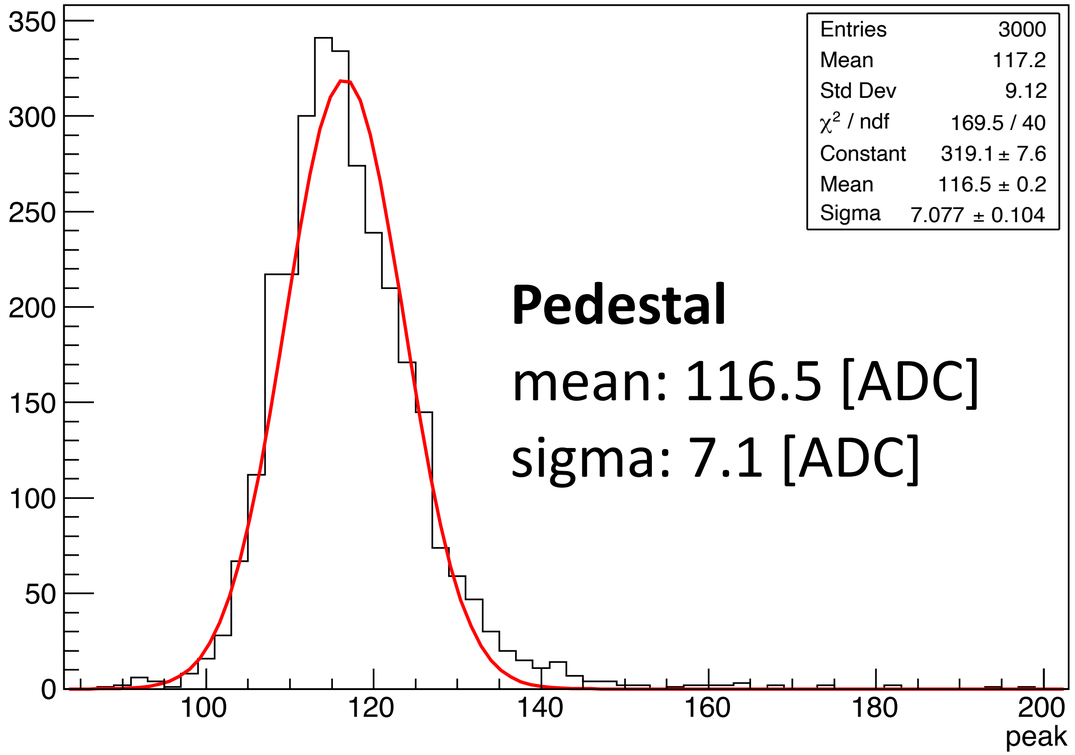


Inside view of the darkbox.

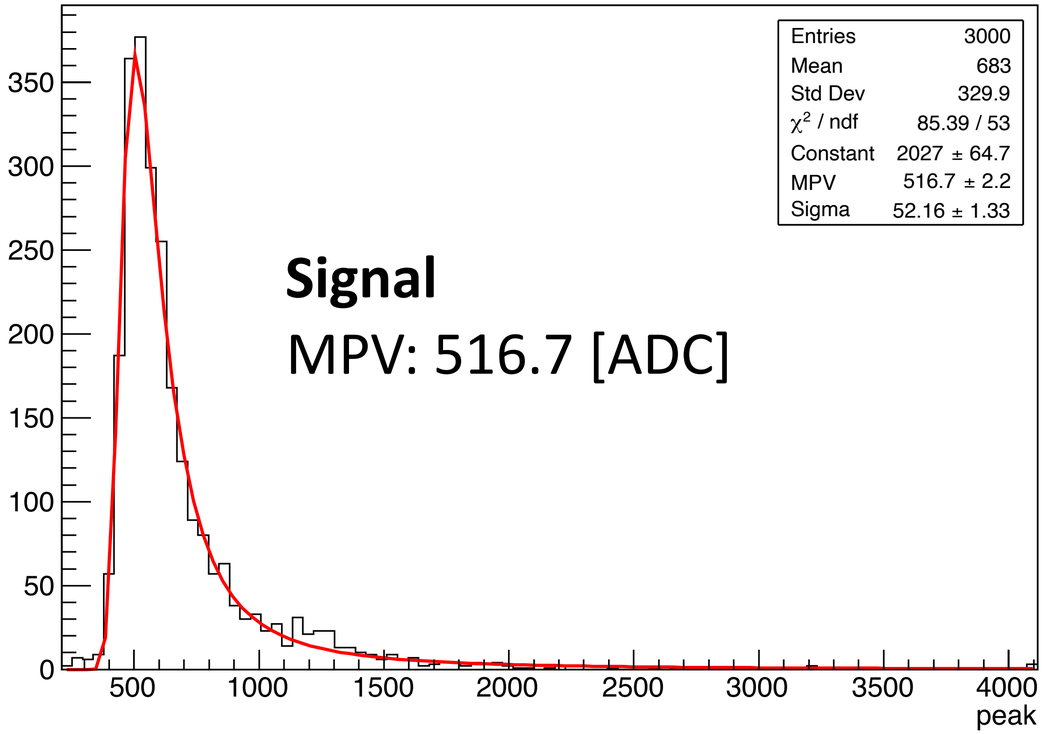
- Shaping the trigger signal using the trigger sensor located vertically is used for signal analysis.
- For signal shaping, ‘discriminator’ and ‘gate generator’ are used.

III. Sensor R&D

vi. Performance Test (SNR)



Pedestal distribution example of the ^{90}Sr measurement.

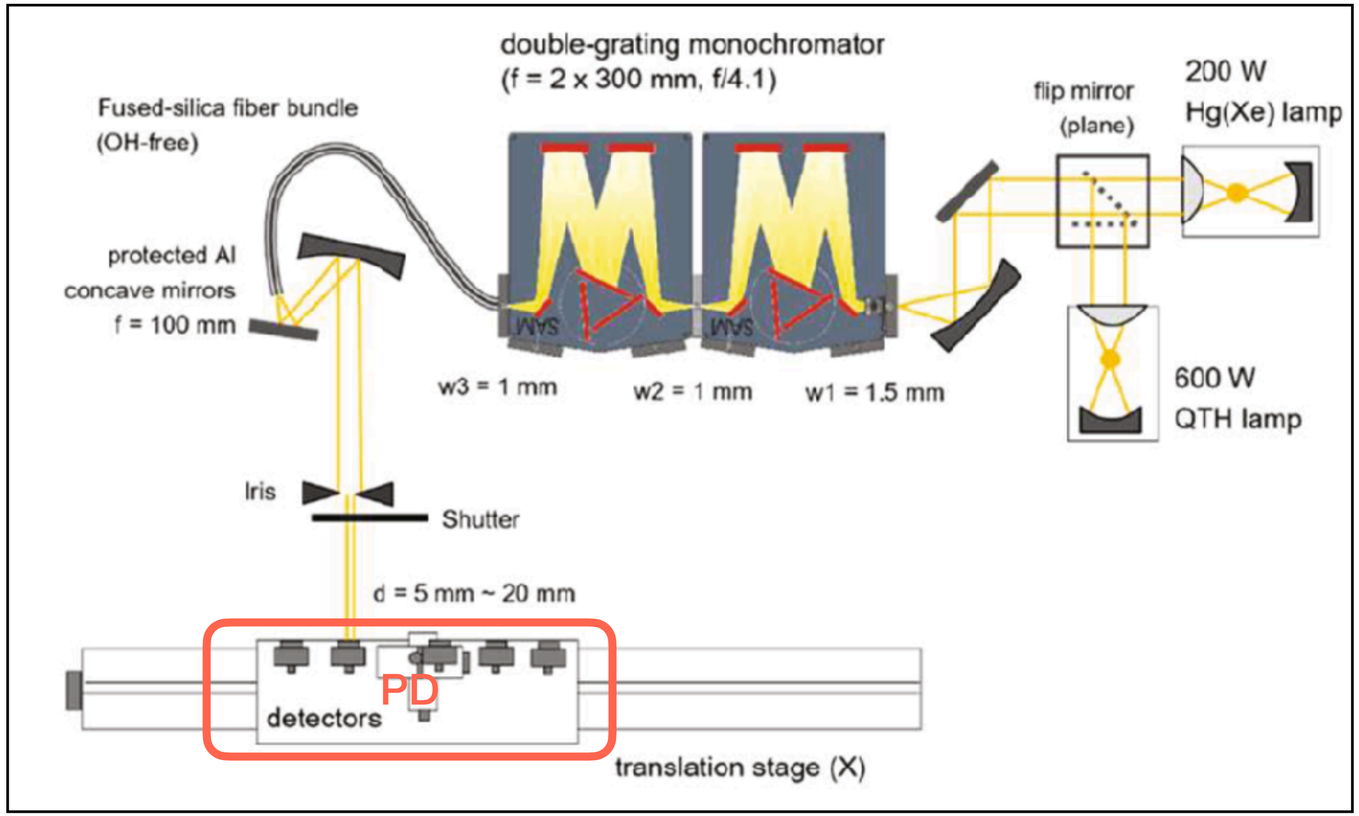


Landau fitting example of the ^{90}Sr measurement.

SNR: 56.4

III. Sensor R&D

vi. Performance Test (Quantum Efficiency)

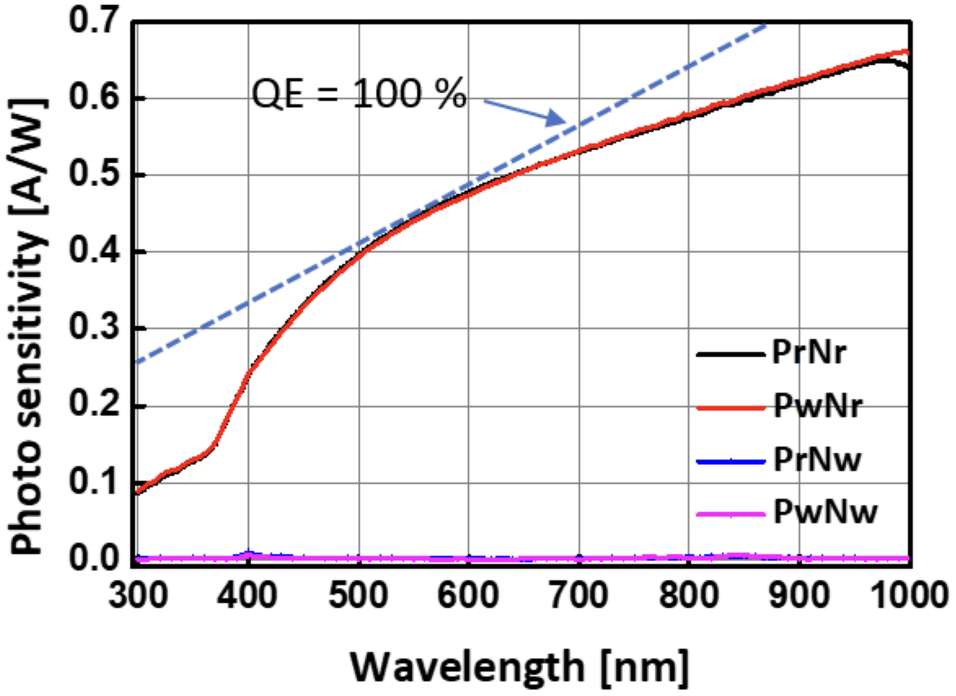


- Spectral responsivity of reference detector
- $s_{Ref}(\lambda) = \frac{A_{Ref}}{W_{lamp}} = [A/W]$
- $ratio = \frac{A_{PAL-PD}}{A_{Ref}}$
- $s_{PAL-PD}(\lambda) = ratio \cdot s_{Ref}(\lambda)$
- QE : $\eta(\lambda) = \frac{hc}{e\lambda} s(\lambda)$

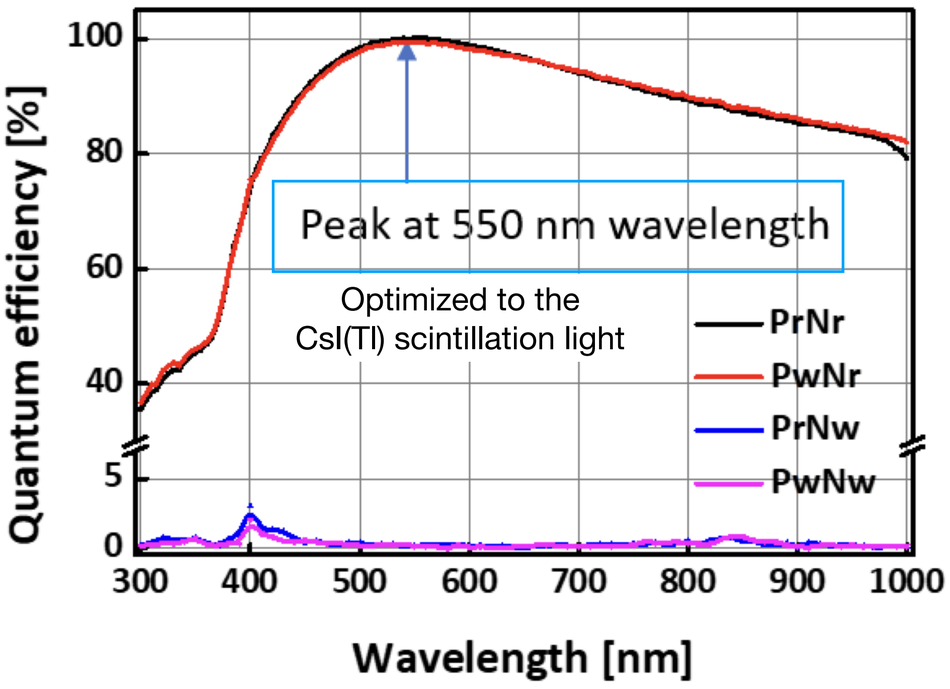
*Quantum efficiency measurement: KRISS (Korea Research Institute of Standards and Science, Daejeon in Korea)

III. Sensor R&D

vi. Performance Test (Quantum Efficiency)



Photosensitivity of the manufactured photodiode as a function of the wavelength of light

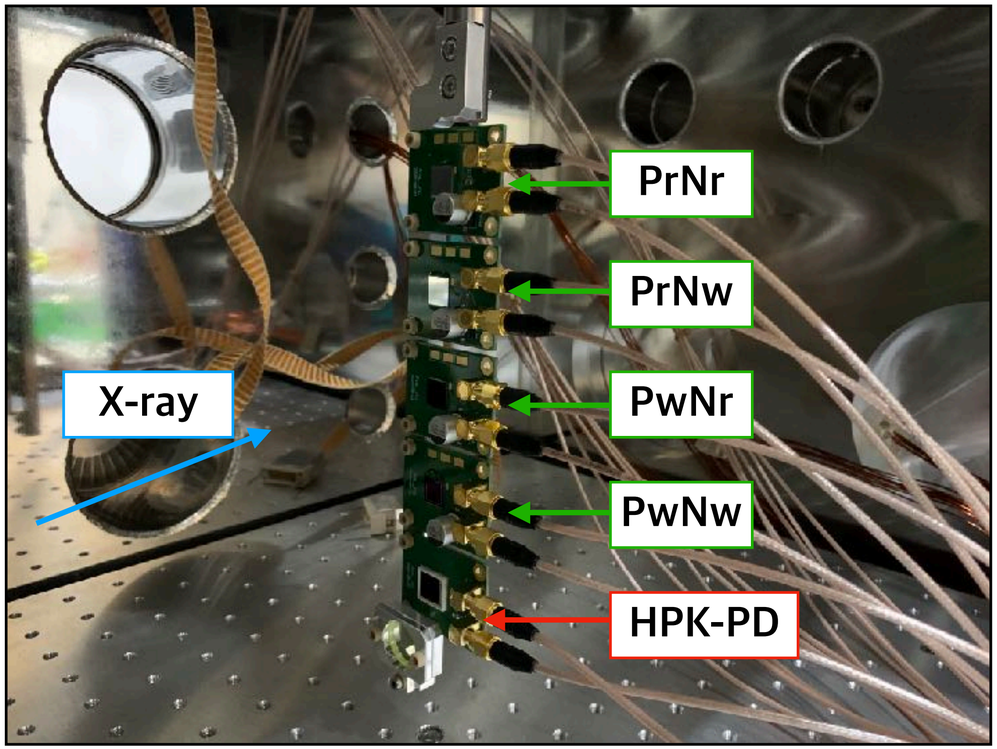


Quantum efficiency of the manufactured photodiode as a function of the wavelength of light

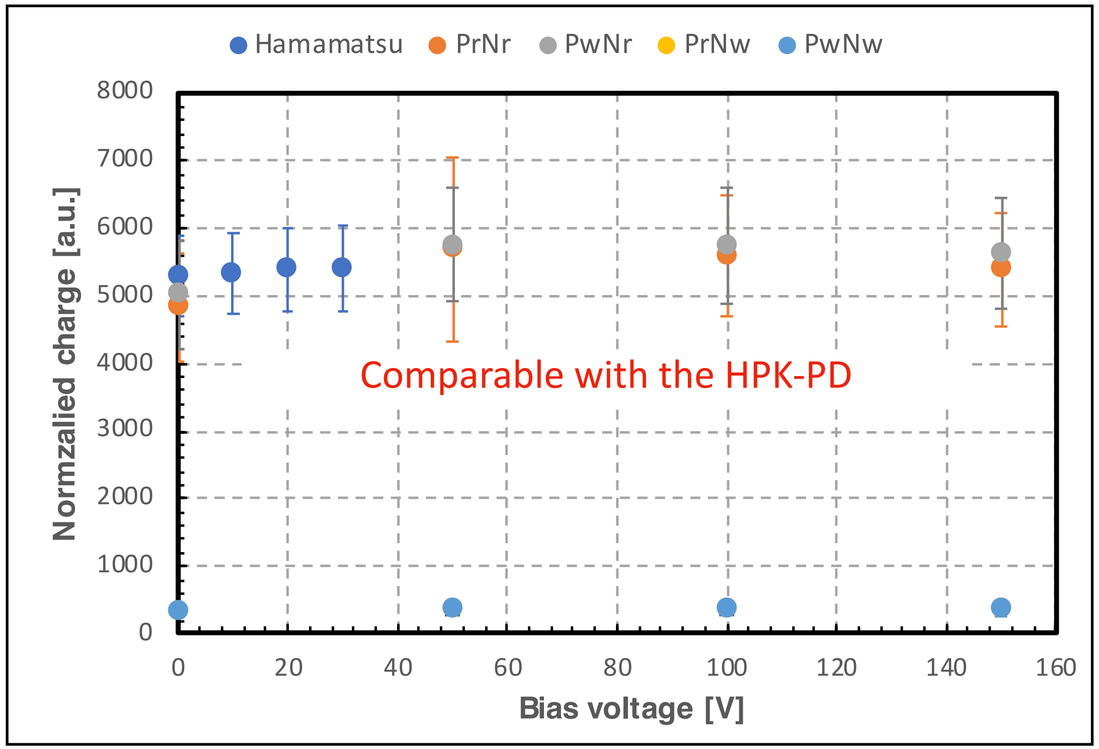
*Quantum efficiency measurement: KRISS (Korea Research Institute of Standards and Science, Daejeon in Korea)

III. Sensor R&D

vi. Performance Test (Beam-test)



Experimental setup for PAL-XFEL beam test.



Beam test result of the PIN photodiode with the reference photodiode.

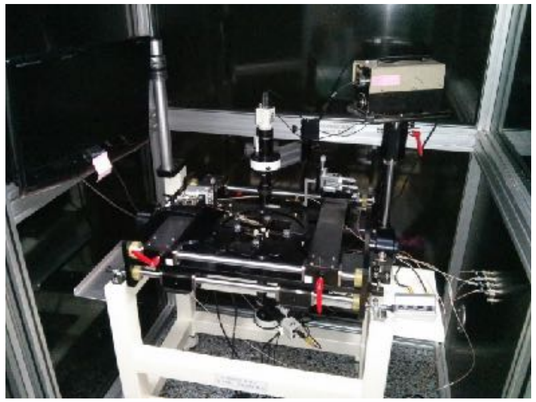
- Reference sensor (HPK-PD): hamamatsu PIN photodiode (S3590-09)

*PAL-XFEL Beam-test: PAL (Pohang Accelerator Laboratory, Pohang in Korea)

“Backup”

IV. Equipments

Single-side probe station



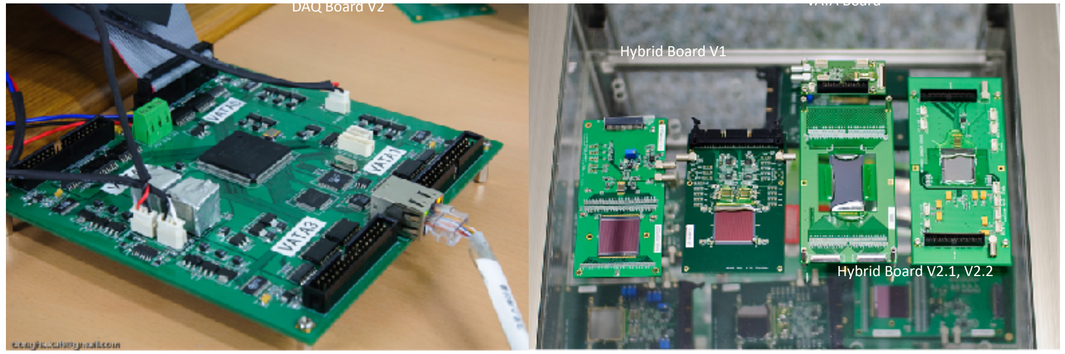
Double-side probe station

IV, CV measurement

NIM module

Wire bonder

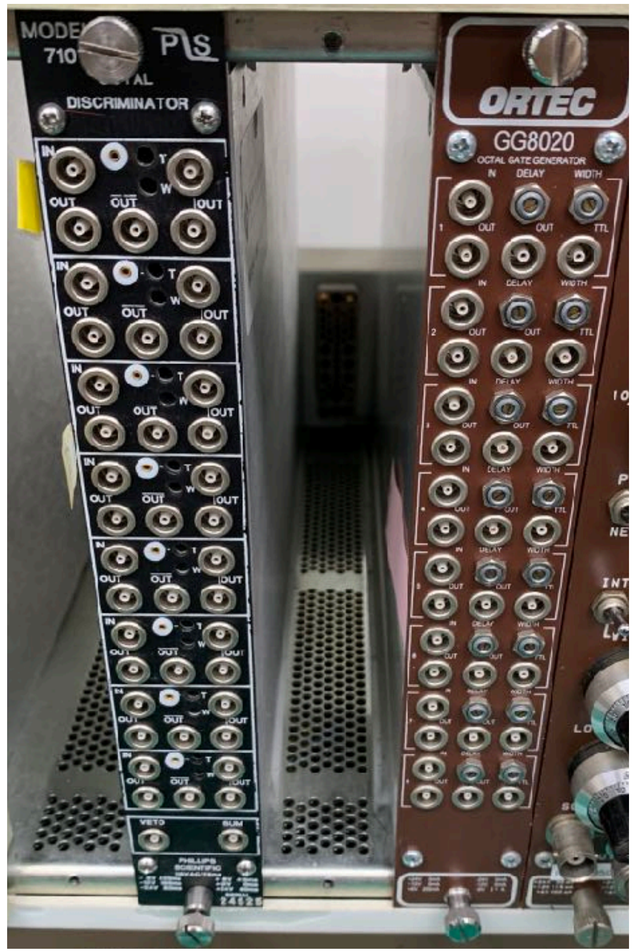
Desiccator



Signal Readout Electronics

IV. Equipments

Gluing machine & pump



Discriminator & gate generator

FADC

Charge integrator