FoCal-E pad in Japan

14th of March, 2023.

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for the ALICE collaboration

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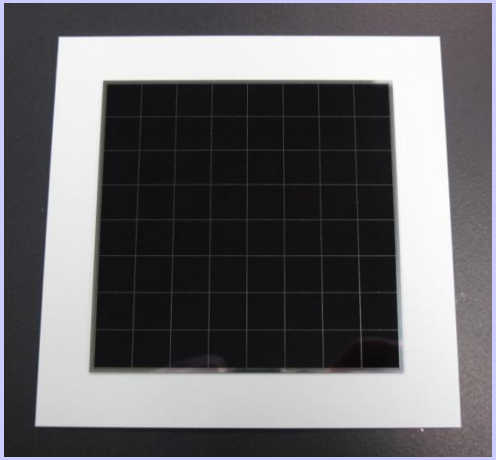
Topics - Recent activities in Japan

1. Silicon pad sensors
2. Irradiation tests
3. Beam tests
4. Others

N-substrate silicon pad sensors

1st version in 2013



Type: N-substrate Silicon PIN photodiode array.
Pad layout: 8 x 8 (= 64 signal channels).
Pad pitch: 11.3mm x 11.3mm.
Sensor size: 92.6mm x 92.6mm.
Thickness: 500um (Active: 480um).
The maximum bias voltage: 220V.
The substrate connection: the surface and backside.
The guard ring: Yes.

Masks came from CNS.

It worked well, but it was very sensitive to a room light.

2nd version in 2017

Thinner sensors for the higher radiation tolerance.

Thickness: 500um → 320um
(Active: 480um → 300um).

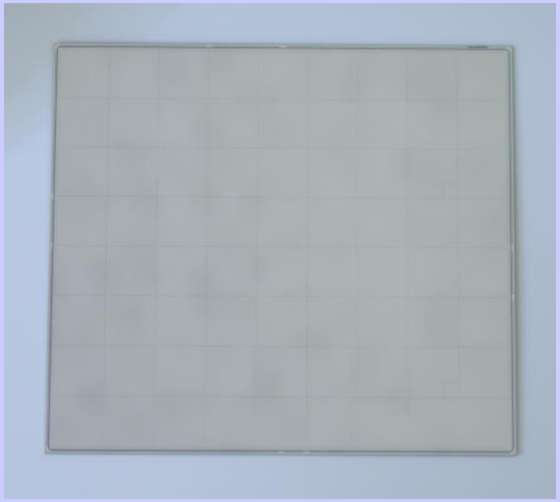
We made some new masks.

The surface was covered with the aluminum layer in order to improve the light shielding, and 60 sensors were used for the "mini-FoCal" detector in 2018.

P-substrate silicon pad sensors

3rd version in 2020

For the even higher radiation tolerance.



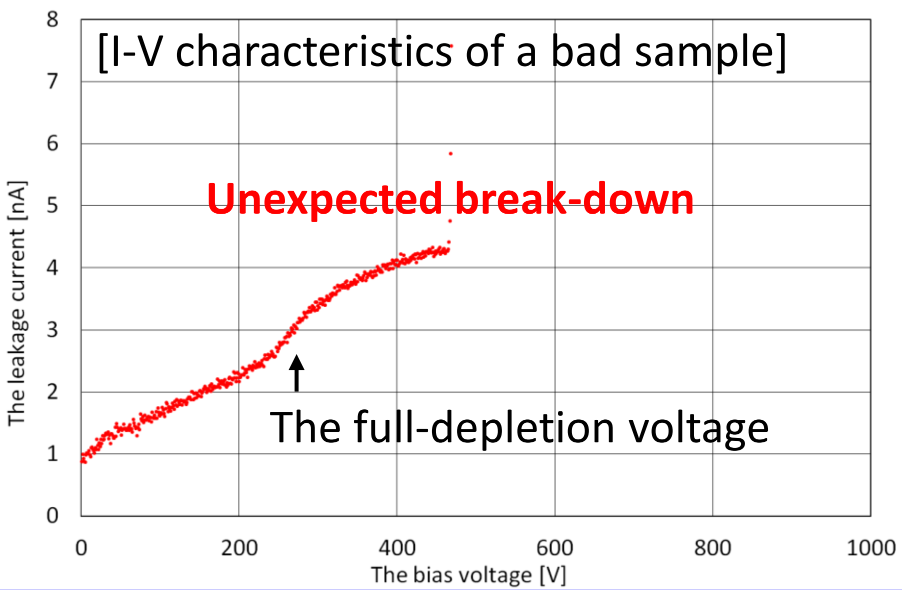
Type: P-substrate Silicon PIN photodiode array.
The additional p-stop structure: Yes.
Pad layout: 9 x 8.
Calibration cell: 2 for HGCROC (3mm x 3mm).
Pad pitch: 10.0mm x 10.0mm.
Sensor size: 92.6mm x 82.6mm.
Thickness: 320um (Active: 300um).
The maximum bias voltage: 1,000V.
The guard ring: Yes (Double).

All masks were renewed !

A very high bias voltage.

The number of pads with an unexpected higher leakage current was not zero, but it was possible to read signals of all pads.

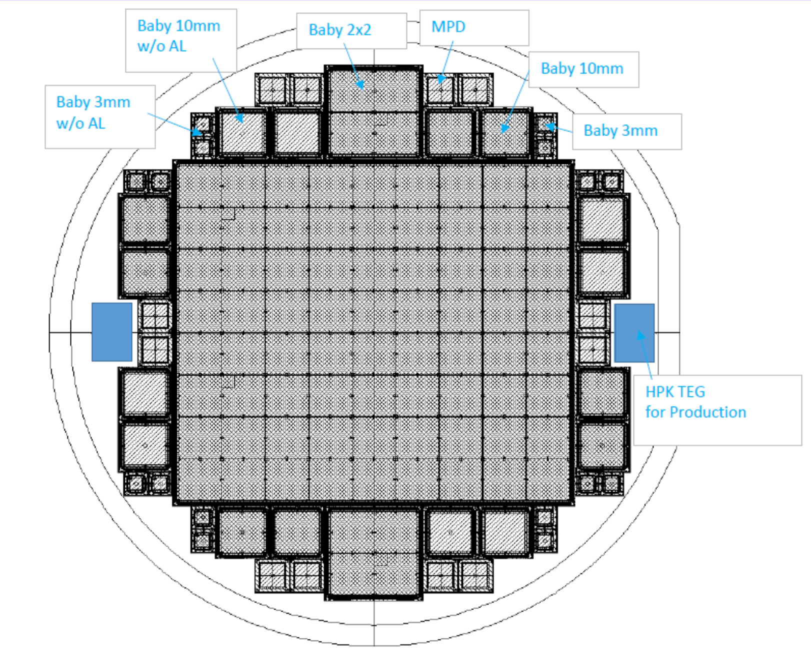
Some sensors caused the break down at a lower bias voltage than the design value (= 1000 V) and it seemed to come from the p-stop structure.



New P-substrate silicon pad sensors

4th version in 2021

A design of the p-stop structure was reconsidered.



Some new masks.

In the test using baby chips, a leakage current to the guard ring had decreased and it became hard to cause the break down at a lower bias voltage.

We found that an electrically floating cell or guard ring had a risk to break the chip. All connections are required on the chip.

5th version in 2022

Unused wire-bonding-pads were removed from sensors.

Some new masks.

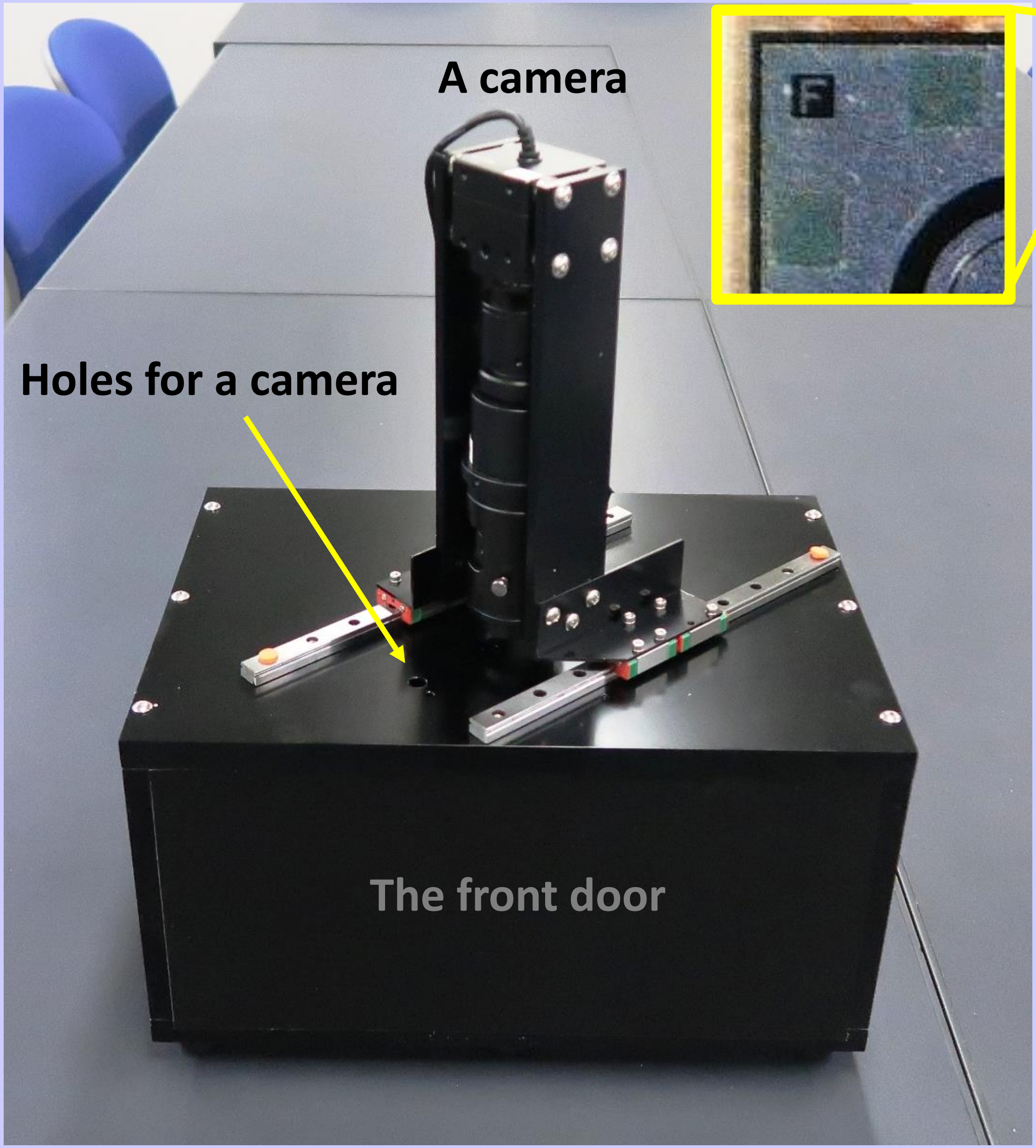
New 20 sensors will be delivered by the end of this month. I will measure the fundamental characteristics as soon as I receive.

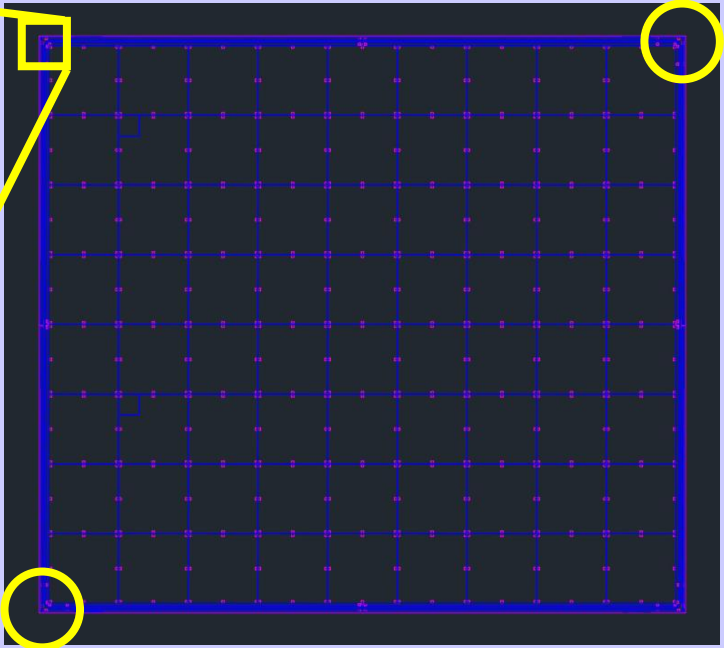
The final design for mass production (?)

Baby chips around the main sensor

Name	Cell pitch	The number of chips / wafer	The number of calibration cells	Guard ring
The main sensor with AL	10mm x 10mm	1	2	Yes (AL: All)
Baby 10mm 2x2 w/o AL	10mm x 10mm	1	1	Yes (AL: Partial)
Baby 10mm 2x2 with AL	10mm x 10mm	1	1	Yes (AL: All)
Baby 10mm 1x1 w/o AL	10mm x 10mm	8	0	Yes (AL: Partial)
Baby 10mm 1x1 with AL	10mm x 10mm	8	0	Yes (AL: All)
Baby 3mm 1x1 w/o AL	3mm x 3mm	8	0	Yes (AL: All)
Baby 3mm 1x1 with AL	3mm x 3mm	8	0	Yes (AL: All)
Monitor PD	6mm x 6mm	12	0	No

A new prove station

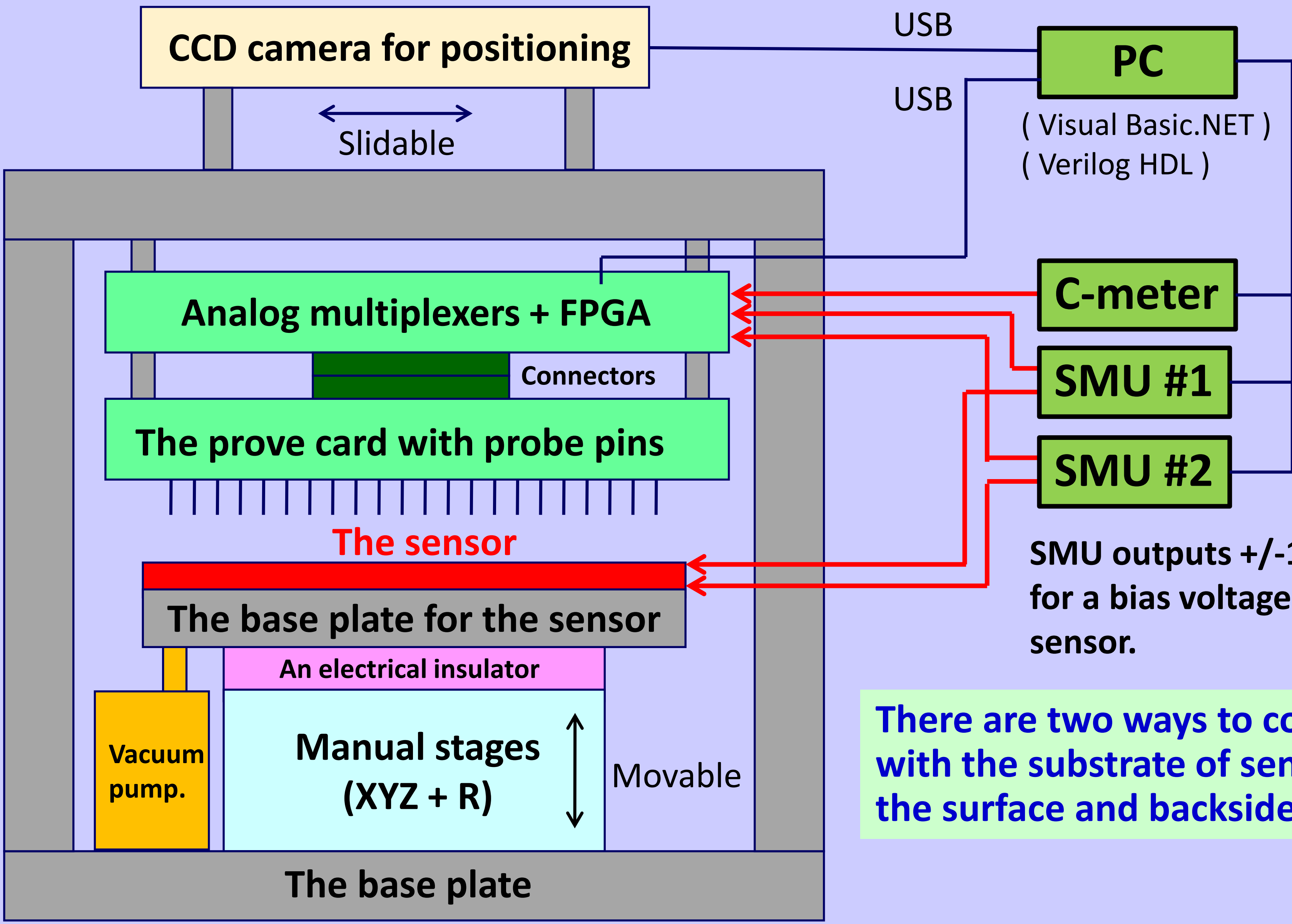




The sensor has alignment marks at the corners.

Width: 350 mm,
Length: 250 mm,
Height: 180 mm (455 mm including the camera).

Connection to the sensor

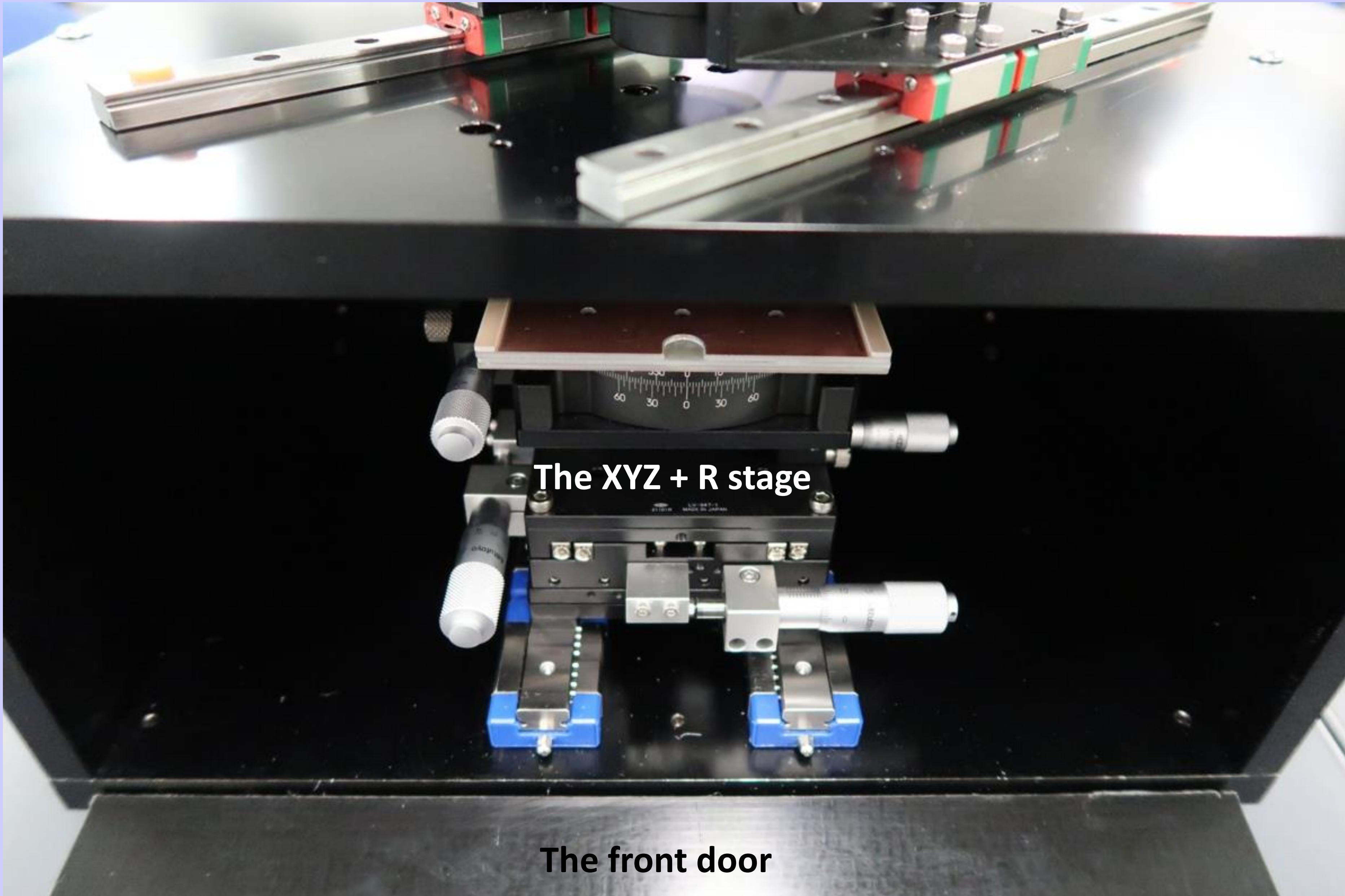


<A sectioned drawing >

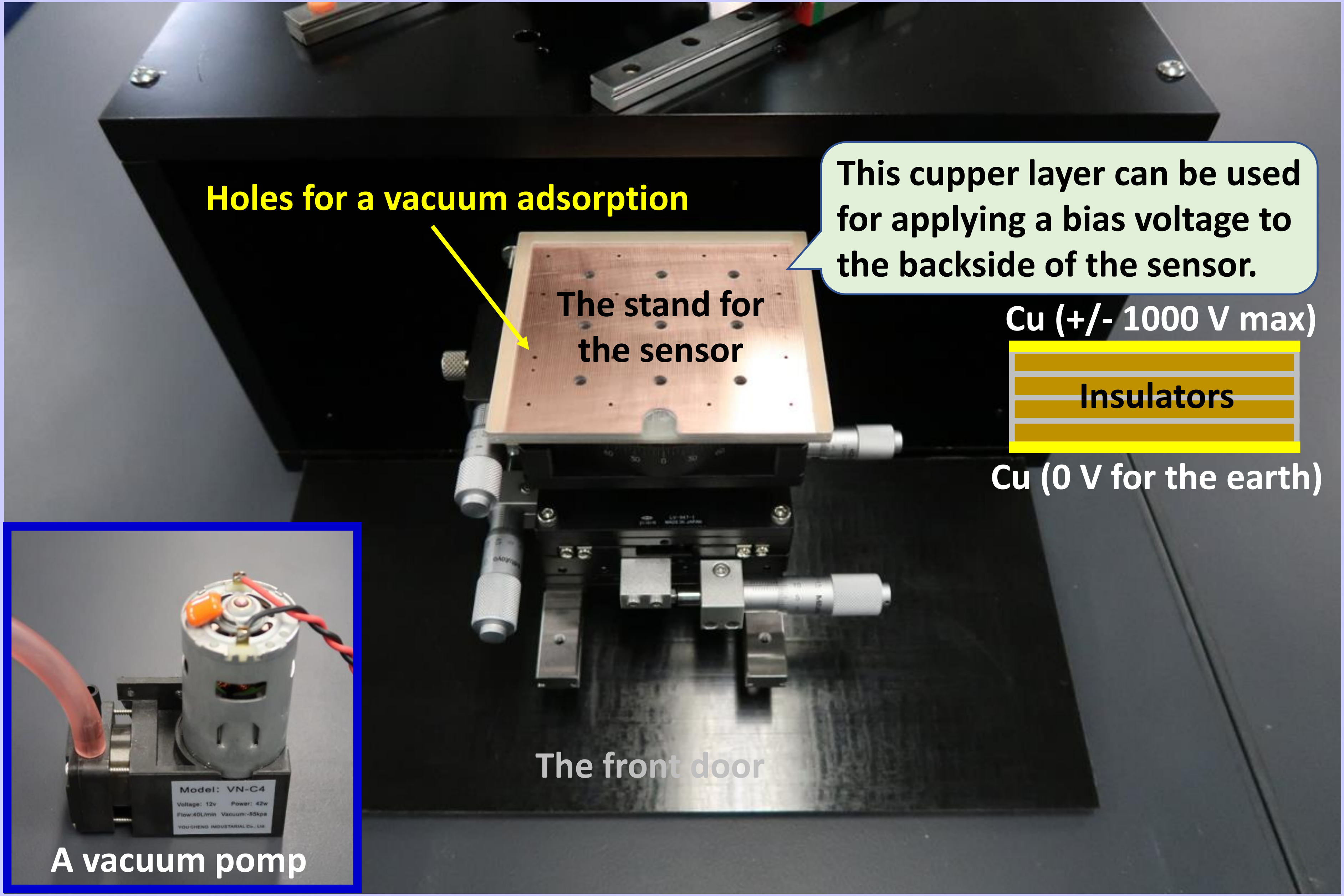
SMU outputs +/-1000V for a bias voltage of the sensor.

There are two ways to connect with the substrate of sensor, the surface and backside.

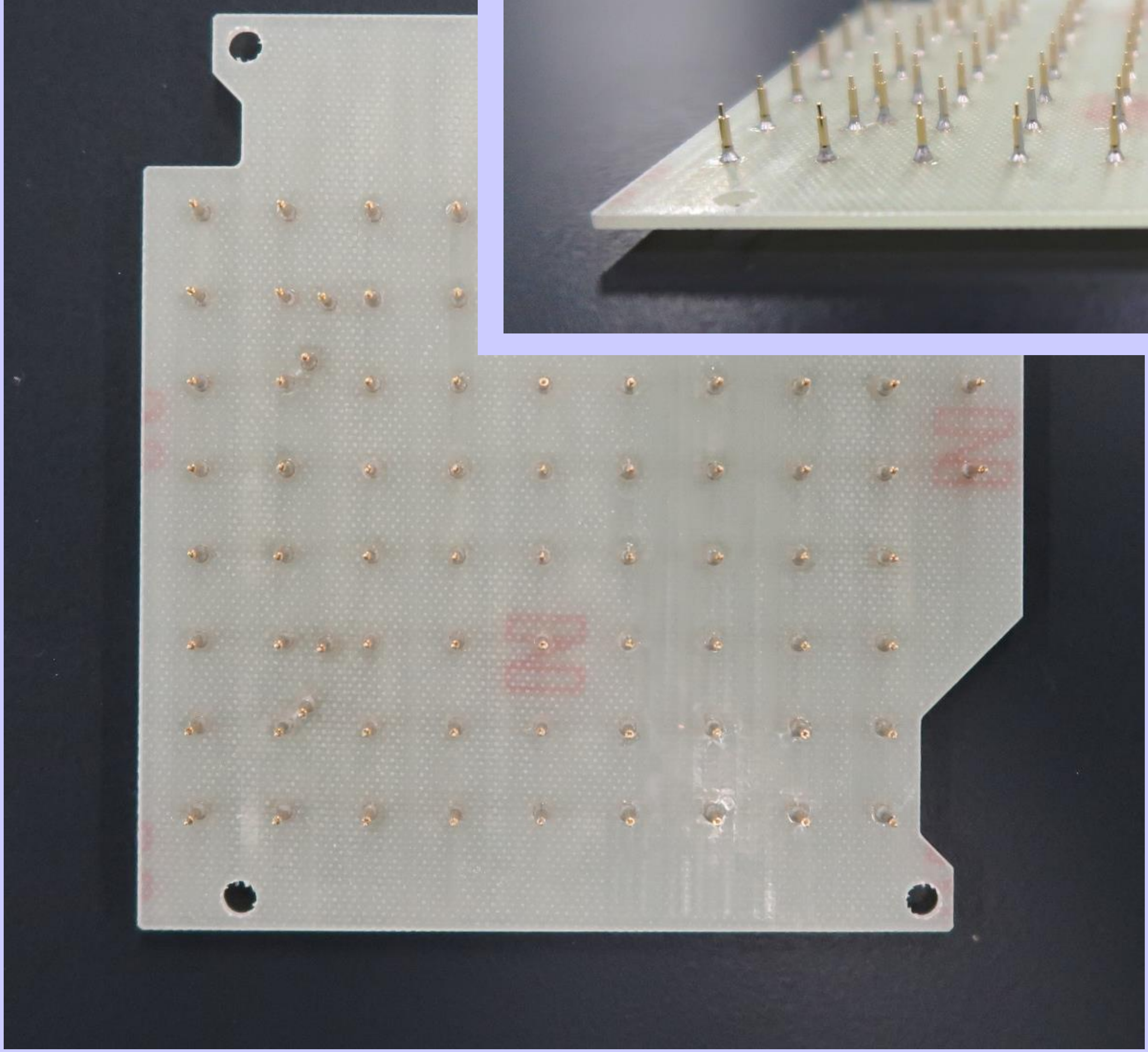
The inside of the probe station

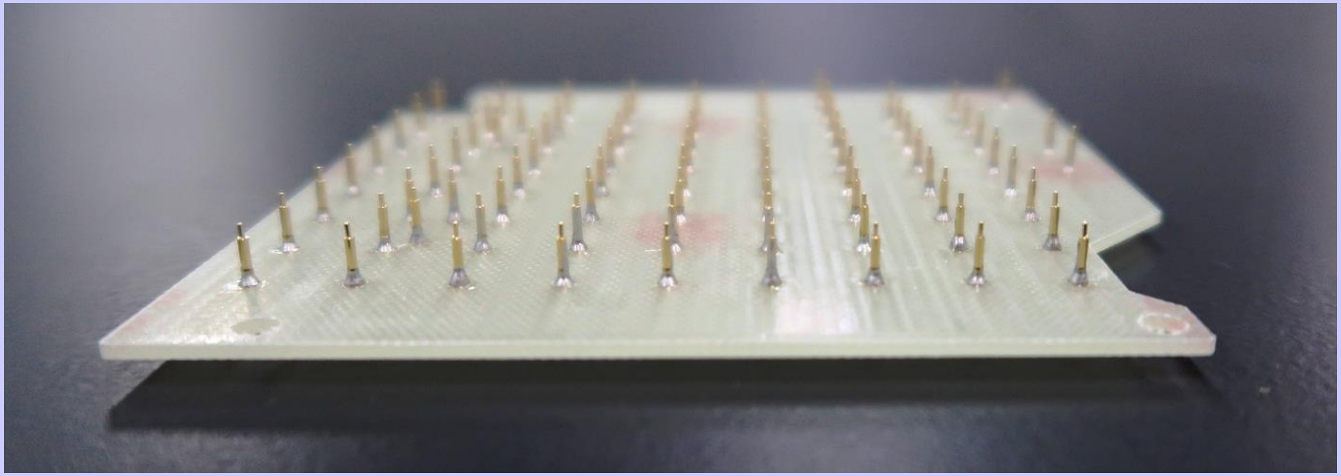


A drawer for easy exchanging of sensors



A card with probe pins





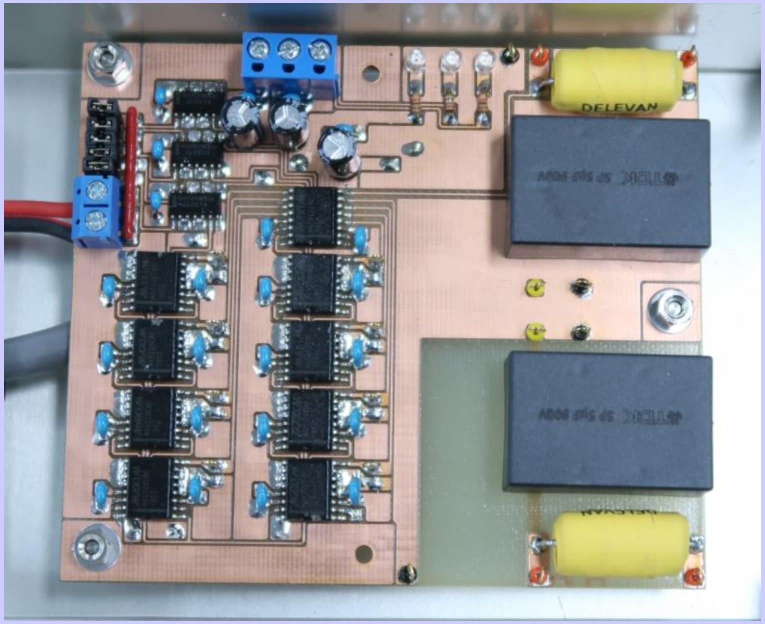
This card has 78 probe pins for connecting with the wire-bonding pad on the main sensor.

It is important to mount probe pins on the PCB with a precise angle and I have developed a special jig for it.

Test measurements

I experimentally started to measure I-V and C-V characteristics of the 2x2 baby chip using the new prove station.

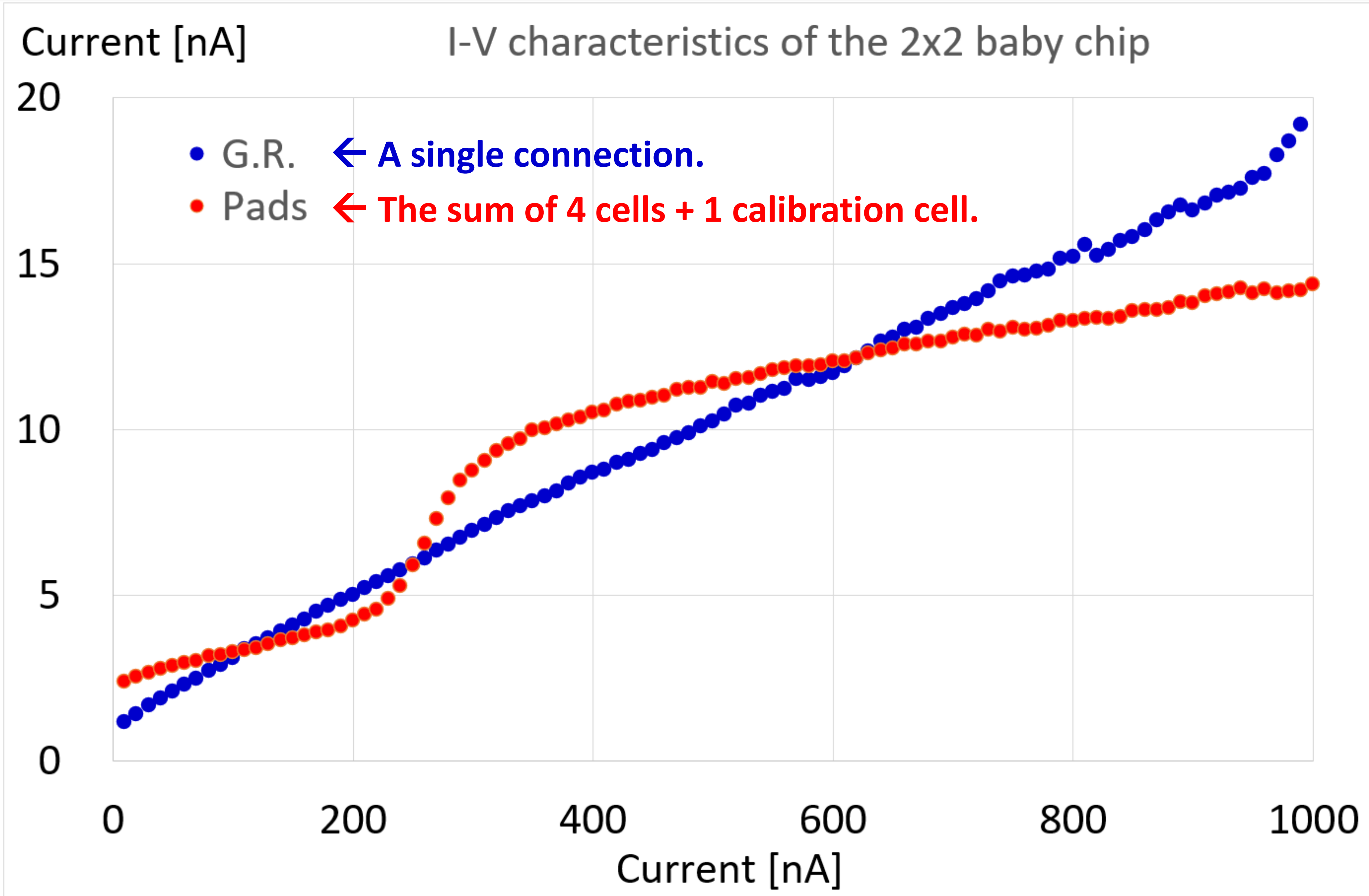
Now, I am testing a part of the analog multiplexer. There are some options such as
(1) the extension of the 8-input analog multiplexer to the 74-input circuit,
(2) the multi-connection lead-relay array, and
(3) KEITHLEY analog switch module.



The 8-input analog multiplexer

KEITHLEY analog switch module

A test result



Topics - Recent activities in Japan

1. Silicon pad sensors
2. Irradiation tests
3. Beam tests
4. Others

2nd irradiation test

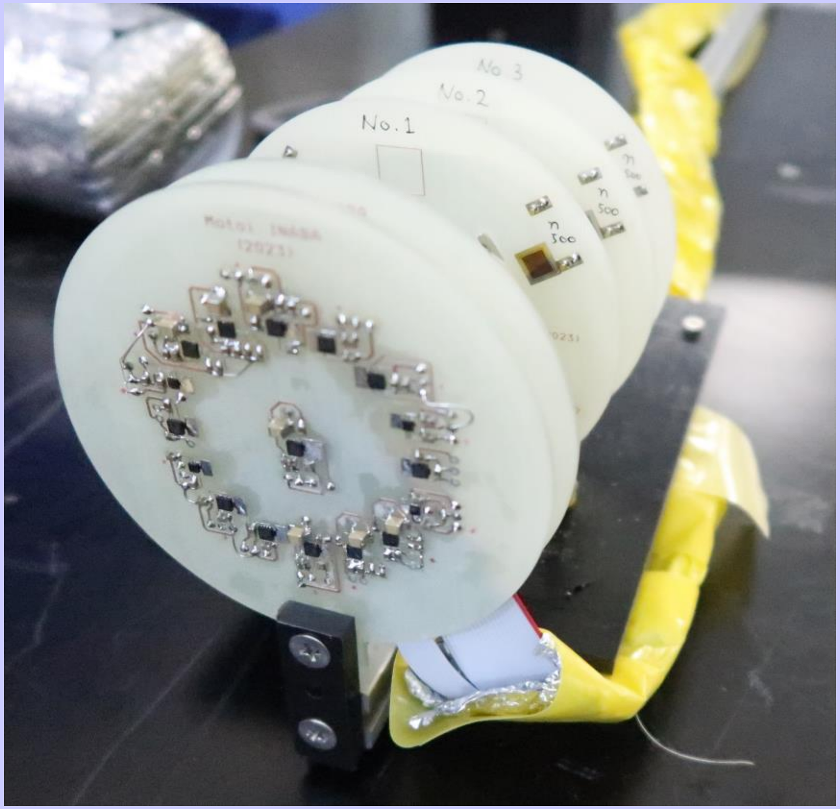
We did the 1st irradiation test at RANS (RIKEN Accelerator-driven compact neutron source) in March last year and got a chance to do the 2nd test this month.

The purpose: The C-V measurements to study a type inversion of the sensor and the radiation hardness test of LDO (Low Drop Out) regulator chips.

Date: 27th of Feb (Pre-test)
7th and 8th of March (Main test)
11th of March (Post-measurement)
Place: RANS in RIKEN

I made five PCBs for the test.

- The 1st layer: 17 LDOs (13 LDOs of them had the input voltage),
- The 2nd layer: 17 LDOs + 20 unmounted LDOs on the back side,
- The 3rd layer (No.1): MPDs and baby chips,
- The 4th layer (No.2): MPDs and baby chips,
- The 5th layer (No.3): MPDs and baby chips.

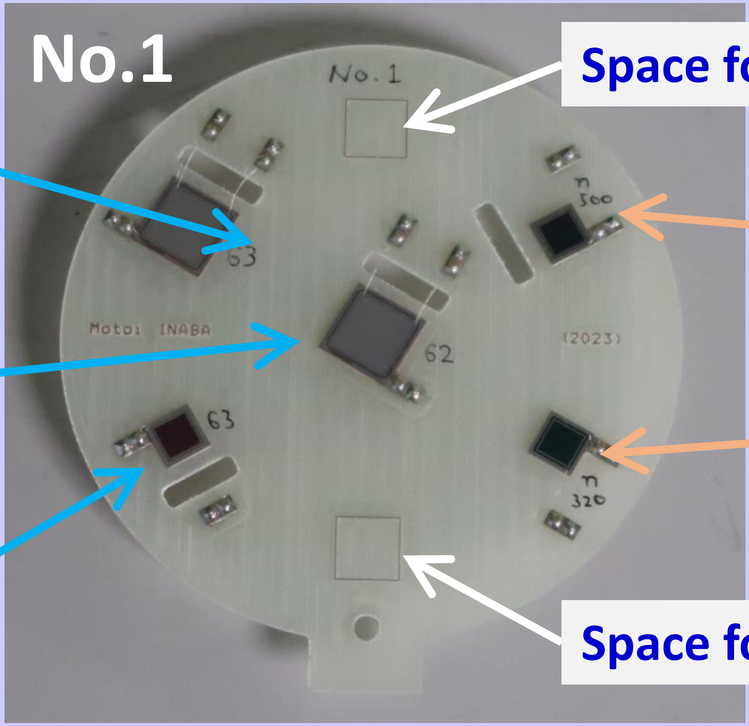


Tested MPDs and 1x1 baby chips

P-sub 320um
1x1 baby
with G.R.

P-sub 320um
1x1 baby
with G.R.

P-sub 320um
MPD w/o G.R.



Space for the indium foil

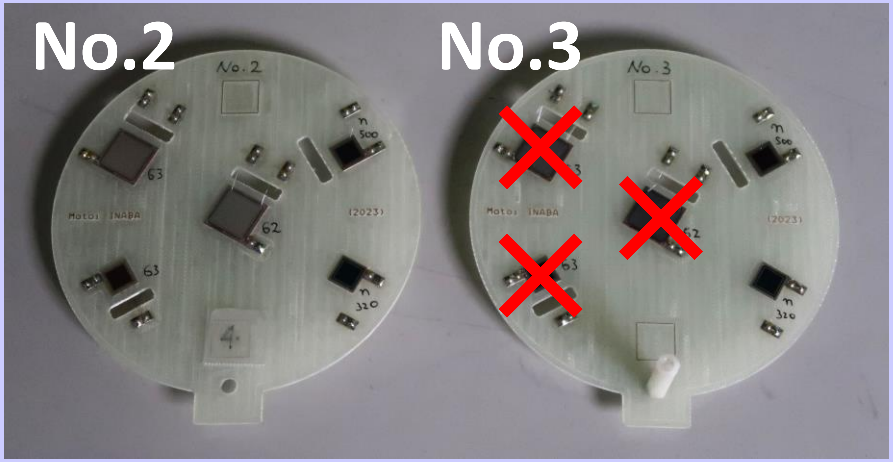
N-sub 500um
MPD w/o G.R.

N-sub 320um
MPD w/o G.R.

Space for the indium foil

Sensors on No.1, No.2 and No.3 PCBs had a different level of the irradiation and we can compare the data of the I-V and C-V characteristics.

Unfortunately, bonding wires for some sensors were broken before installation.

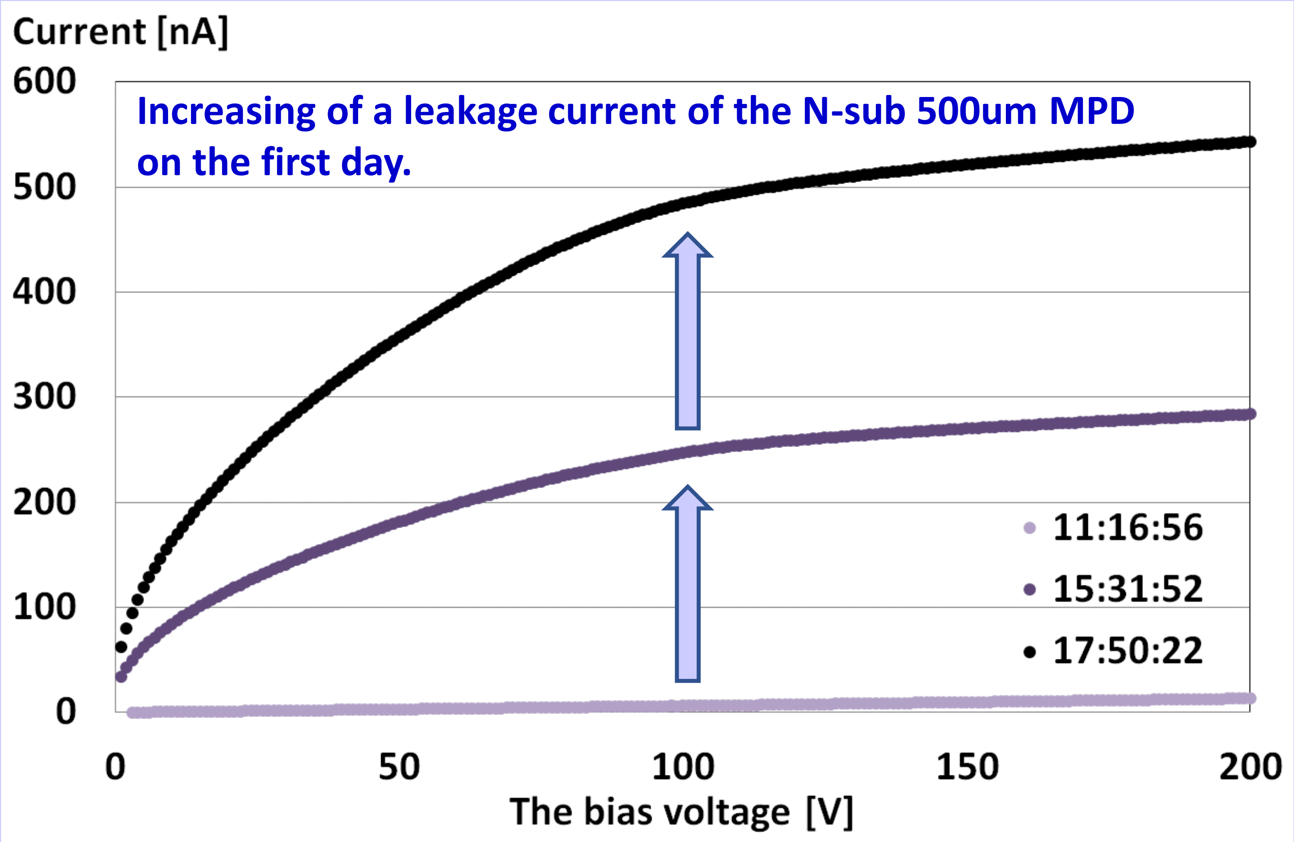


RANS equipment

Two source meters,
two electrometers,
three voltage meters,
one C-meter and
two 13-ch analog switches
are connected with PC.

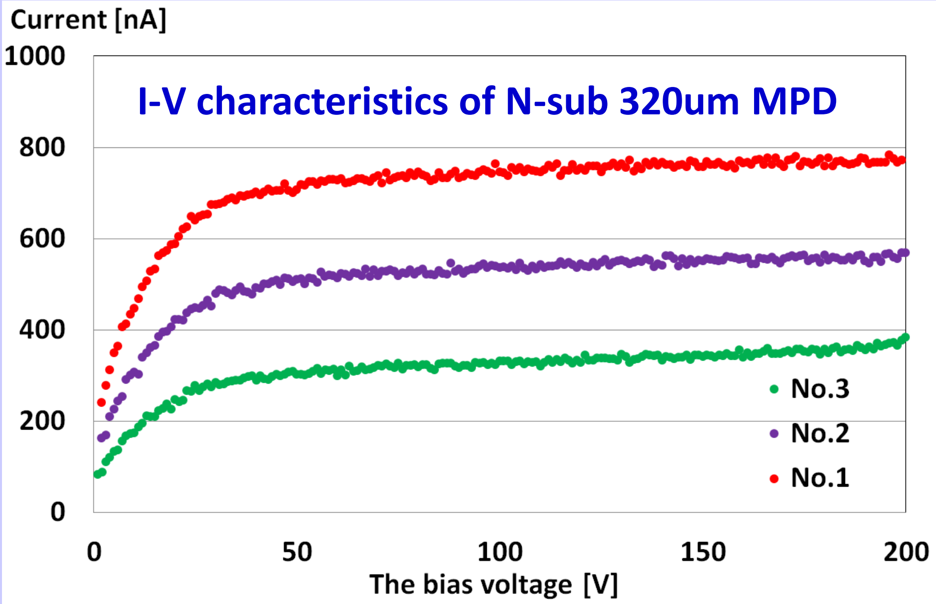
The irradiation test

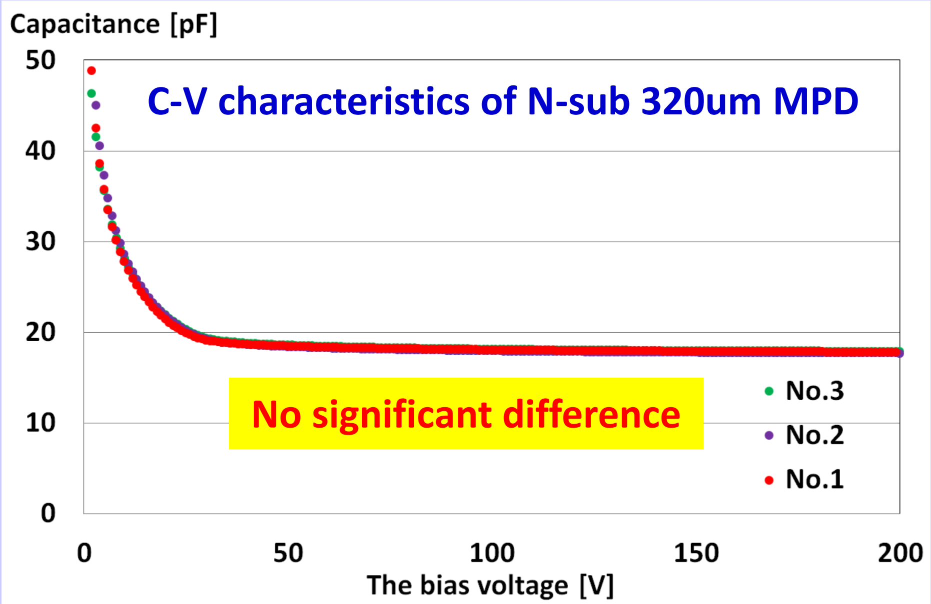
7th of March: 2 runs using a low-intensity neutron beam (1-hour x 4uA each),
8th of March: 3 runs using a low-intensity neutron beam (1-hour x 4uA each).
After removal of silicon pad sensors, other 2 runs of a high-intensity neutron beam (about 2 hours x 40uA in total).

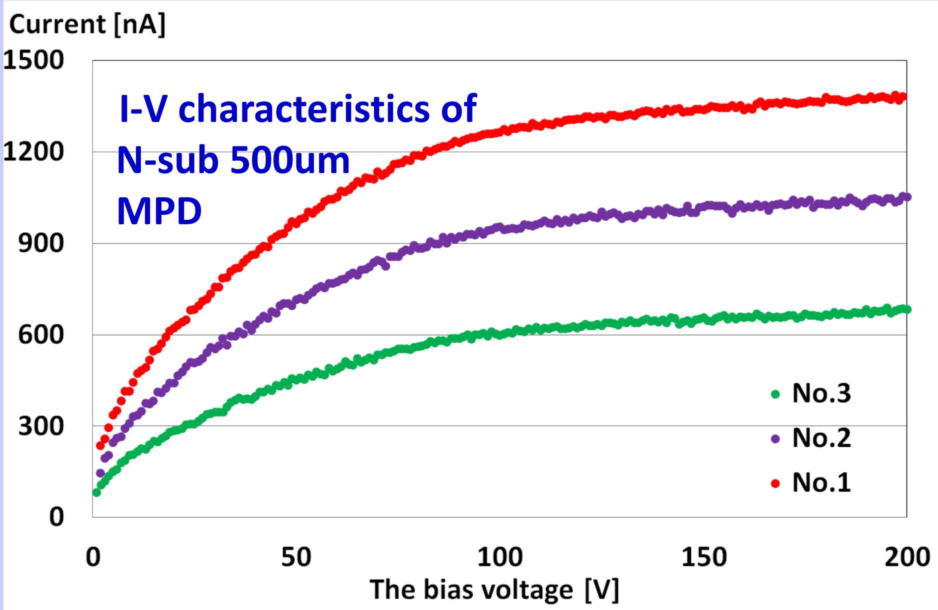


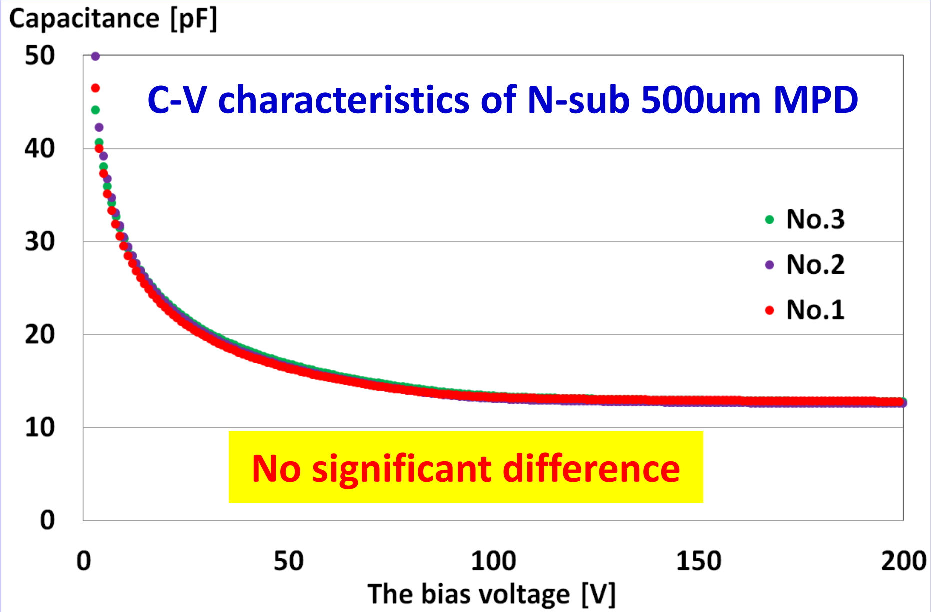
As we expected, a leakage current was getting higher according to the irradiation.

Results of the N-substrate MPD









Results so far

N-substrate MPD

A leakage current had increased according to the irradiation, and then it had decreased by the annealing effect. In three days, C-V characteristics were measured. Sensors on three PCBs had a different level of radiation, it comes into view as a difference of leakage currents. However, no significant difference of the full-depletion voltage among three MPDs could be found.

We will keep watching.

P-substrate MPD

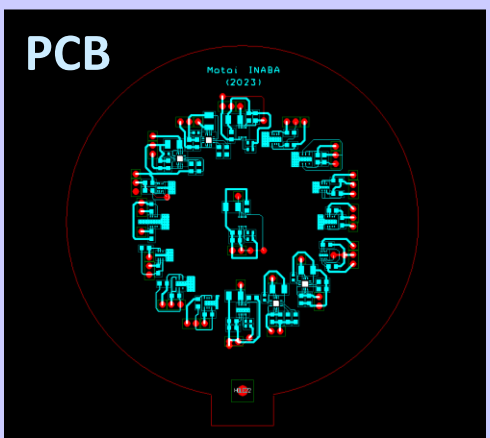
The data analysis to compare MPDs on No.1 and No.2 is on-going. We could not take the data on No.3 PCB because of damaged wires.

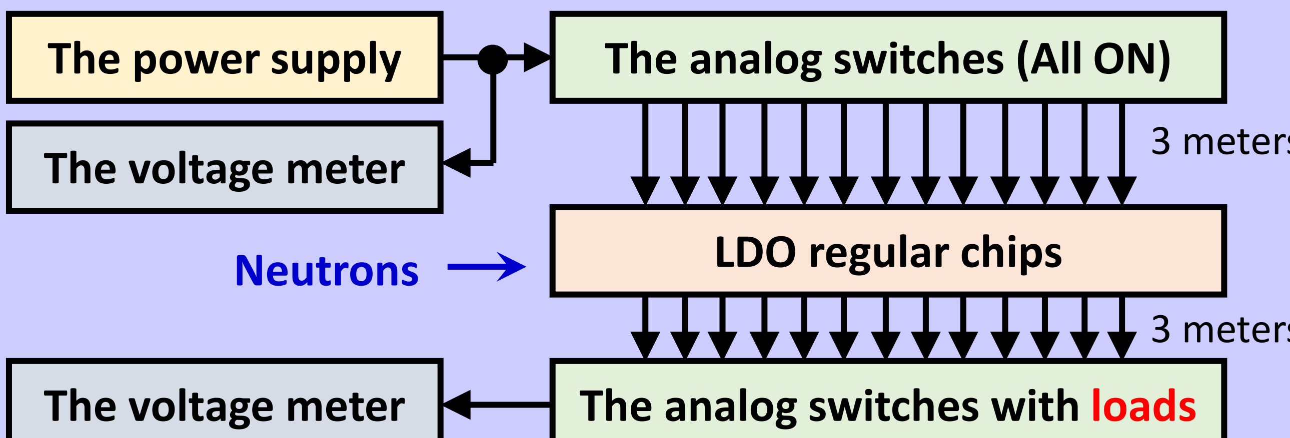
P-substrate 1x1 baby chips

The data analysis to compare baby chips on No.1 and No.2 is on-going. We have no way to repair broken wires on No.3 in the radiation control area.

LDO regulator chips for HGCROC

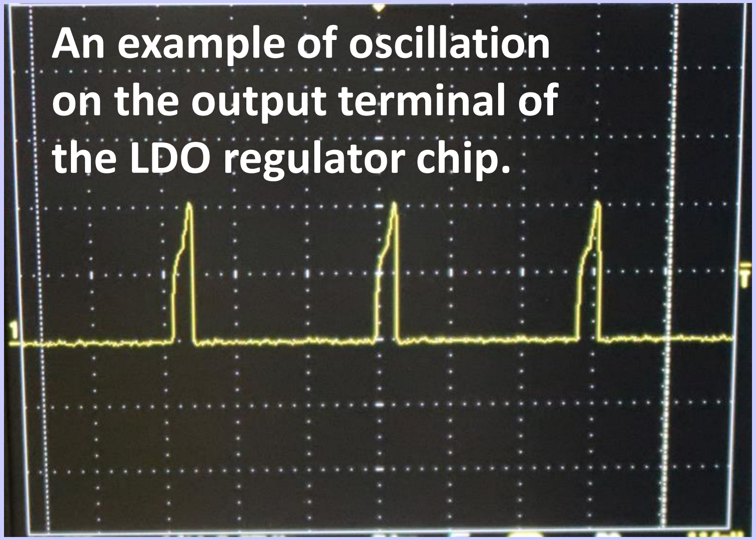
Series of LDOs	Company / Supplier	The number of tested LDOs
NCP59763	Onsemi	3 online / 3 offline / 20 unmounted
TPS746	Texas Instruments	2 online / 2 offline
LD49100	STMicroelectronics	2 online / 2 offline
NCP187	Onsemi	2 online / 2 offline
NCV8187	Onsemi	0 online / 4 offline (Unstable)
AS1376 (*)	Mouser Electronics	2 online / 2 offline * No longer in production, but we have some chips.
ADP1761	Analog Devices	1 online / 3 offline
ADP1763	Analog Devices	1 online / 3 offline

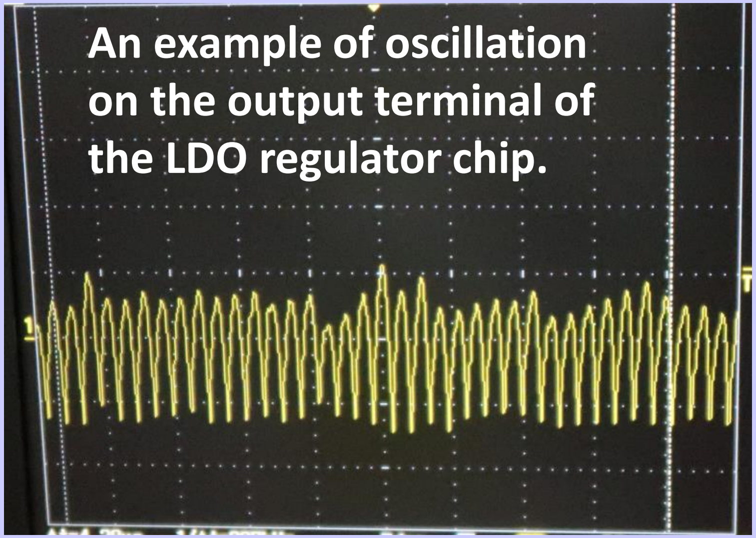




Test conditions and results

Although we would like to test the LDO regulator chip only, I found that some LDO regulator chips could not stop oscillation without passive components in the pre-test at RANS. Therefore, the irradiation test of LDOs regulator chips was carried out with some capacitors and resistors. No protection diode was mounted.





It is very important to know what happens on the LDO regulator chip. The input and output voltages of 13 LDO regulator chips were monitored remotely.

As a tentative result so far, five LDO regulator chips were stable to the end, the output of one chip suddenly went down, two chips slowly went down, two chips slowly went up (this is dangerous) and three chips were unstable.

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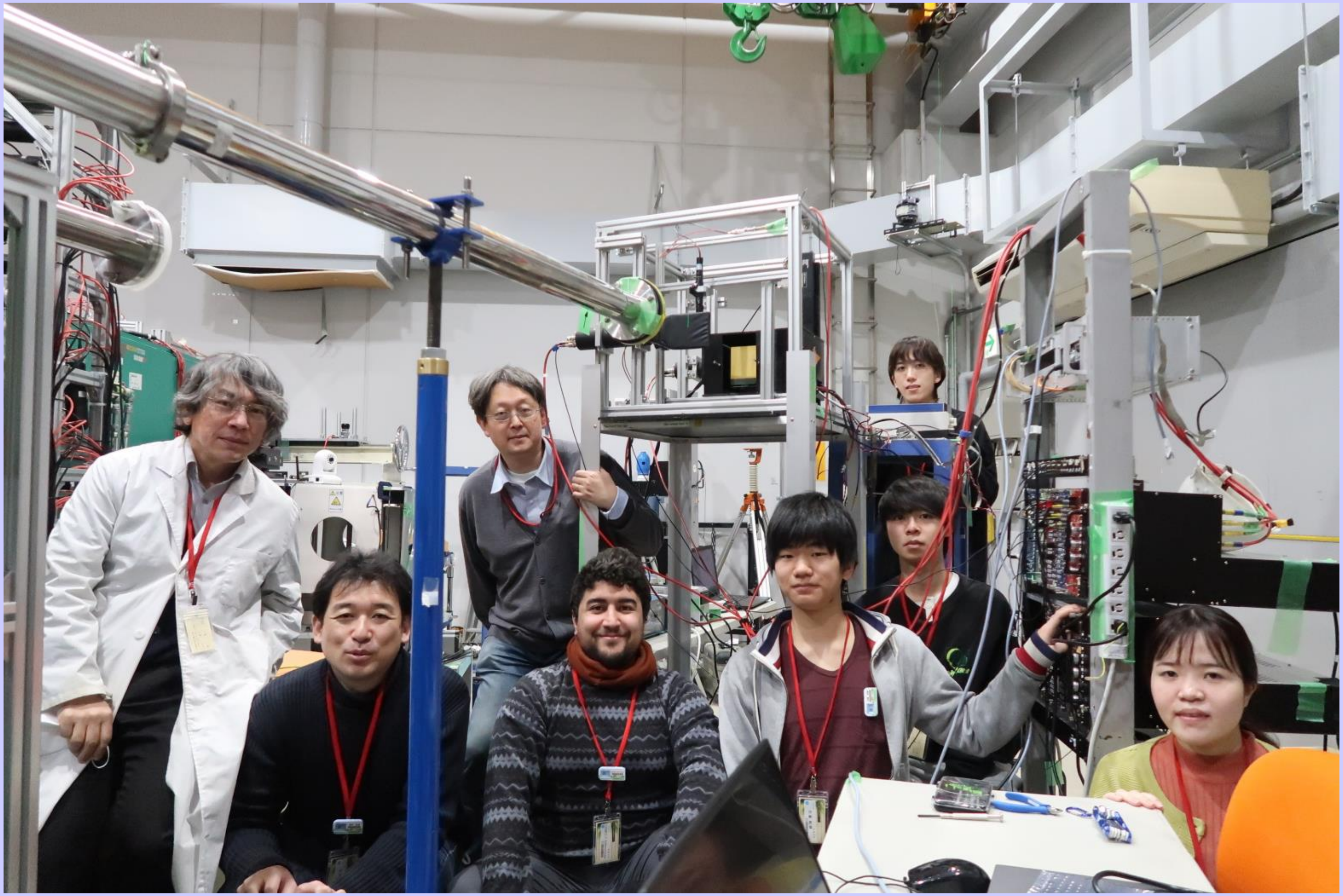
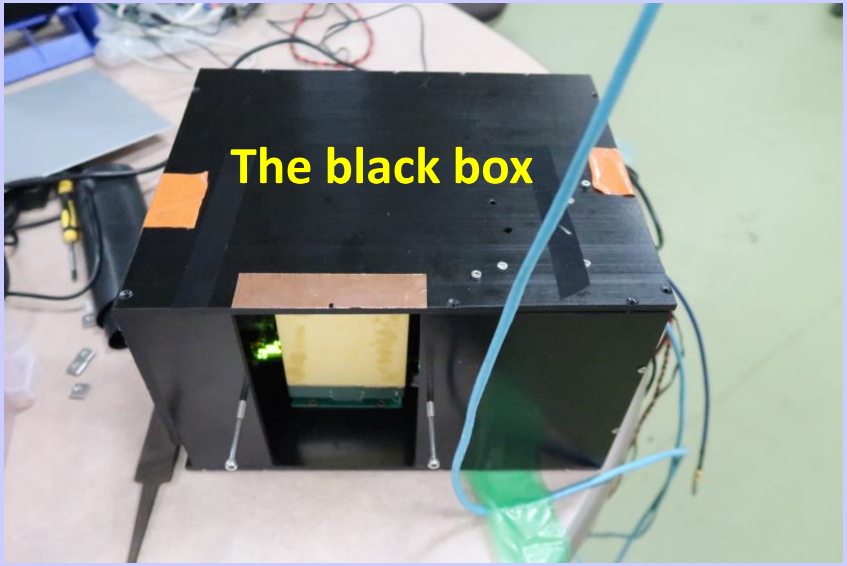
Beam test at ELPH (Tohoku Univ.)

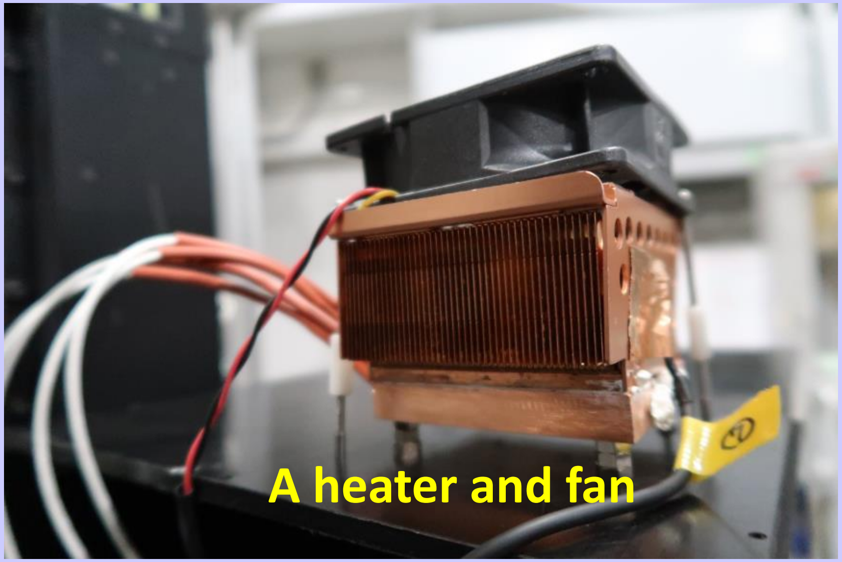
We carried out the beam test of the silicon pad sensors at ELPH from 20th to 23rd of February. This time, we focused on the MIP data in different temperatures and S/N of the irradiated sensors.

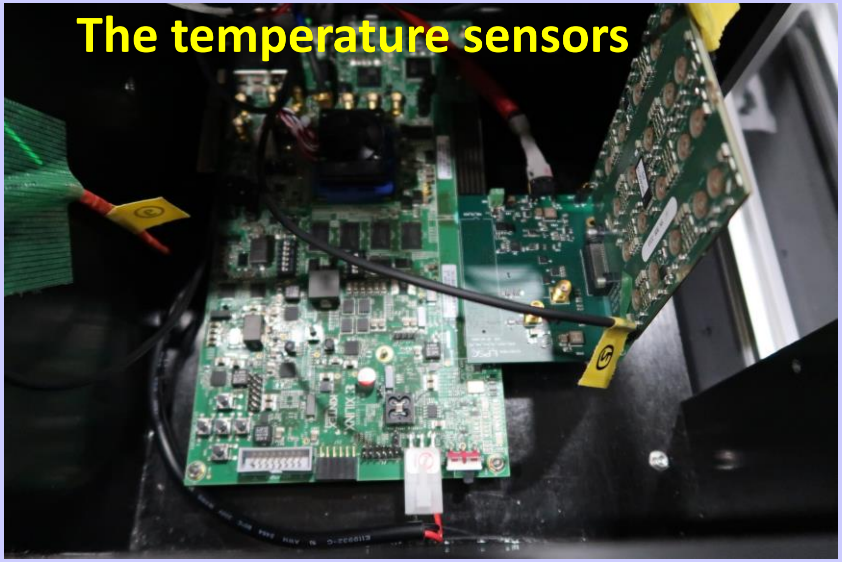


The temperature control system

In order to increase the temperature, I made a special black box with a heater.







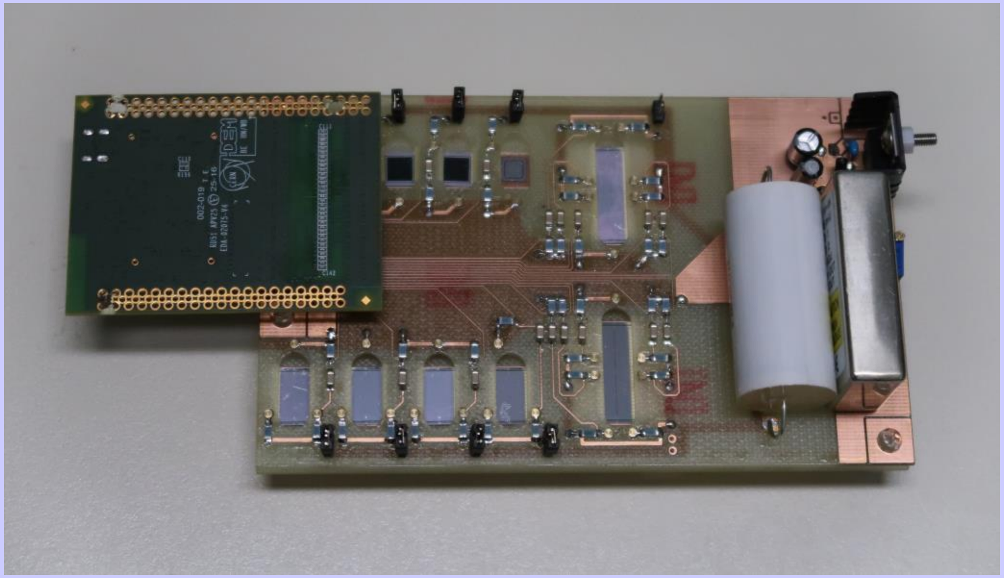
Temperature dependence

We took the data at a room temperature, 30, 35, 40 and 45 degrees C.

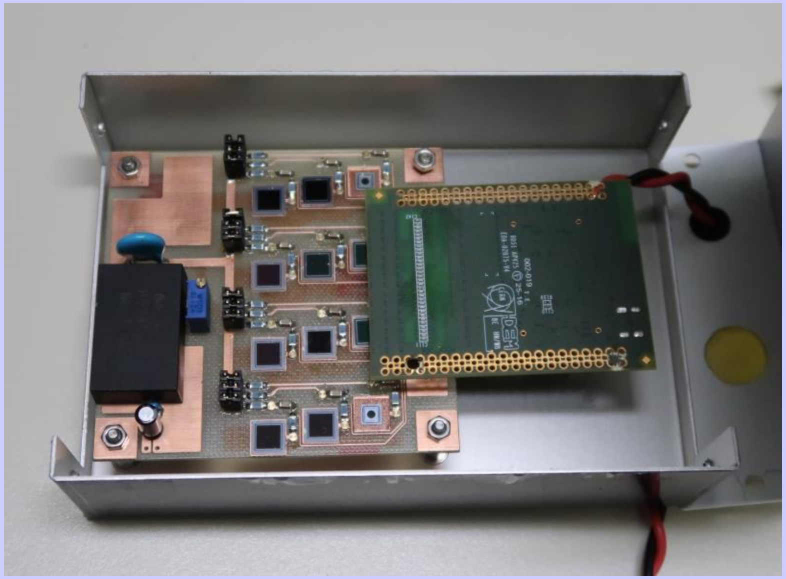
45 degrees C is the maximum operation temperature of the KCU105 FPGA board and it is difficult to buy new one. No significant difference of the MIP data could be found at 45 degrees C and below.

Test of the irradiated sensors

We had some MPDs that we used for the irradiation test at RANS one year ago, and now we can take out them from the radiation control area. I made PCBs with the irradiated MPDs and we tried to take the MIP data. As a result, we could not see a signal. We are investigating the reason.



P-substrate irradiated MPDs and baby chips with the APV25 hybrid board.

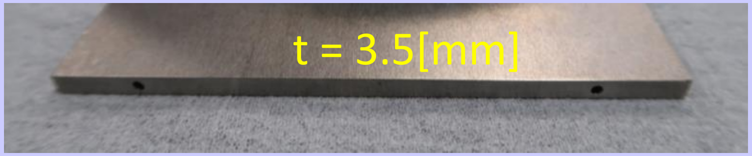


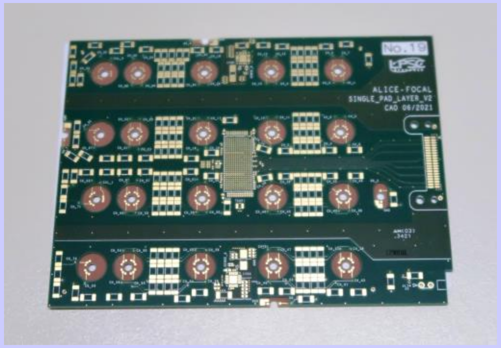
N-substrate irradiated and non-irradiated MPDs with the APV25 hybrid board.

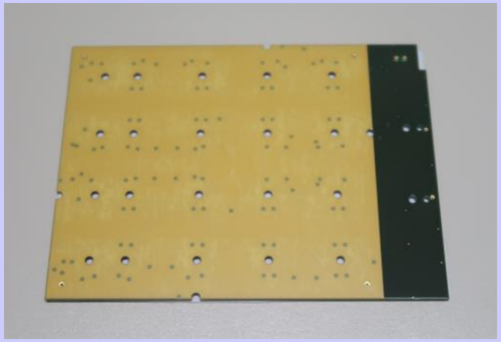
The independent isolated high-voltage generators make 80 V and 600 V bias voltage for the n-sub and p-sub sensors, respectively, on the PCB.

Others and summary

1. Silicon pad sensors
2. Irradiation tests
3. Beam tests
4. Others







A test production of the Tungsten alloy plates.

A test production of the 10-layer single-pad PCB.

Test assembling of electronical components on the PCB including HGCROC V2 ASIC (on-going).

A wire-bonding test using the deep-access wire bonder (on-going).

BGA packaging of HGCROC V2 ASIC (on-going)

5-pad PCB design and so on.

Thank you for your attention.