Cadmium Telluride pixel sensor development for high sensitivity X-ray imaging device

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Outline

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- Basic properties of CdTe sensor
  - Ohmic sensor (Pt electrode)
  - Schottky diode sensor (In, Al electrode)
- SP8-01 and SP8-02 prototype CdTe detector
  - Beam test with SP8-01
  - Stability test with SP8-01 and SP8-02
- Summary

Introduction

- Pixel detector was expected to be a next generation 2D X-ray detector from the early stage of the 3rd generation synchrotron radiation facilities.
- PILATUS detector developed by SLS/PSI has realized X-ray photon counting imaging and is applying in advanced applications.
- SPring-8 has closely collaborated with in the PILATUS project and contributed to module fabrication and developing advanced application methods.

To expand the pixel detector technology to high energy X-ray region above 100 keV which is available at SPring-8 in Japan, we started CdTe pixel detector development in collaboration with ISAS/JAXA.

Properties of the semiconductors

	CdTe	CZT	Ge	Si
density (g/cm^3)	5.85	~5.8	5.33	2.33
atomic number	48, 52	48, 30, 52	32	14
band Egap energy (eV)	1.44	~1.65	0.67	1.12
ε (eV)	4.43	~5.0	2.96	3.62
resistivity (Ωcm)	10^9	10^9~10^{11}	3900	1400
$(\mu\tau)_e$ (cm^2/V)	~2×10^{-3}	~1×10^{-3}	0.42	0.22
$(\mu\tau)_h$ (cm^2/V)	~1×10^{-4}	~3×10^{-5}	0.72	0.84

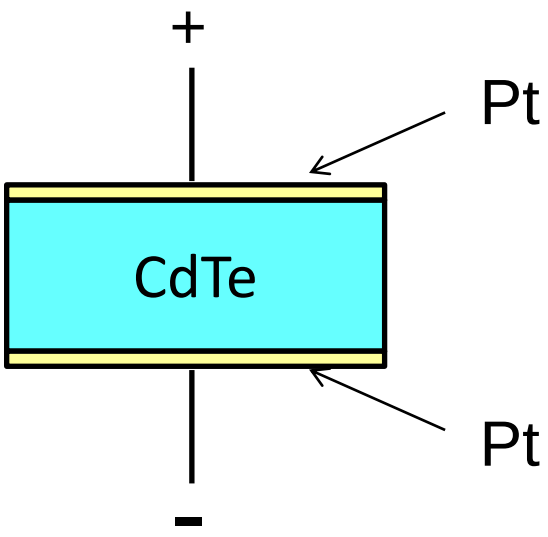
For development of high sensitivity X-ray imaging device,

- ✓ high density & atomic number material
- ✓ uniformity of electric properties (resistivity…)
- ✓ effective electrode (ohmic, diode)
- ✓ readout electronics and bonding

are key technologies!

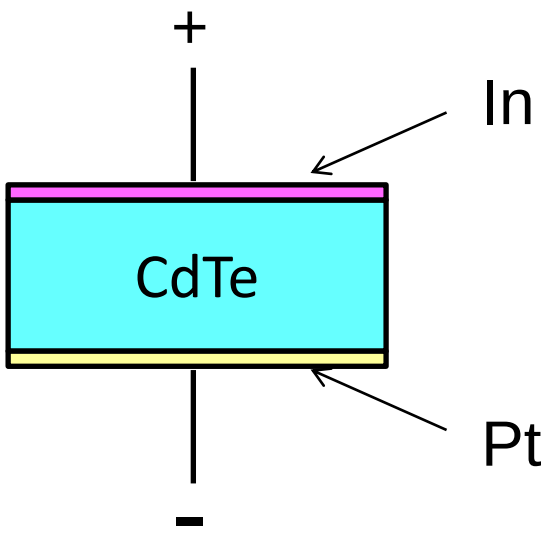
Ohmic- and Schottky-type sensor

Ohmic-type



Long term stability
but high leakage current
low energy resolution

Schottky-type

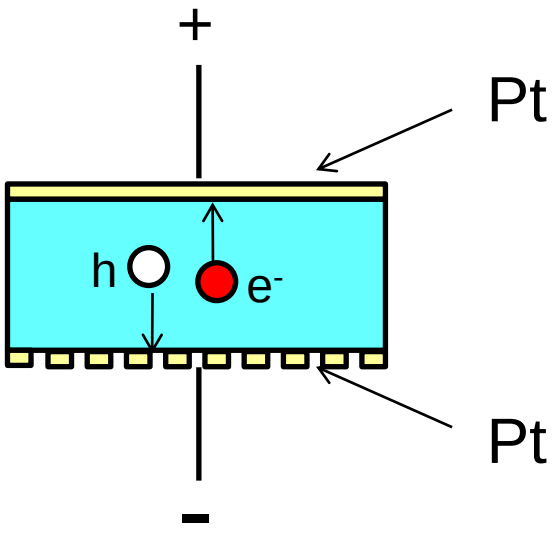


very low leakage current
high energy resolution
but polarization problem

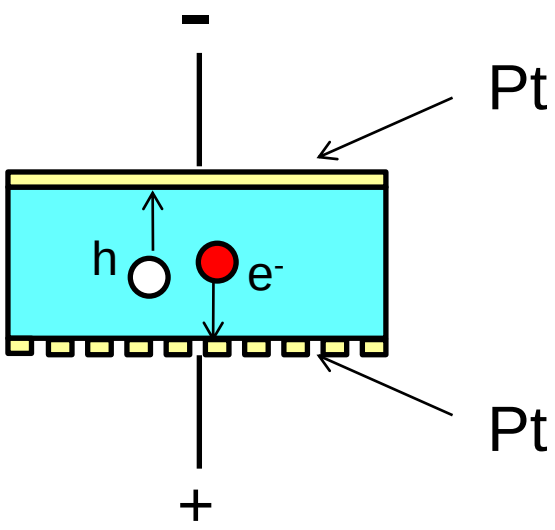
Because of relatively small $\mu\tau$ value of CdTe, high bias voltage (~1000V/mm) is required to improve charge collection efficiency.

Ohmic-type pixel sensor

hole-collection mode



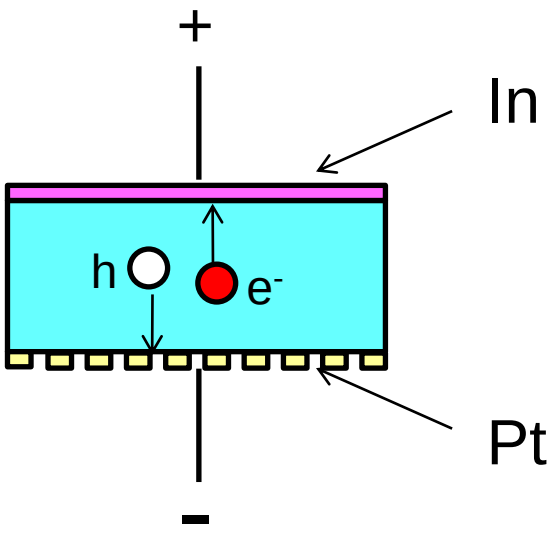
electron-collection mode



Both of hole- and electron-collection mode can function by inversing bias polarity.

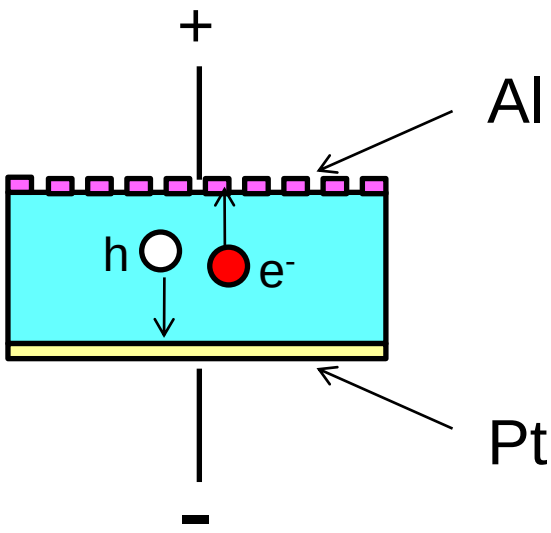
Schottky-type pixel sensor

hole-collection mode



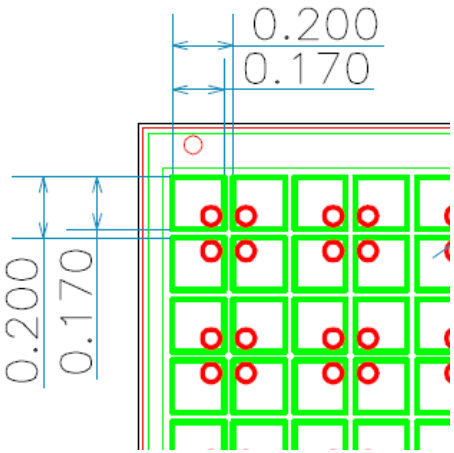
Standard In-Schottly pixel sensor only functions as hole-collection mode.

electron-collection mode



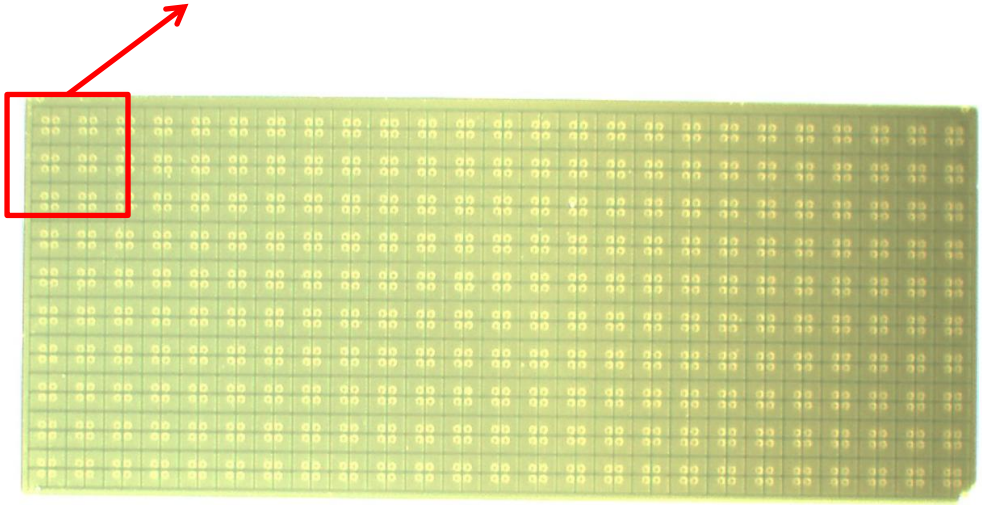
Al pixel-electrode sensor can realize to function as an election-collection type diode sensor.

SP8-01 and SP8-02 sensors

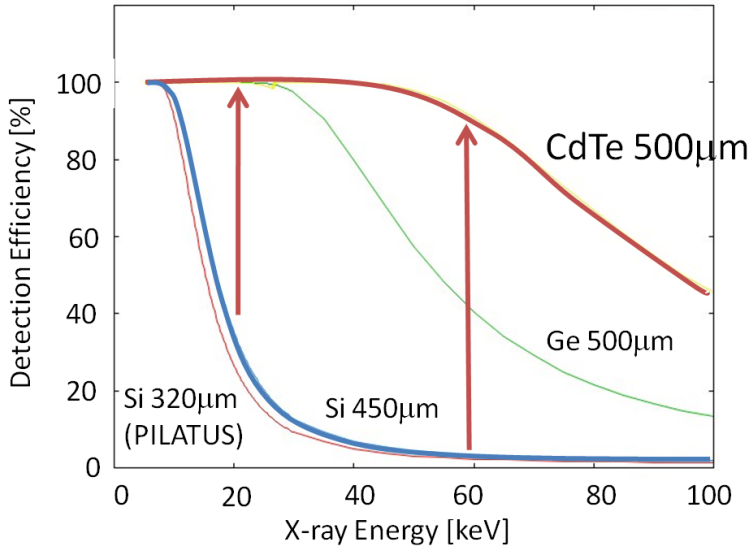


	Pixel size	format	thickness	elecrtode
SP8-01	200 × 200μm^2	16 × 16	500μm	Pt/CdTe/Al-pixel
SP8-02	200 × 200μm^2	20 × 50	500μm	Pt/CdTe/Pt-pixel In/CdTe/Pt-pixel Pt/CdTe/Al-pixel

Bias 300 ~ 500 V

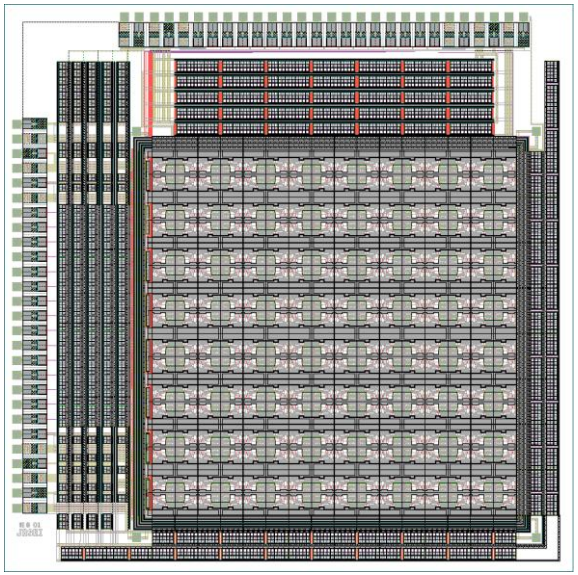


SP8-02 sensor

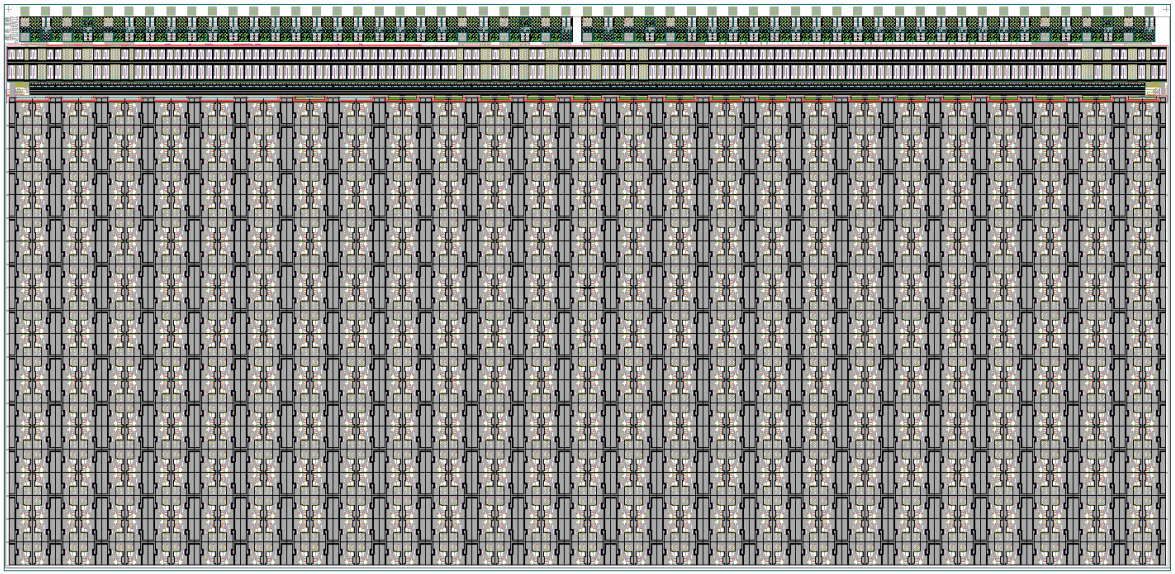


ASIC layout designed with TSMC 0.25μm CMOS

SP8-01



SP8-02

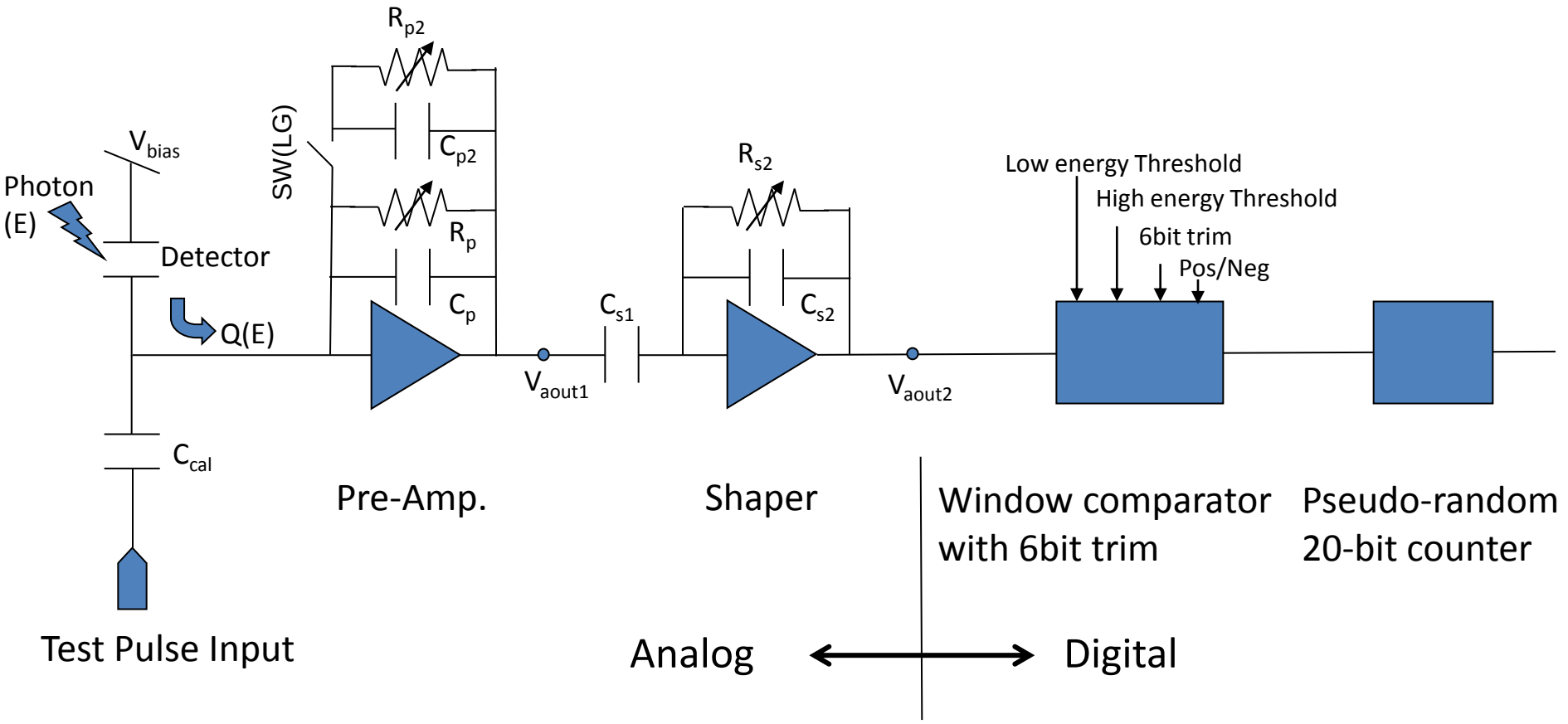


	ASIC size	Pixel size	format	ASIC production	1st bonding
SP8-01	5mm × 5mm	200mm × 200mm	16 × 16	October 2009	January 2010
SP8-02	5mm × 10mm	200mm × 200mm	20 × 50	April 2011	June 2011

SP8-01 and SP8-02 ASIC architecture

- To realize all requirements of the readout circuit,
  ⇒ full custom ASICs have been developed

Block diagram of readout for 1 pixel

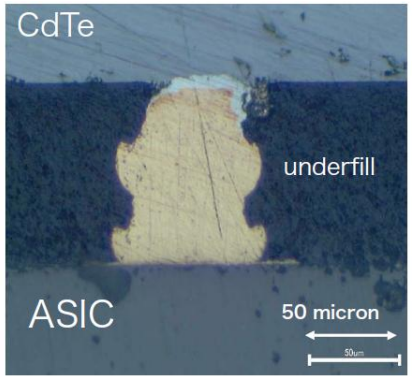


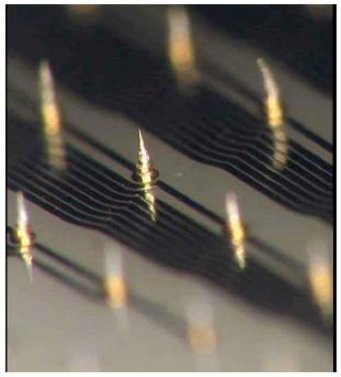
In/Au-stud bonding

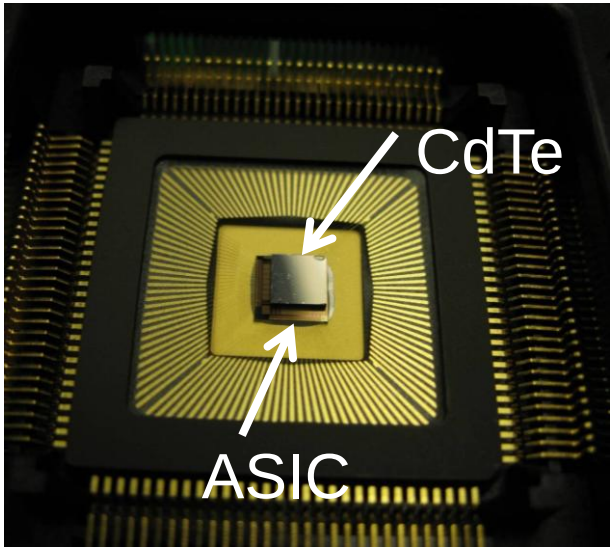
- Double stud bumps 40 ~ 50 μm in height were processed on the ASIC with Au wires 25 and 18 μm in diameter
- Small Indium was applied on the stud tips
- ASIC was bump-bonded to the sensor by a standard flip chip technique
- Sensor hybrid was wire-bonded to a commercial ceramic package

chip level process

low temperature and soft process

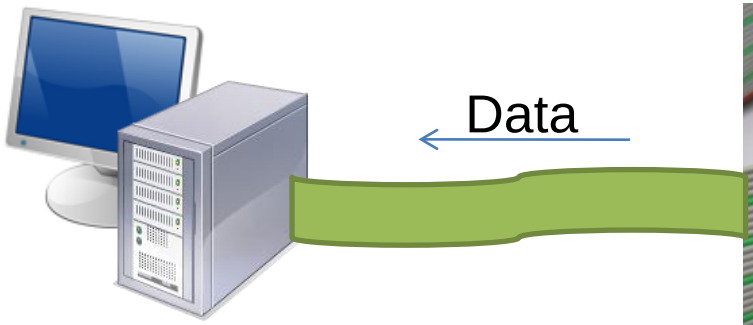


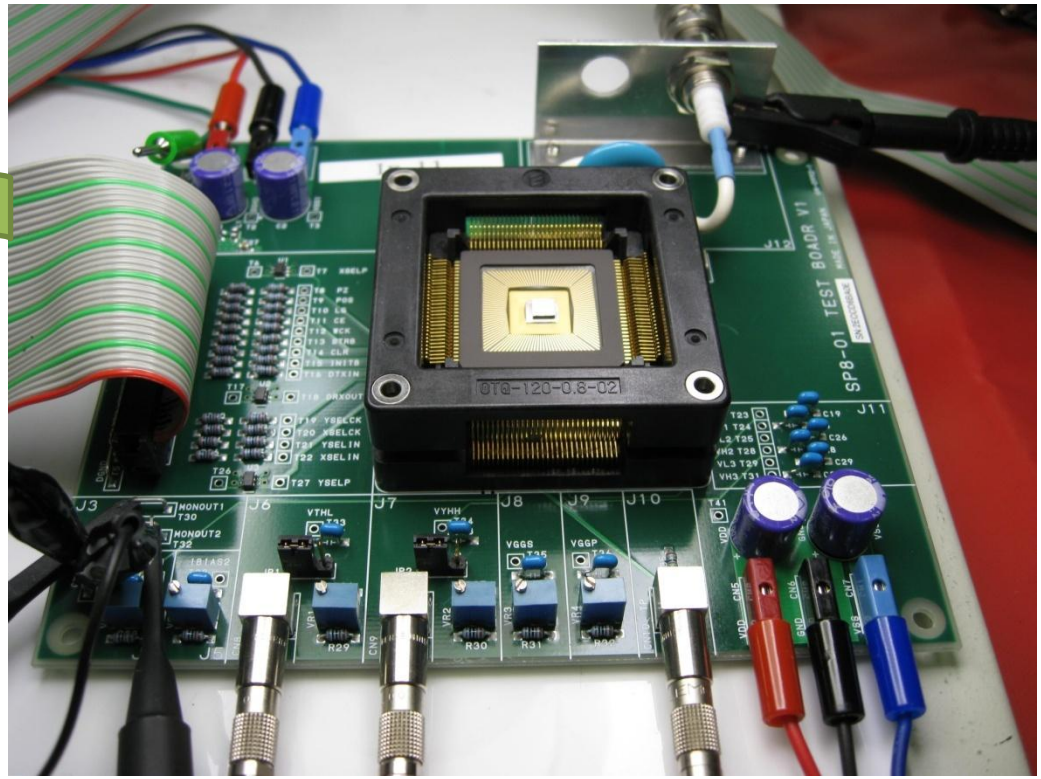




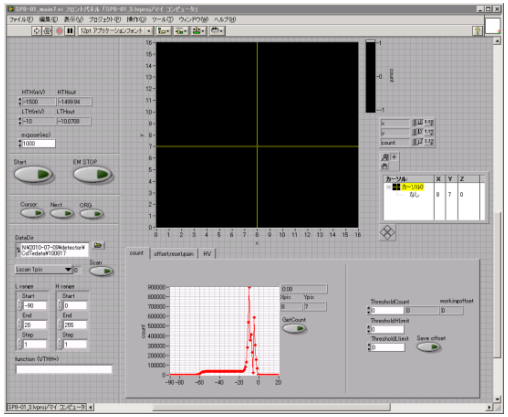
SP8-01 sensor package

SP8-01 test board and control system



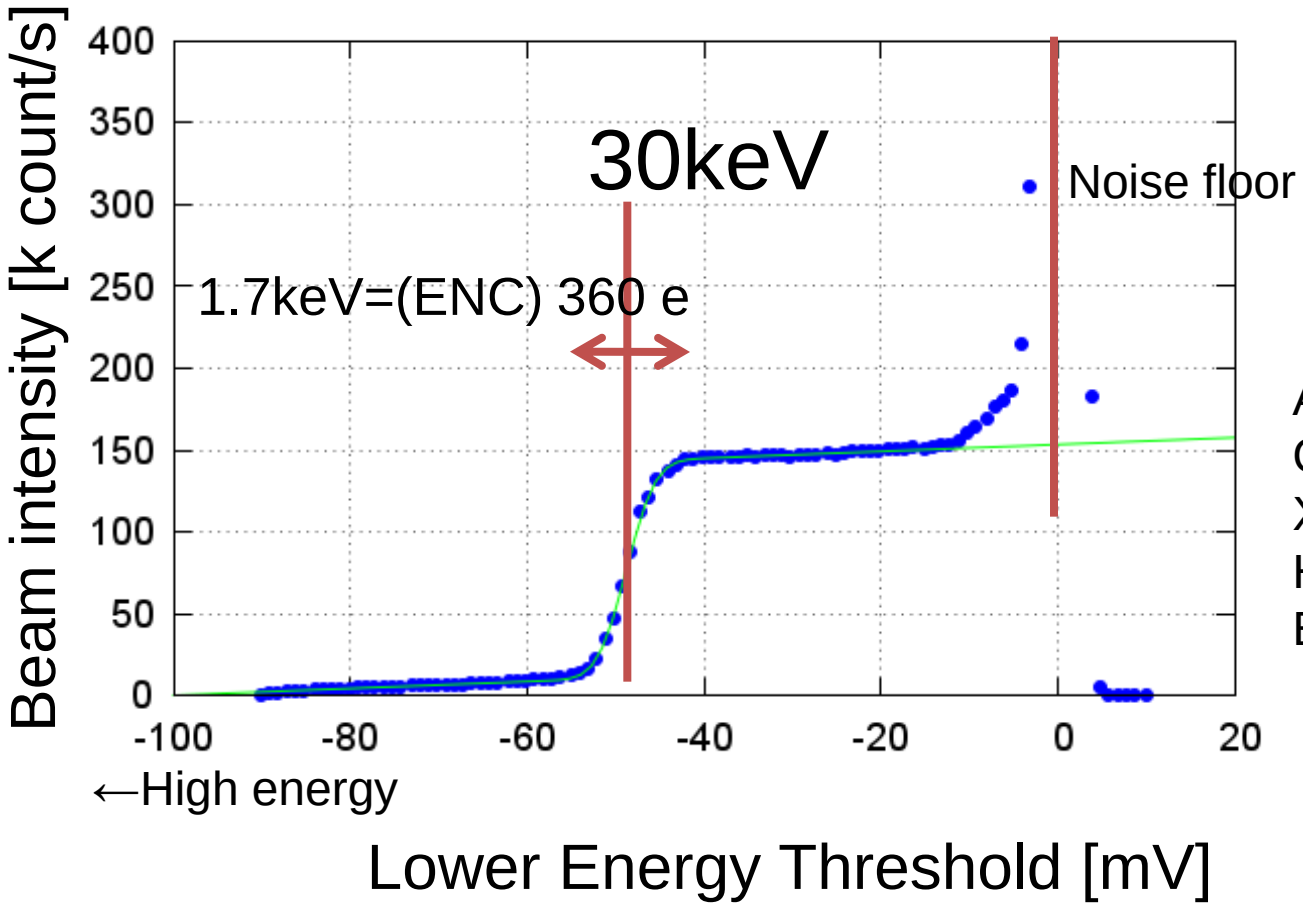


Readout board: NI- PCI 7831
(DIO, AD/DA with FPGA)
+
LabVIEW software



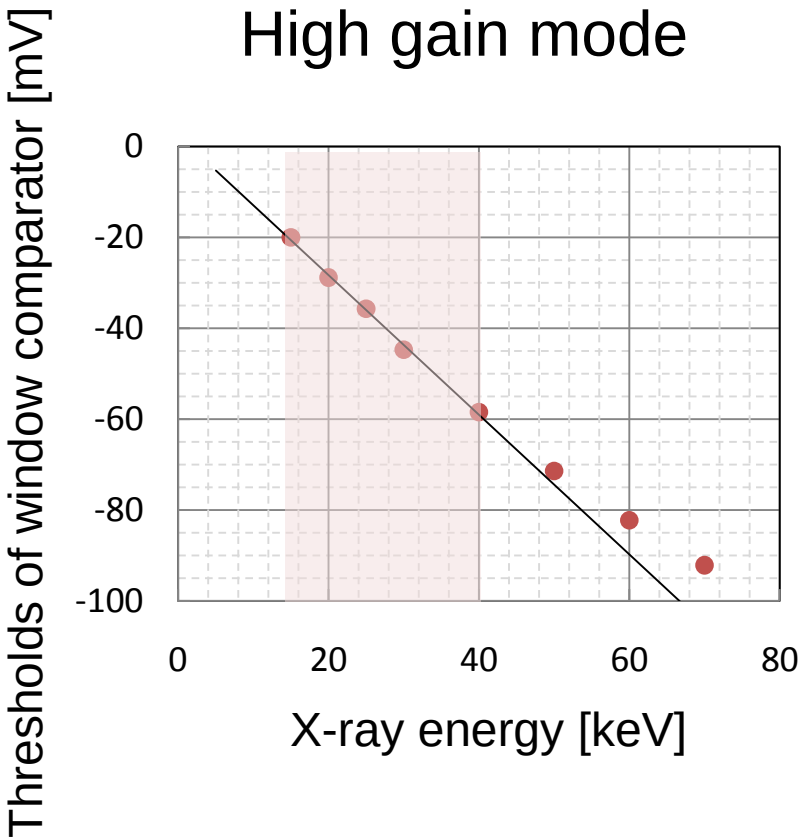
Threshold dispersion of SP8-01 Al-Schottky sensor

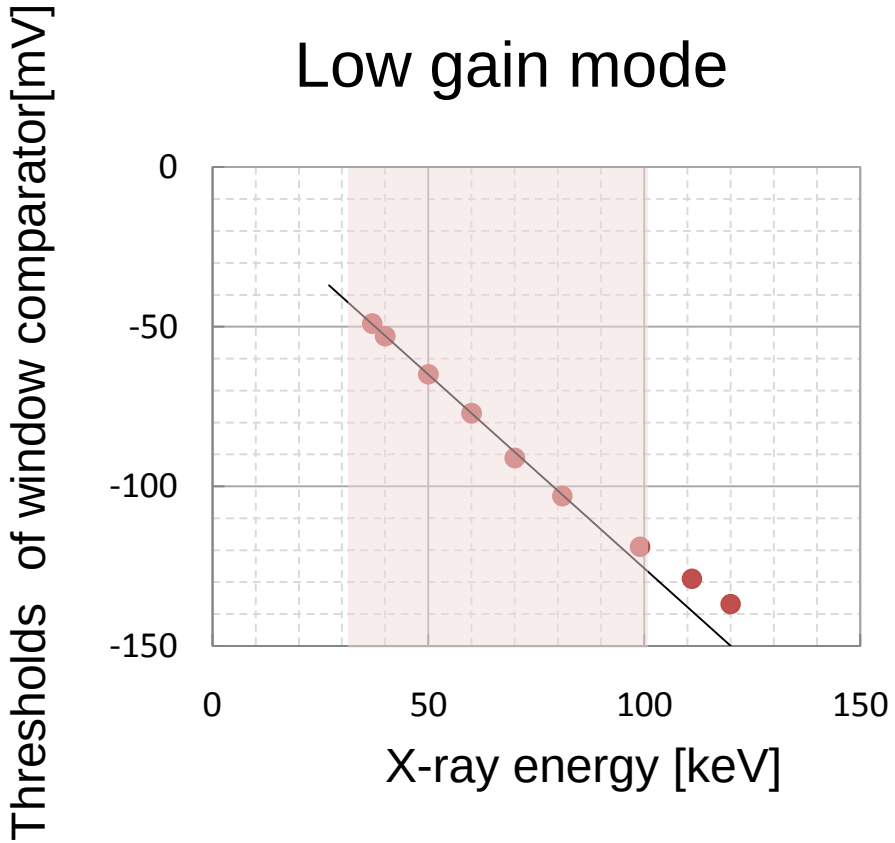
- Lower-energy threshold scan with 30keV pencil beam
  - Infection point of 30 keV ⇒ -49.5mV
  - Threshold dispersion ⇒ 360 e- (1.7keV) rms @ 30 keV



Al/CdTe/Pt (-charge)
Gain : Hig Gain
X-ray Energy : 30keV
HV: -300V
Exposure time : 0.1s

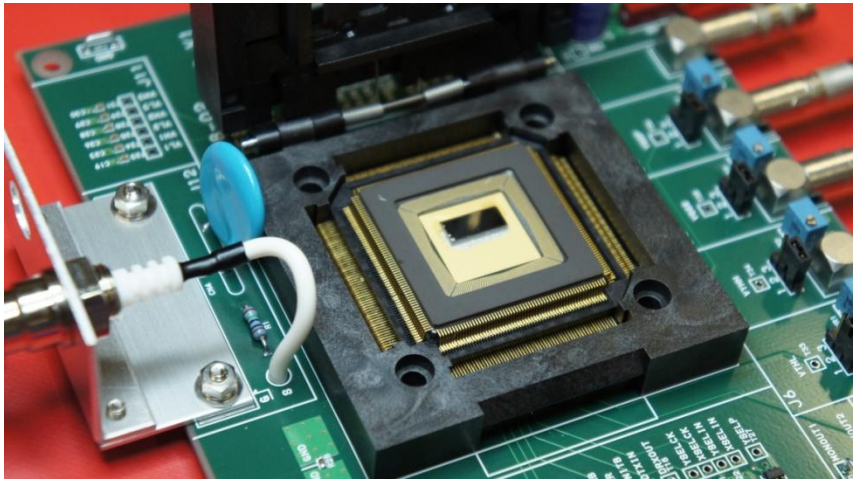
Linearity of high and low gain mode with SP8-01





Stability test with thermostatic chamber

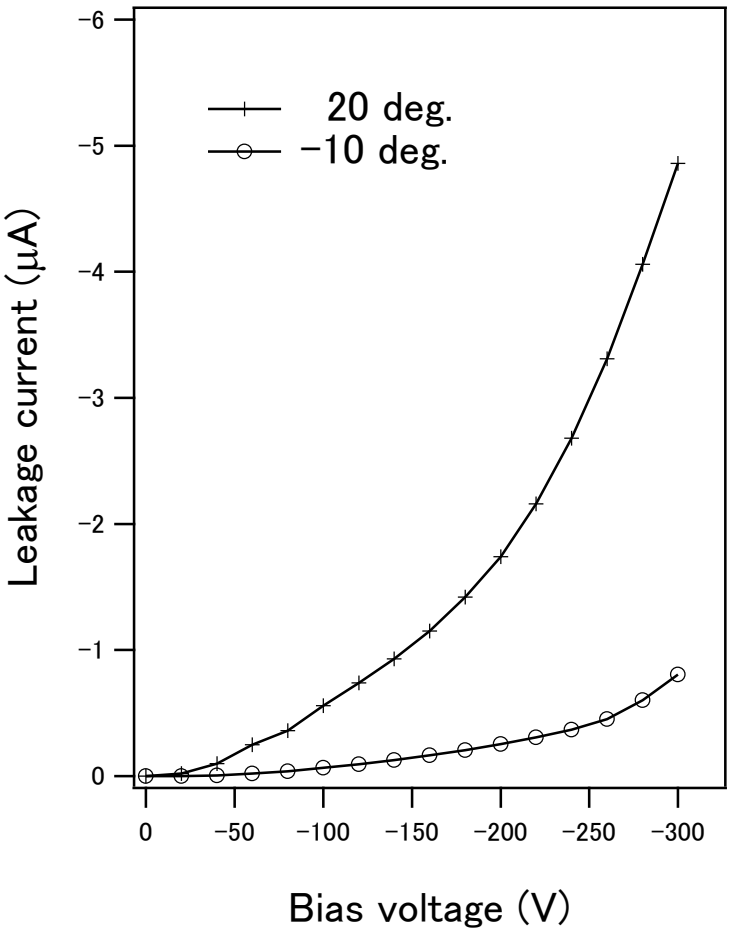
- Temperature was controlled between -20 ~ +25 degree.
- Humidity was downed to less than 30% at room temperature and keep this condition at low temperature.
- Then stability test was carried out by continuous low level threshold scans.

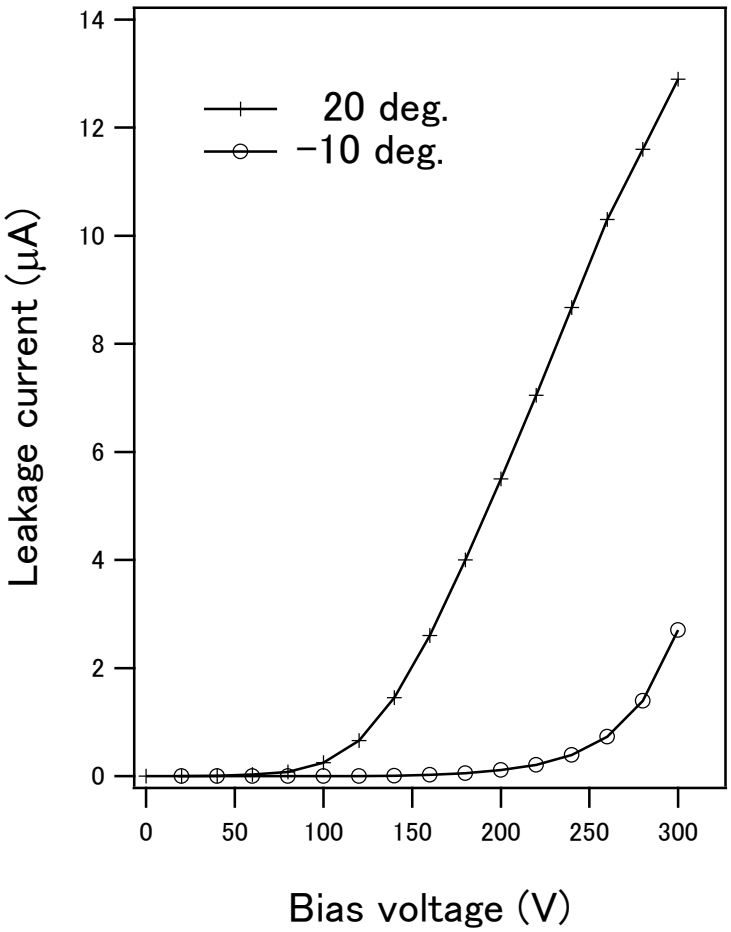


SP8-02 test board

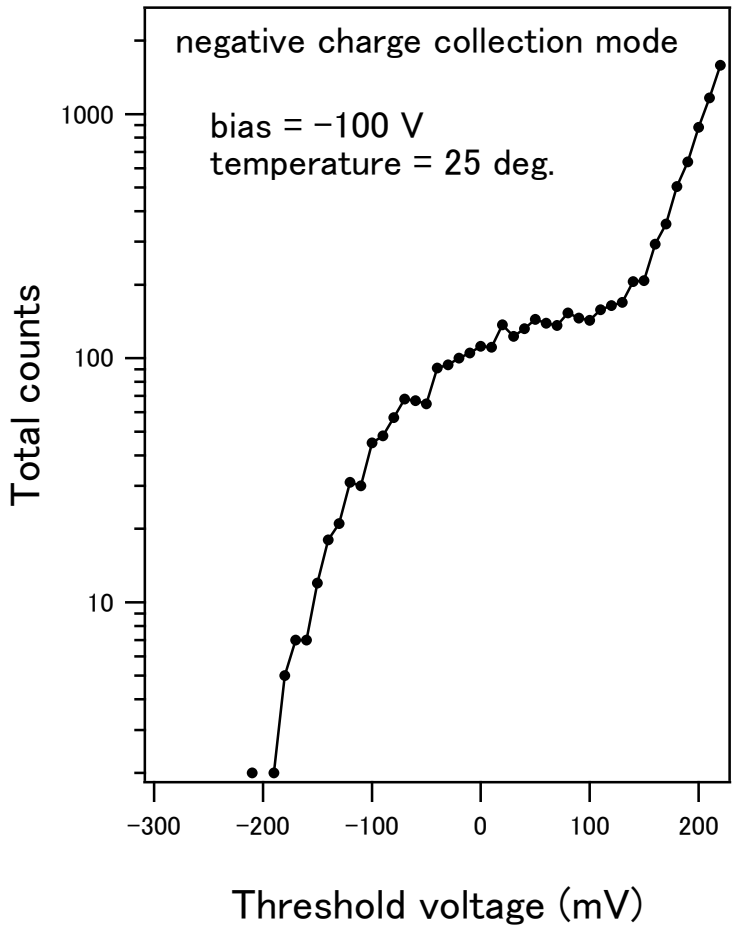
thermostatic chamber

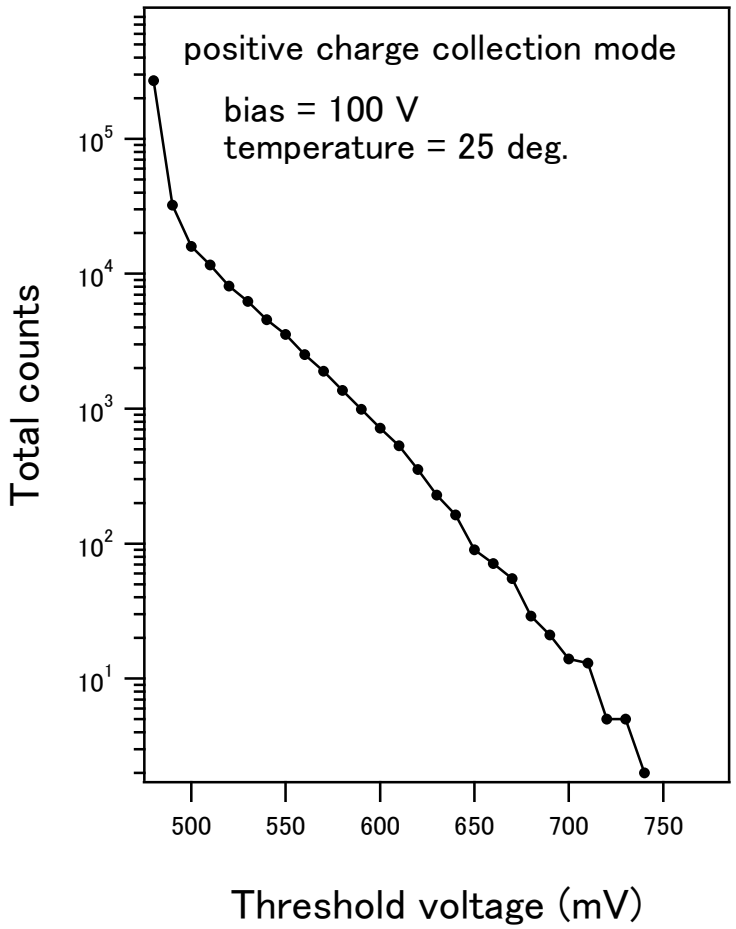
I-V curve with Pt-Ohmic SP8-02 sensor



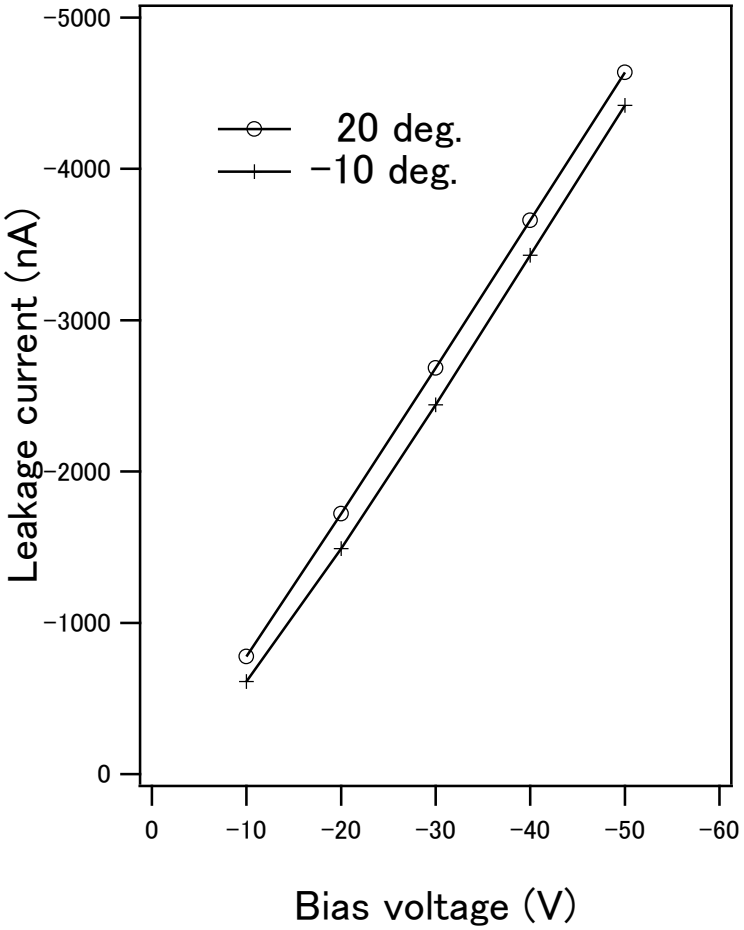


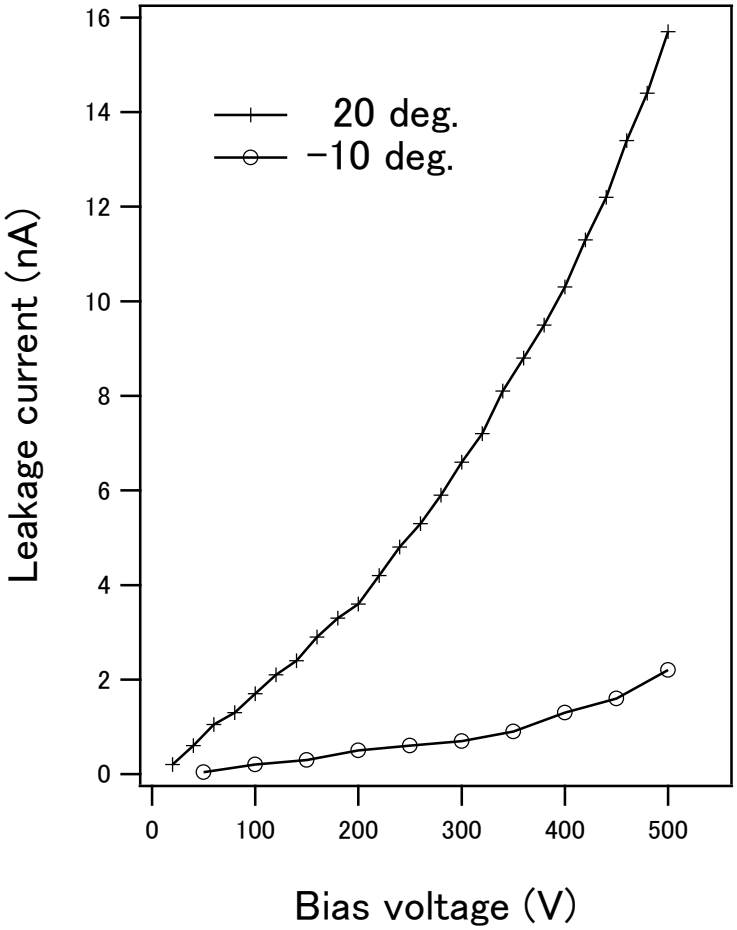
Threshold scan with Pt-Ohmic SP8-02 sensor



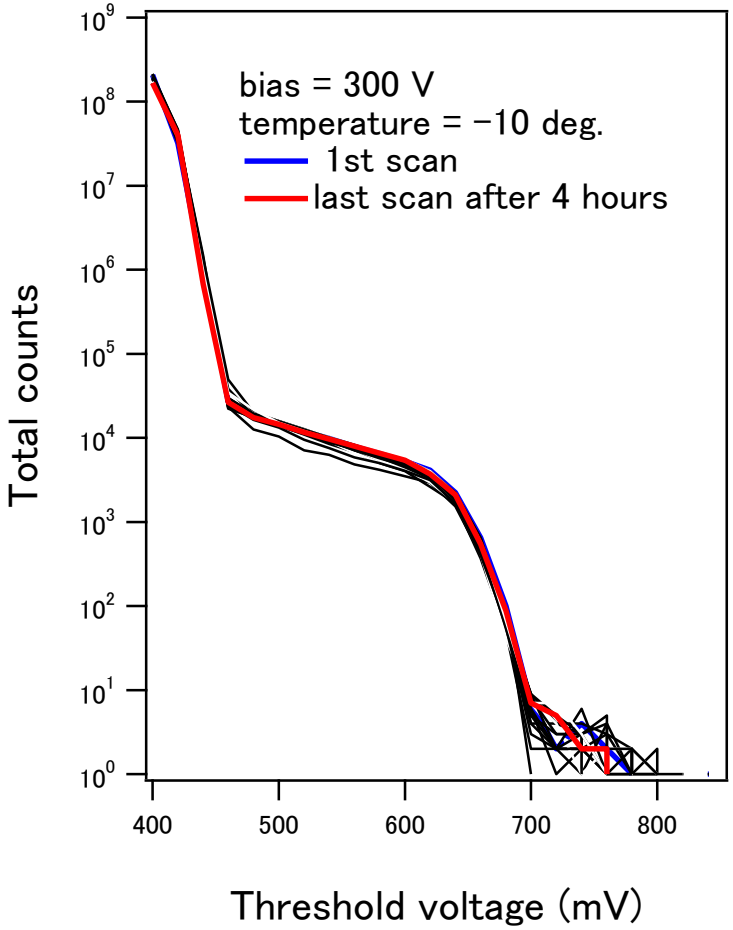


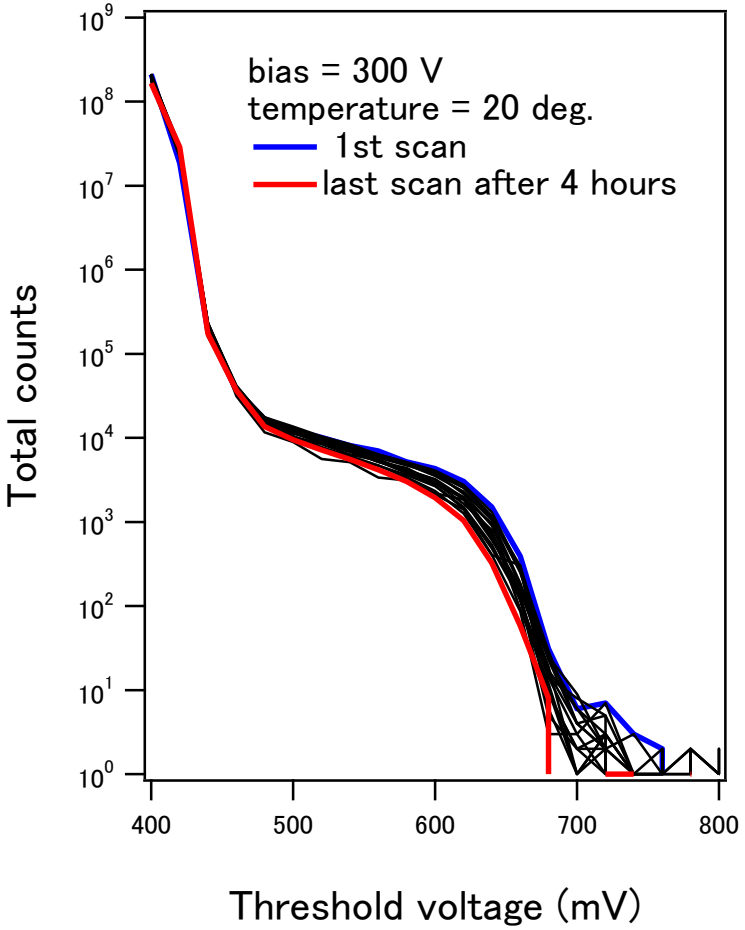
I-V curve with In-Schottky SP8-02 sensor



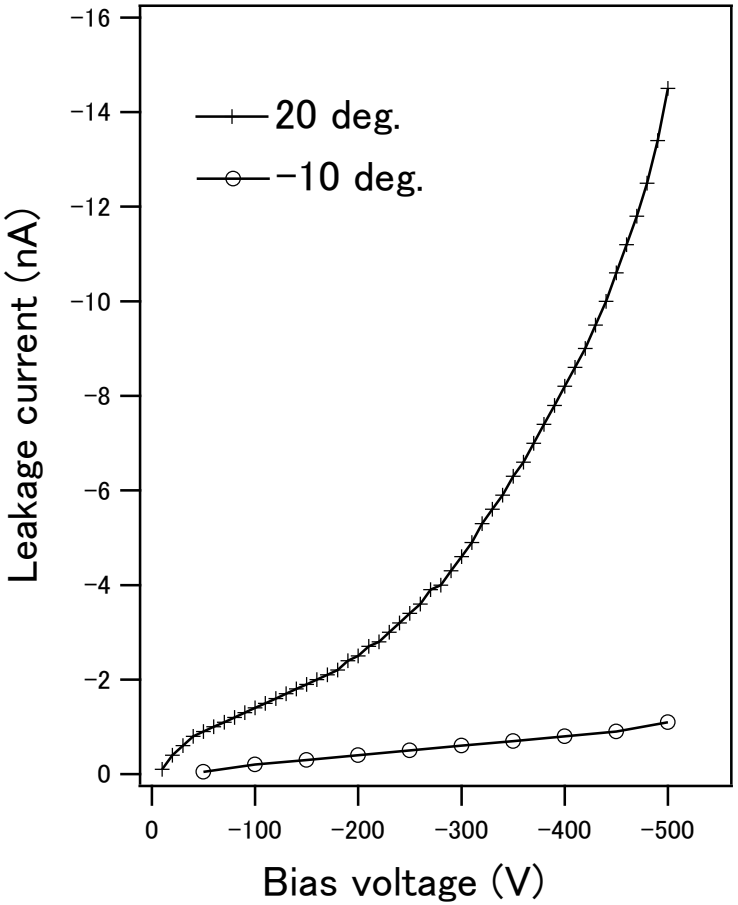


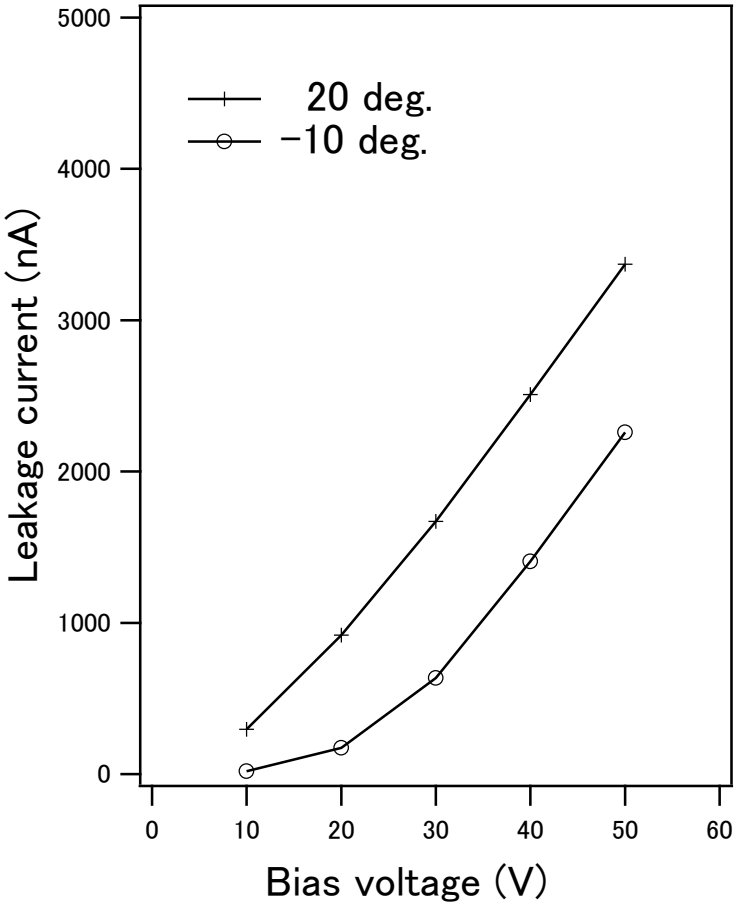
Threshold scan with In-Schottky SP8-02 sensor



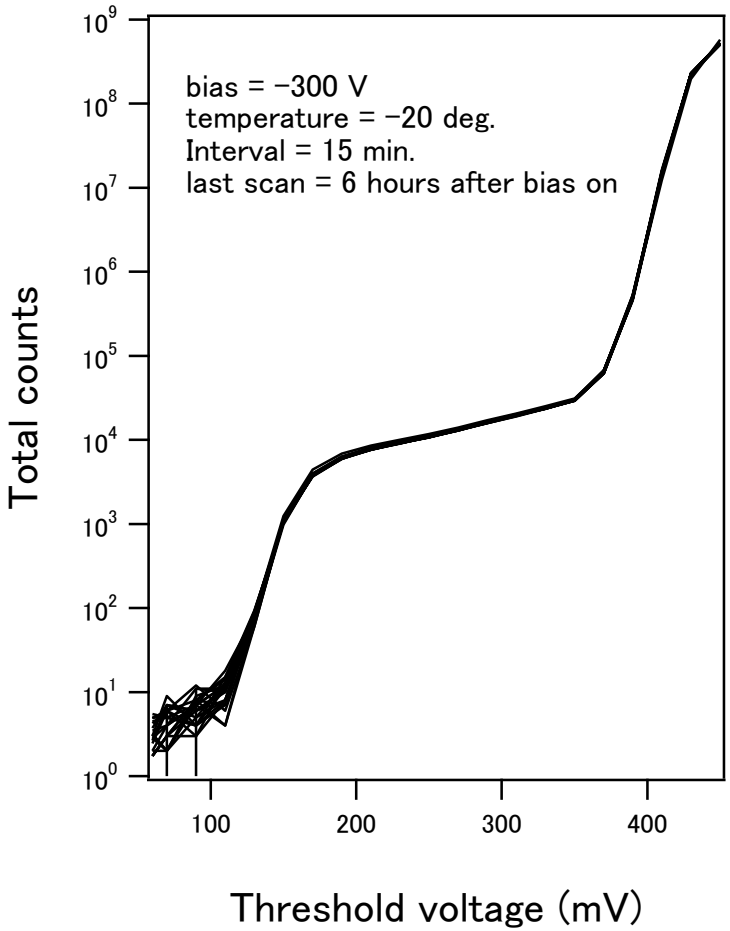


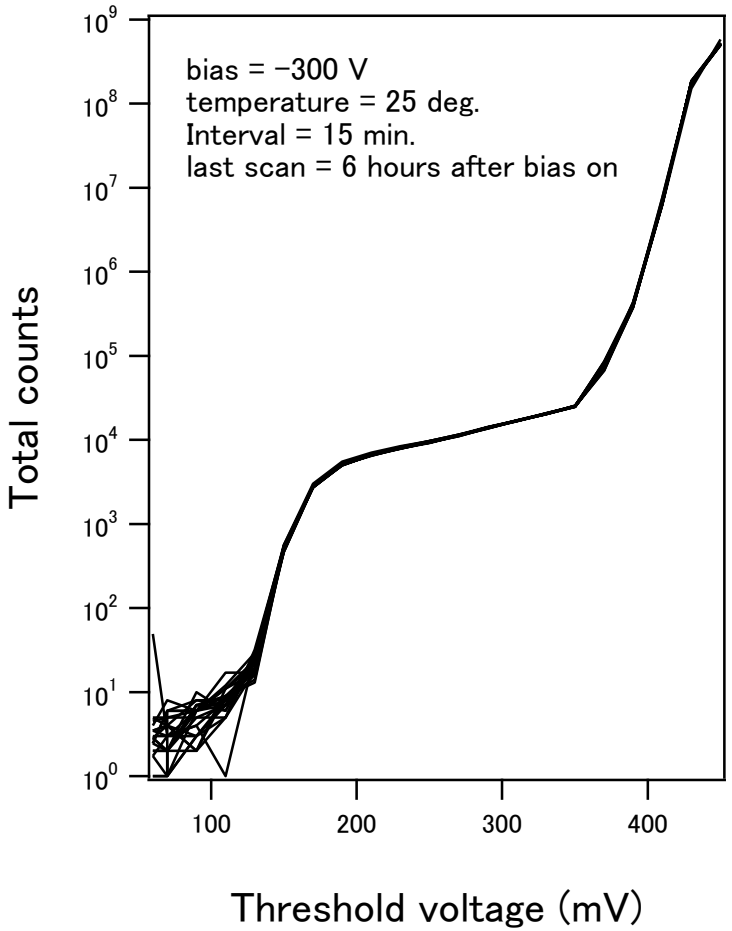
I-V curve with Al-Schottky SP8-02 sensor



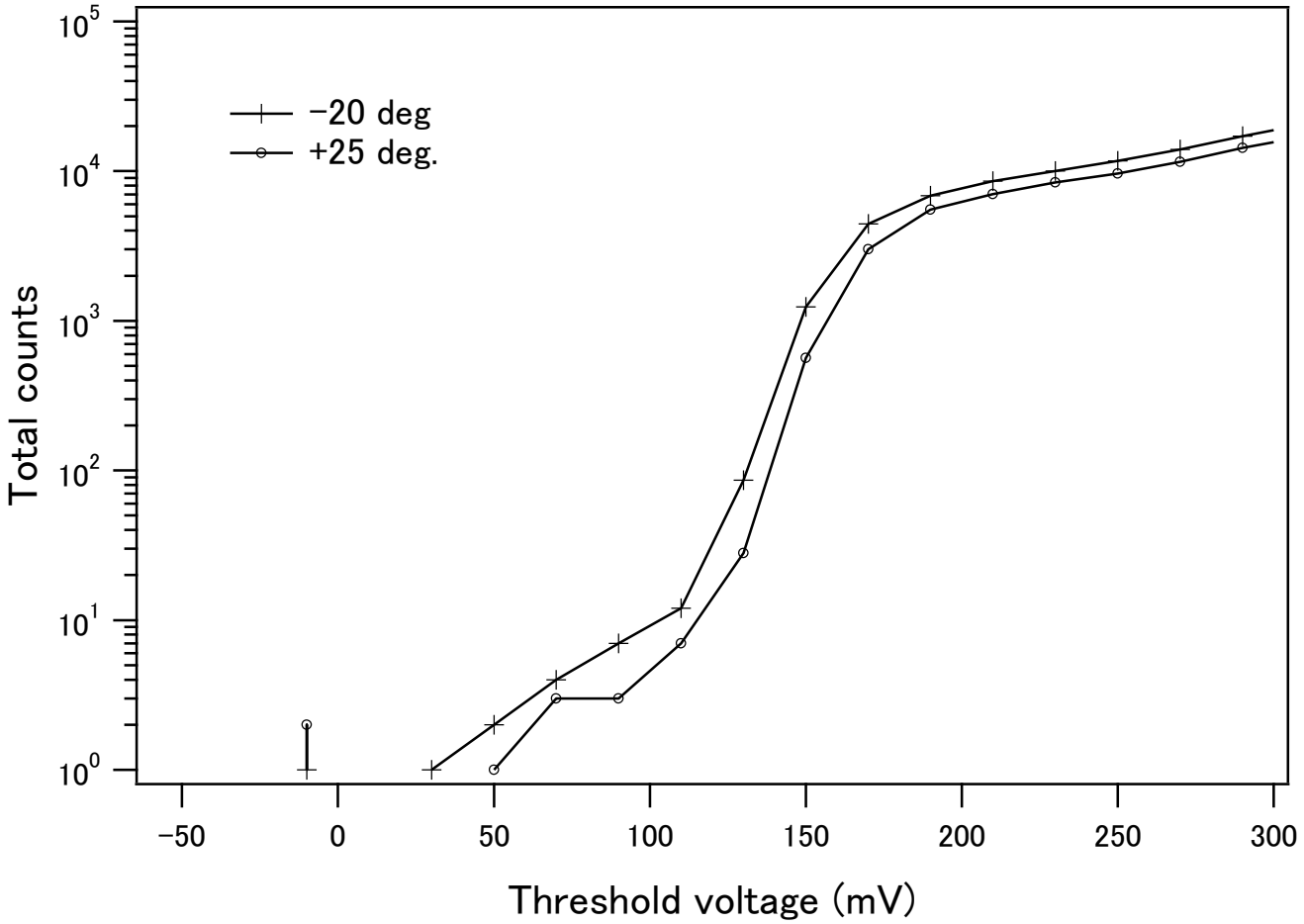


Threshold scan with Al-Schottky SP8-02 sensor

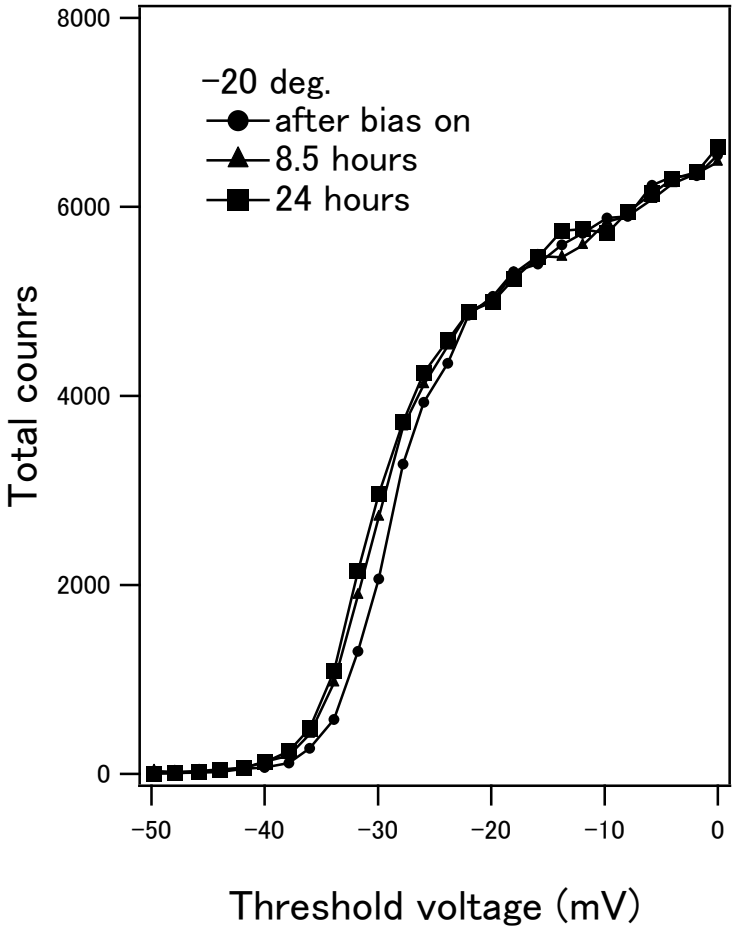


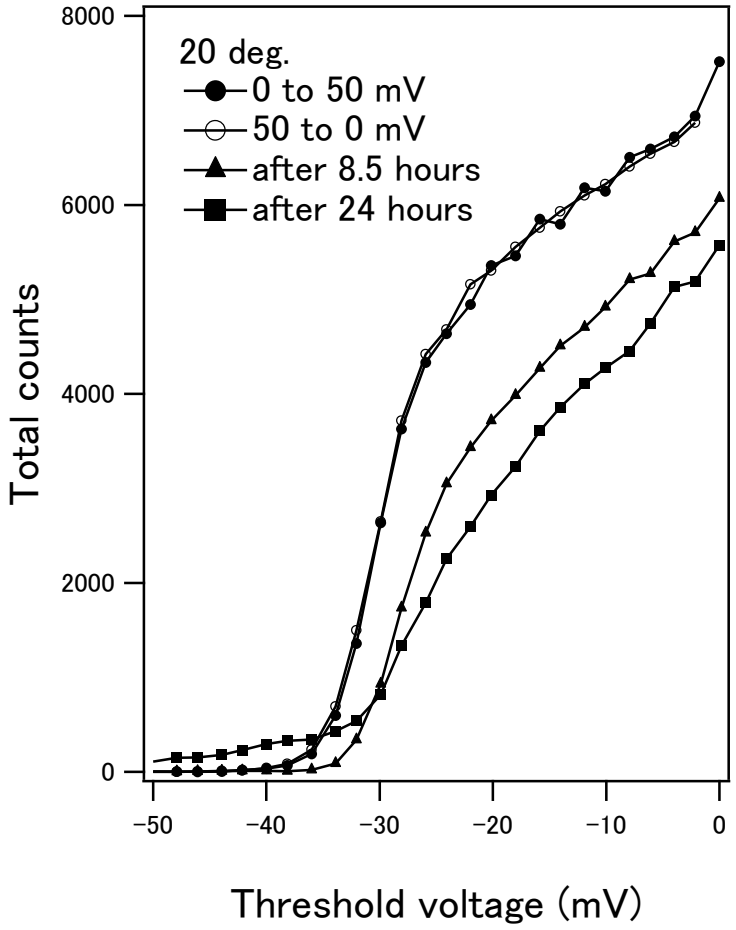


Threshold scan with Al-Schottky SP8-02 sensor



Threshold scan with Al-Schottky SP8-01 sensor





Summary

- PILATUS detector has realized X-ray photon counting imaging and many systems are in use at synchrotron radiation facilities around the world.
- To aim the next generation detector SPring-8 started to develop high energy X-ray photon counting pixel detector with CdTe sensor technology in collaboration with JAXA.
  - ✓Detection efficiency in H X-ray region Si (320μm, 450μm) ⇒ CdTe (500μm)
  - ✓Energy-selected-X-ray diffraction single (lower) level ⇒ window comparator
- The 1st prototype of SP8-01 achieved the expected performance with Al Schottky sensor (electron collection type) in 15 – 120 keV region but polarization effect was found at room temperature.
- In the next step, we developed the 2nd prototype of SP8-02 with Al-Schottky, In-Schottky (hole collection type) and Pt-ohmic (both collection type) sensors.
- In-Schottky sensor worked well as an diode mode but instability was found at room temperature.
- On the other hand, Al-Schottly sensor could function much stably even at 25 degree in a preliminary result.
- The 2nd assemble run is scheduled at the end of this month and we will investigate reliability study with a modulate temperature operation in detail.