CdTe Pixel Detector Development for Synchrotron Radiation Experiments

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Outline

- Introduction
- Requirements for CdTe detector
- Design and fabrication of 3rd prototype, SP8-02B
- Performances of SP8-02B
  - Bumping check
  - ENC
  - Stability of detection efficiency
- Summary and future plan

Introduction

- SPring-8 is a synchrotron radiation (SR) facility with an 8GeV storage ring.

⇒ Experiments which require high energy X-ray (-100keV) belong to the most important experiments in SPring-8.

- Target experiments:
  - High energy X-ray diffraction from 30 to 120 keV
  - High energy resonant X-ray inelastic scattering around 20 keV
  - White X-ray beam diffraction

Introduction

Detector that is suitable for SPring-8 is

- A photon-counting large-area hybrid pixel detector, like PILATUS.

The detector should have:

- High sensitivity in high energy X-ray region (15 - 100keV)

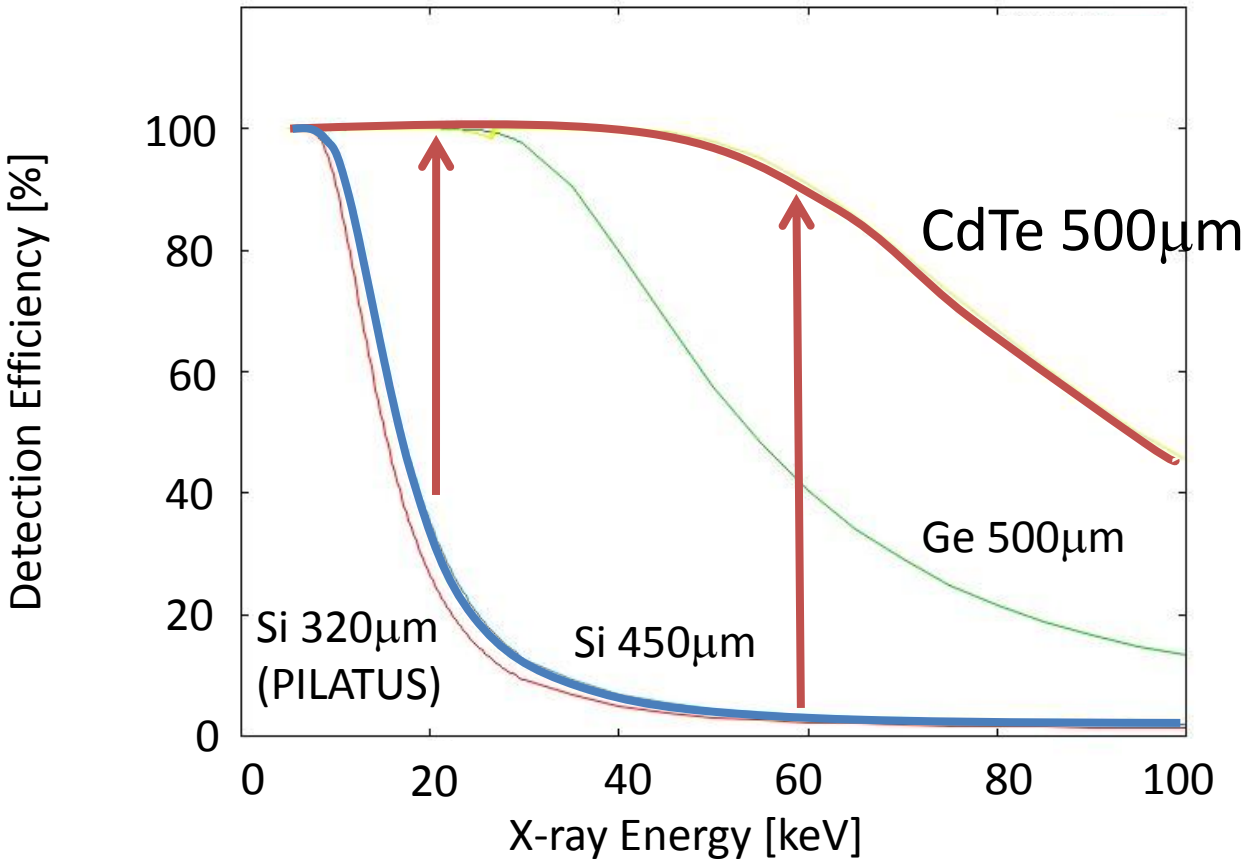
  ⇒CdTe sensor

- Function to cut high energy. This is important in…
  - High energy X-ray diffraction… because:
    X-ray beam from monochromator contains high harmonic order X-ray
  - High energy resonant X-ray inelastic scattering:
    Cosmic ray is comparable to X-ray signal
  - White X-ray beam diffraction:
    Limiting energy range ease the analysis

  ⇒Readout with a window-type discriminator

Introduction

- Detection Efficiency of Sensors
  - CdTe has almost 100% detection efficiency up to 40keV, more than 50% at 60-100 keV where Si has only 1.5%



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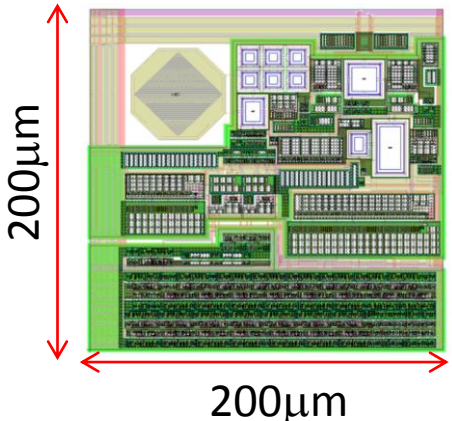
  ⇒Readout with a window-type discriminator

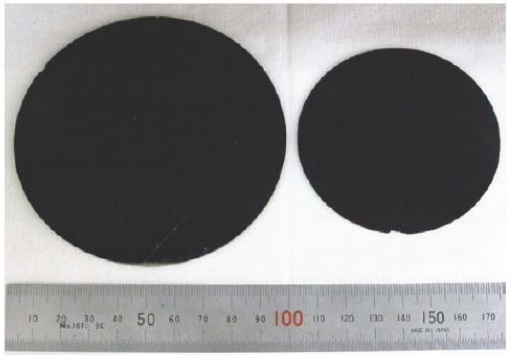
Introduction

PIXEL2012 Sep 3-7 2012, Inawashiro,
T. Hirono JASRI/SPring-8

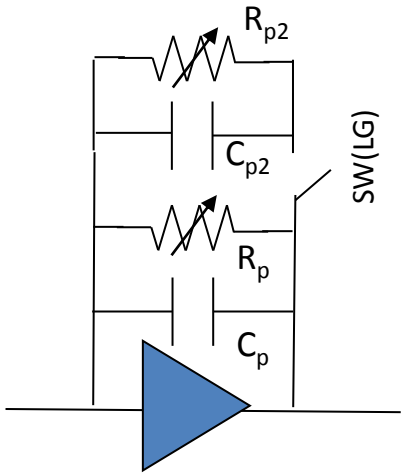
Design specification for CdTe detector in SPring-8

- Pixel size : 200 μm x 200 μm
- Size of module: 40 mm x 40 mm (10 mm x 40 mm)
- Energy range: 15- 40 keV, 30 – 100 keV with a gain switch
- Maximum counting rate : 10^7 count/sec
- Window-type discriminator
- Noise count : < 1 count/hr/mm^2
- High stability





ACRORAD

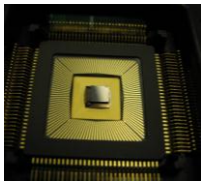


Introduction

- Steps to realize a large area imaging detector

SP8-01

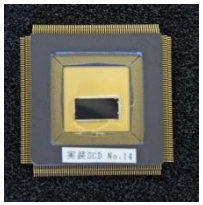
16 x 16 pix
3.2 x 3.2mm^2



Small Single chip

SP8-02

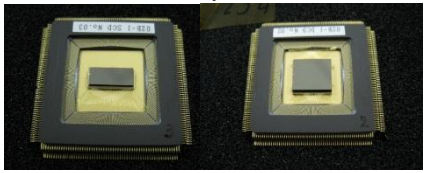
20 x 50 pix x 1 chip
4 x 10mm^2



Medium size
3-side buttable chip
ASIC is the same as
SP8-01

SP8-02B

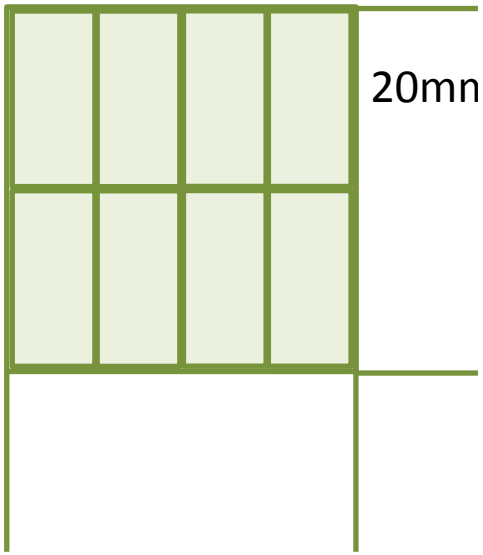
20 x 50 pix x 1,2 chips
4 x 10mm^2, 8 x 10 mm^2



Multi-chip module
Optimized ASIC

20 x 50 pix x 8 chips
To apply to some SR experiments
that do not require large detection area

SP8-03 (final design)



Requirements of SP8-02B

SP8-02B was developed to meet the design specifications that the former prototypes could not achieve.

The former prototypes achieved..

- Pixel size : 200 μm x 200 μm
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- Energy range: 15- 40 keV, 30 – 100 keV with a gain switch
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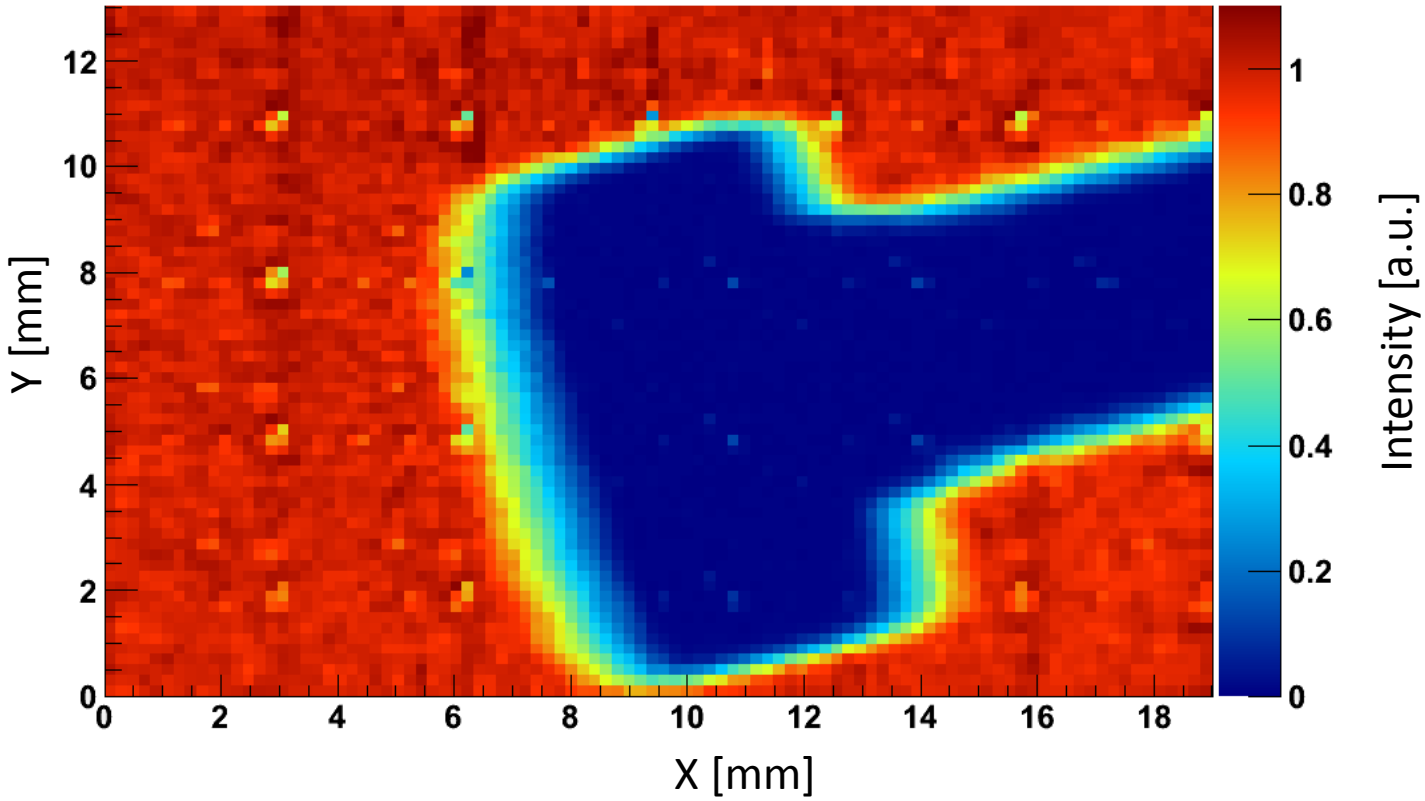
- High stability

Pixel Size

- X-ray shadow image with SP8-01 detector



Pt/CdTe/Al-pixel
Gain : High Gain
HV: -300V
Exposure time : 10s
Energy: 32KeV
Combined image
with 4 x 6 positions

SP8-01(pixel size of 200 x 200 um^2) worked as an imaging detector

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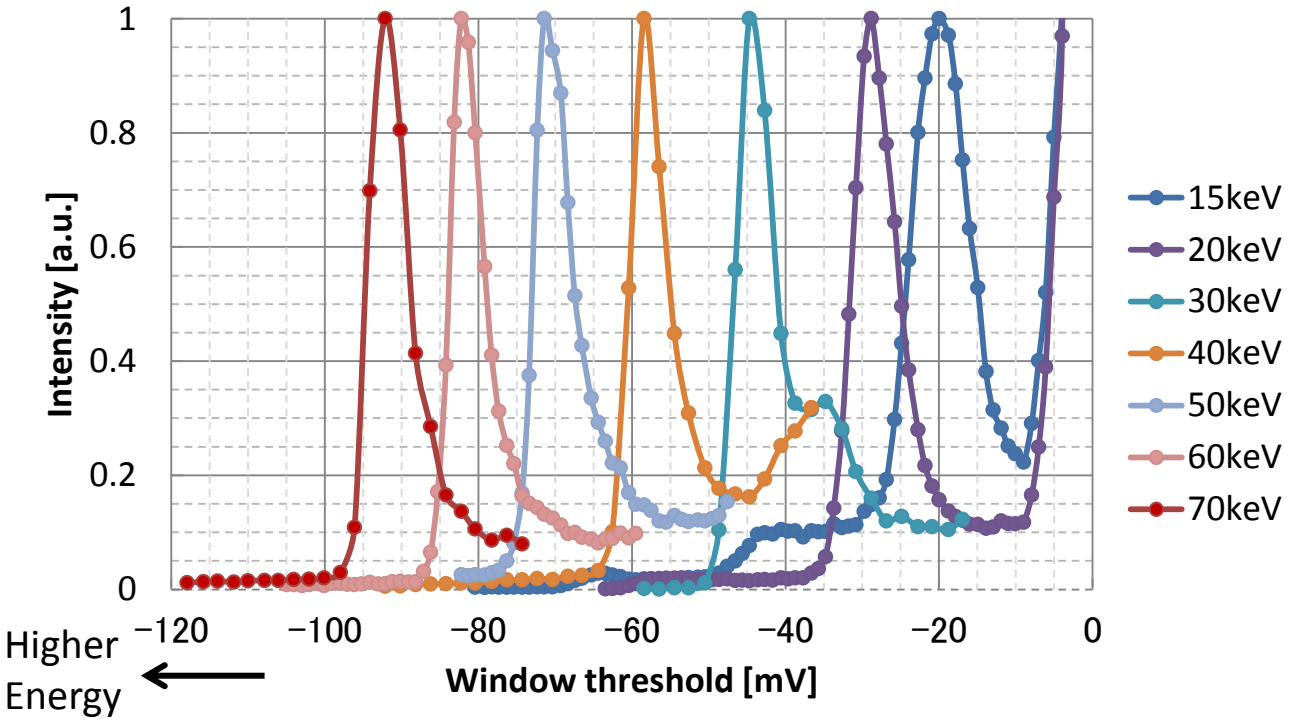
- Noise count : < 1 count/hr/mm^2
- High stability

Window Discriminator

- Threshold scan of window-type discriminator with SP8-01 detector
  - Monochromatic X-ray beams of various energies were irradiated to the SP8-01 detector.



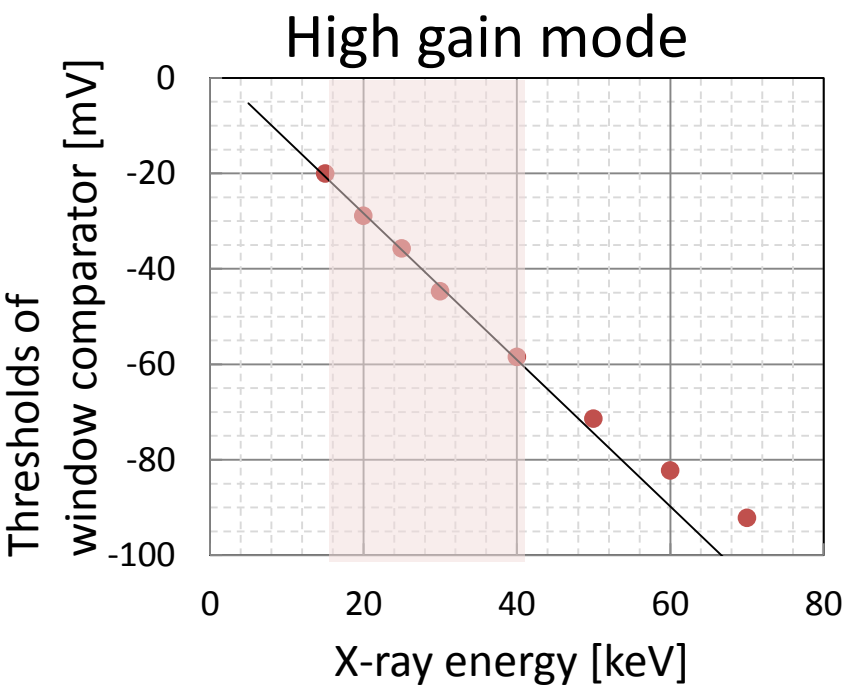
Pt/CdTe/Al-pixel
Gain : Hig Gain
HV: -300V
Exposure time : 1s
Window width :5mV (3.2keV)
Beam intensity : attenuated to less than 10^5 photons/pixel/sec

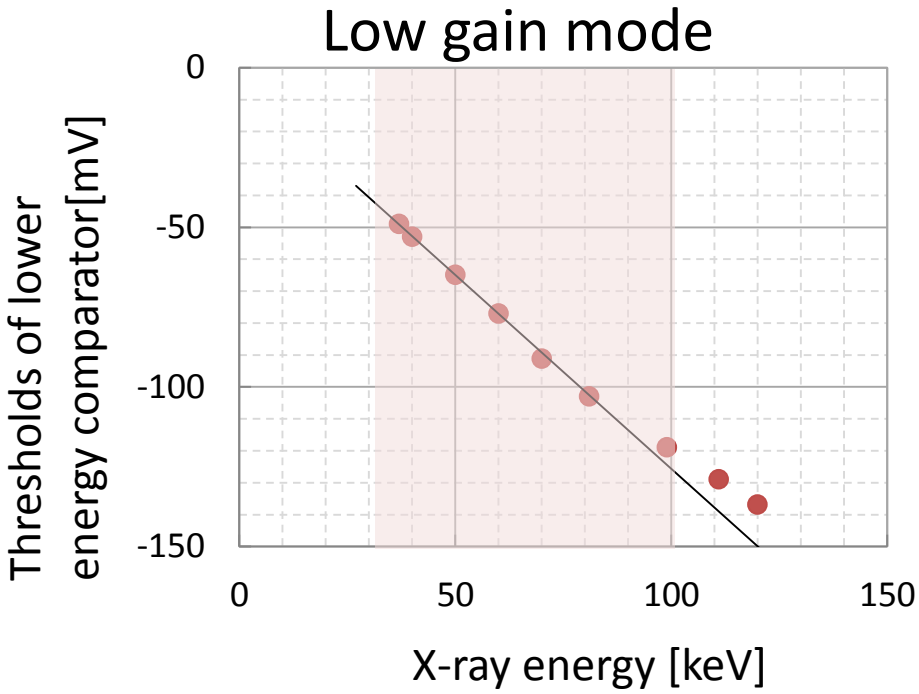
Intensity was normalized at peak.

The window-type discriminator of SP8-01 worked fine

Energy Range

- Energy linearity in 15 - 100 keV with SP8-01
  - The readout has 2 gain modes, 15-40 keV and 30-100keV





SP8-01 had the energy linearity of > 95% in range of 15 – 100 keV.

Requirements of SP8-02B

SP8-02B was developed to meet the design specifications that the former prototypes could not achieve.

The former prototypes achieved..

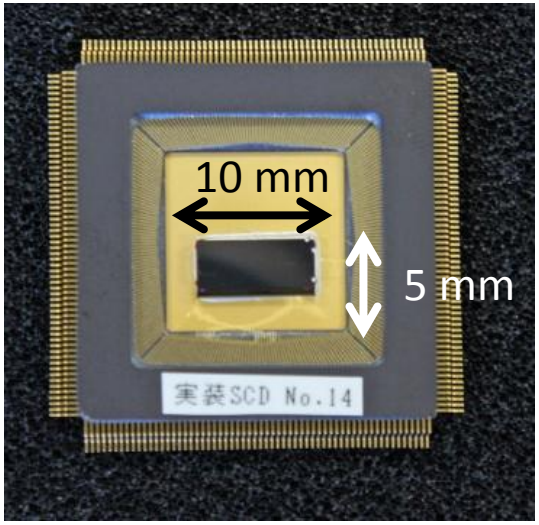
- Pixel size : 200 µm x 200 µm 
- Window-type discriminator 
- Energy range : 15- 40 keV, 30 – 100 keV 
- Size of module: 40 x 40 mm (10 x 40 mm)
- Maximum counting rate : 10^7 count/sec
- Noise count : < 1 count/hr/mm^2
- High stability

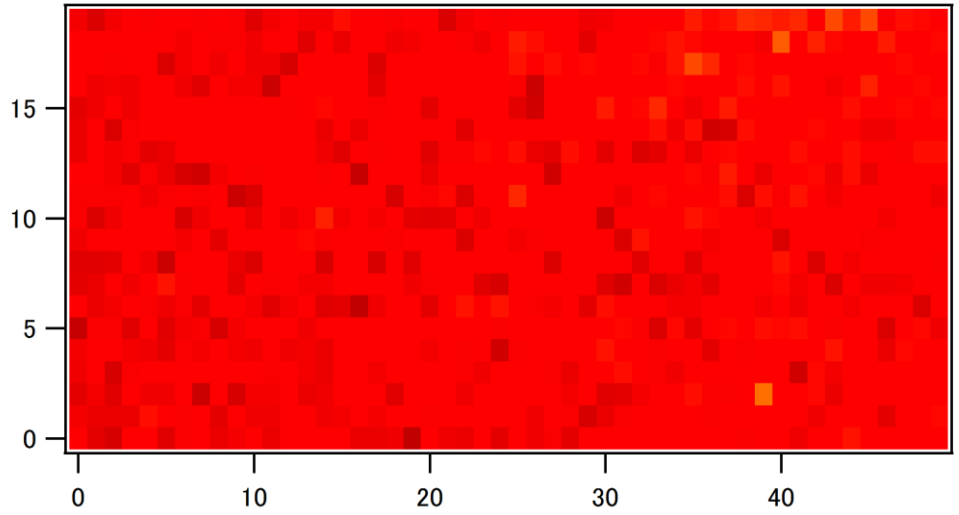
Detector Size

- Bonding of SP8-02
  - CdTe sensor were bumped to ASIC by In/Au bumping

SP8-02 (size of 10 mm x 5 mm) was fabricated without any defective pixel

Sensor: Pt/CdTe/pixelated Al
Source: ^{241}Am (60 keV)
Exp. time: 10 sec
Readout: SP8-02
Bonding: Au/In stud bonding





Requirements of SP8-02B

SP8-02B was developed to meet the design specifications that the former prototypes could not achieve.

The former prototypes achieved..

- Pixel size : 200 µm x 200 µm
- Window-type discriminator
- Energy range : 15- 40 keV, 30 – 100 keV
- Size of module: 5 x 10 mm 40 x 40 mm (10 x 40 mm)

Requirements of SP8-02B

The specification for the 3rd prototype, SP8-02B, that were not achieved by the former prototypes:

- Size of module: 8 x 10 mm
- Maximum counting rate : 10^7 counts/sec

  ⇒Settling time of amplifier was > 1usec (SP8-02) 
- Low noise count : < 1 count/hr/mm

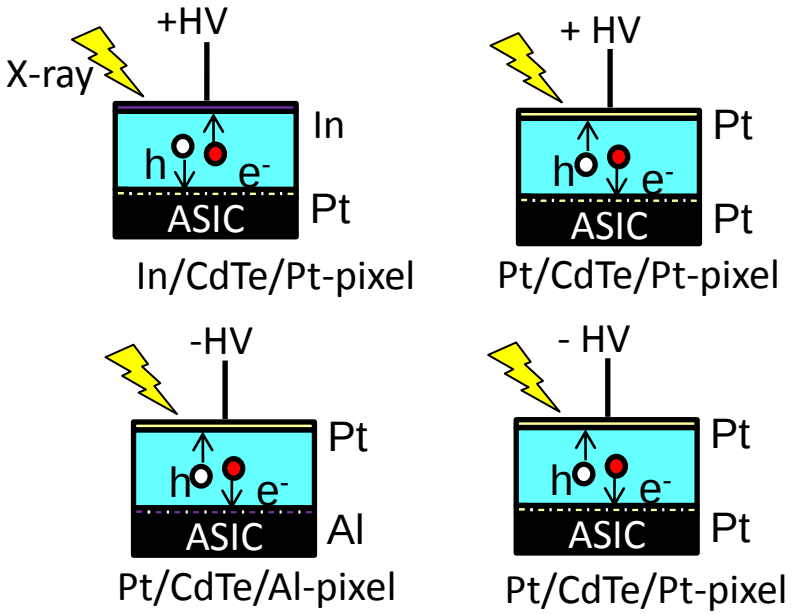
  ⇒SP8-01 had 153 count/hr/mm at 20 keV 
- High Stability
- Good uniformity of threshold-level

  ⇒Dispersion of threshold-level between pixels was very large (SP8-02) 

Design of SP8-02B (Sensor)

- Basic Properties of CdTe sensors

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



- CdTe has a large density and atomic number but a short lifetime compared to Si.
- Ideally, electrons, which have a larger mobility and a longer lifetime than holes in CdTe, have to be collected for high energy resolution. In particular the Schottky type detector functions as a diode device, which reduces the leakage current.

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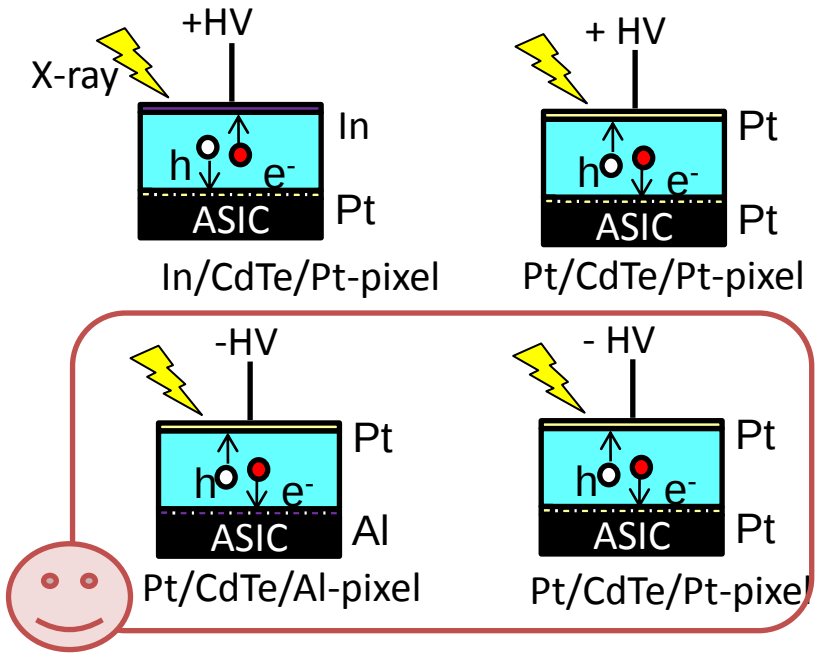

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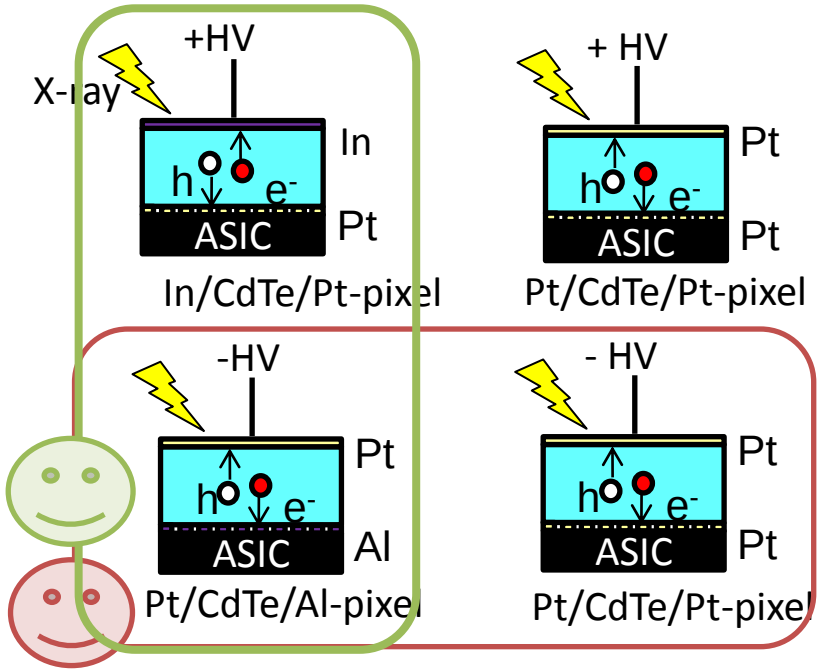

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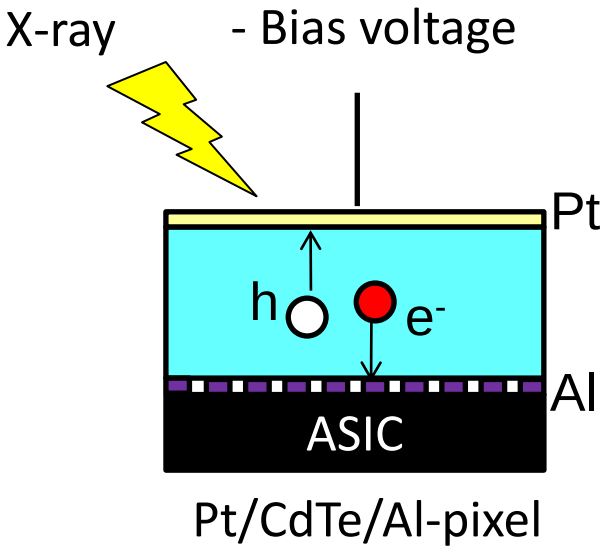
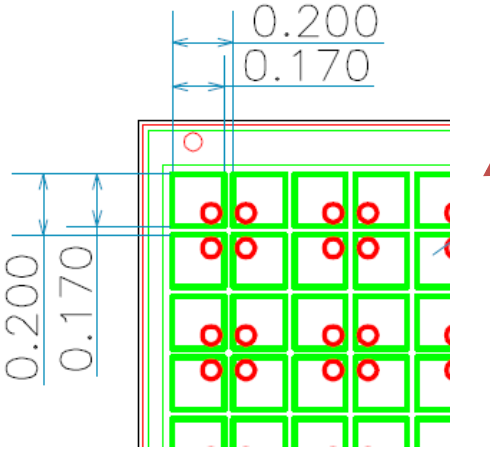
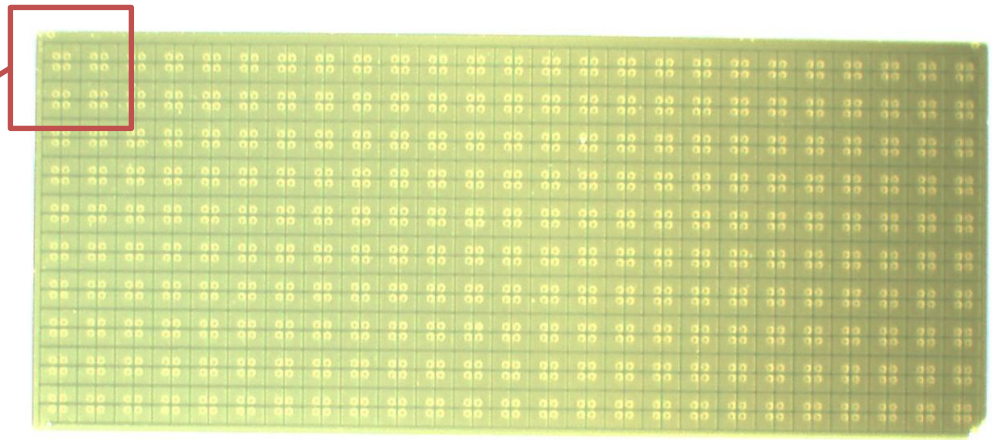


Pt/CdTe/Al-pixel

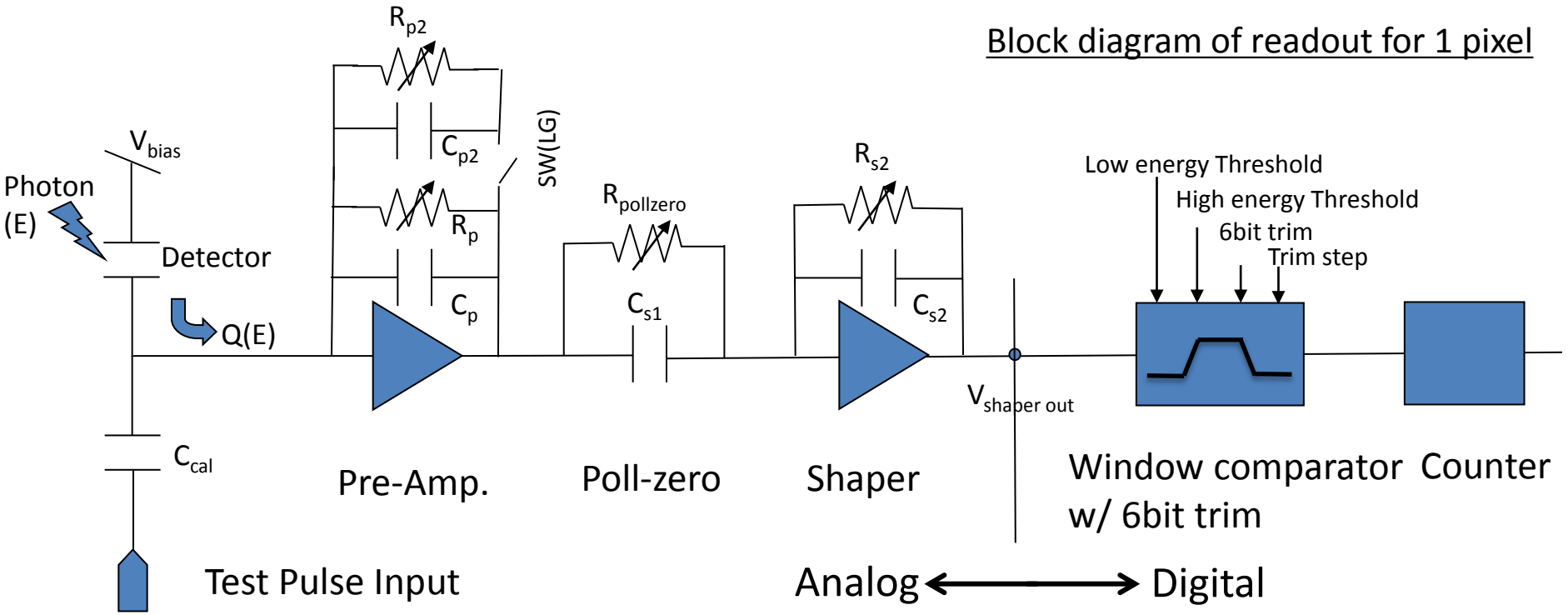
- In the previous work, we have measured that Pt/CdTe/pixelated-Al had larger time-stability and less leakage current.
- The electrodes were Al-Schotky on the pixelated side and Pt on the bulk side
- We have designed and fabricated sensors with the pixel size of 200 µm x 200 µm. The matrix is 20 x 50 pixels and 40 x 50 pixels. The process was performed by ACRORAD Co., Lt





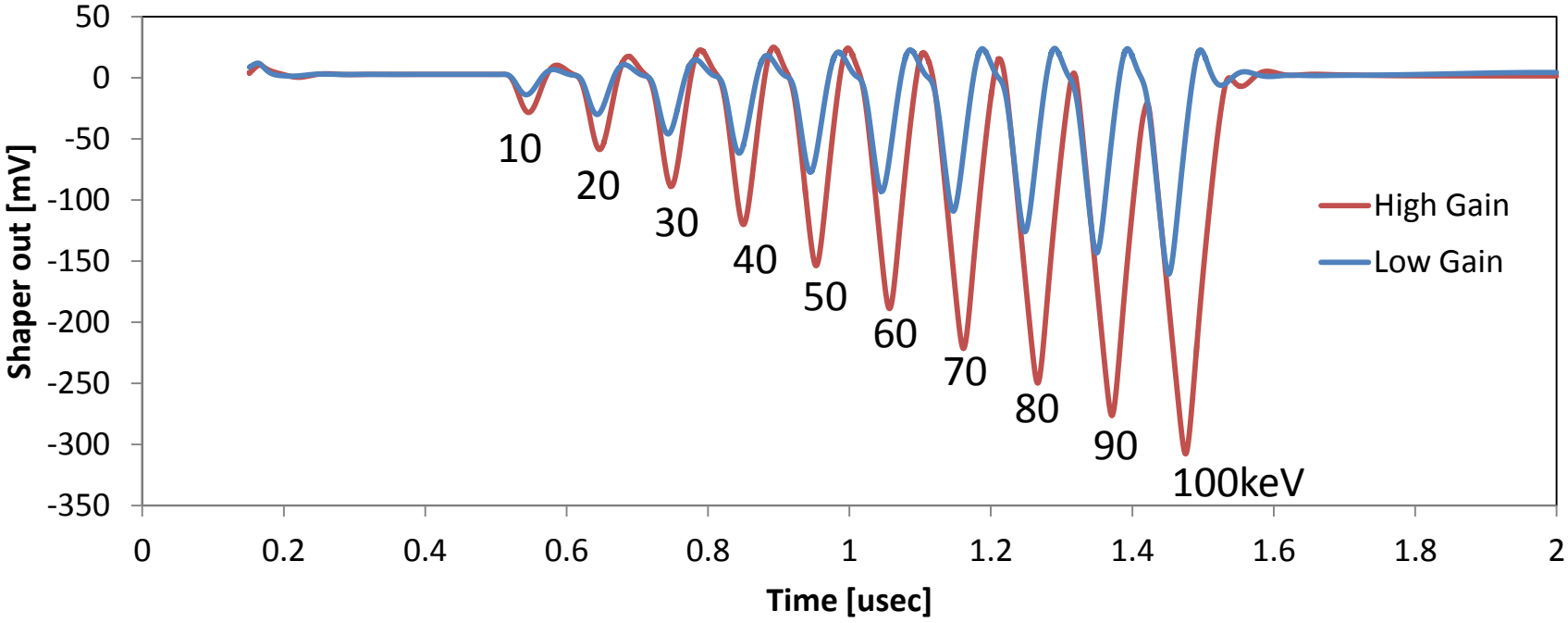
Design of SP8-02B (ASIC)

- To realize the specifications, the custom-designed ASIC for SP8-02B was developed
  - More power and ground lines
  - Increased gain of amplifiers
  - Unused switches were eliminated
  - Possibility to adjust the step of offset trim
  - Advanced poll-zero circuit



Design of SP8-02B (ASIC)

- Result of a simulation of the analog amplifier

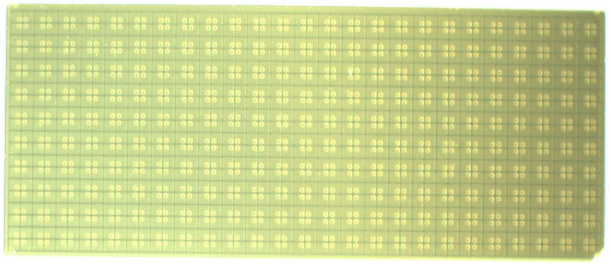


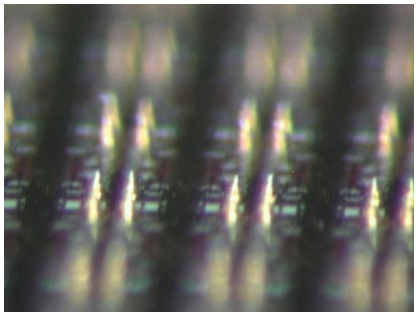
ASIC was simulated with the input charge corresponding to 10 -100keV in 100nsec

⇒All the parameters of the circuit were fixed to match the requirements.

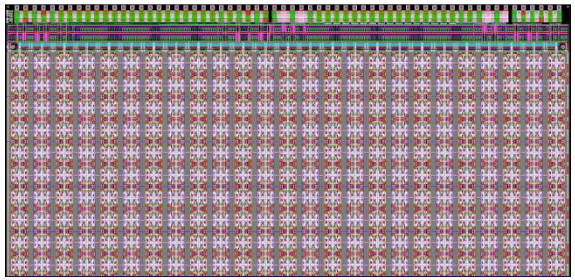
Fabrication of SP8-02B

SP8-02 CdTe sensor



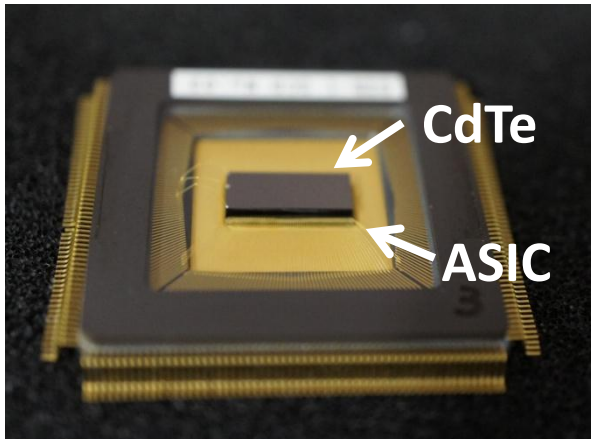


SP8-02B ASIC

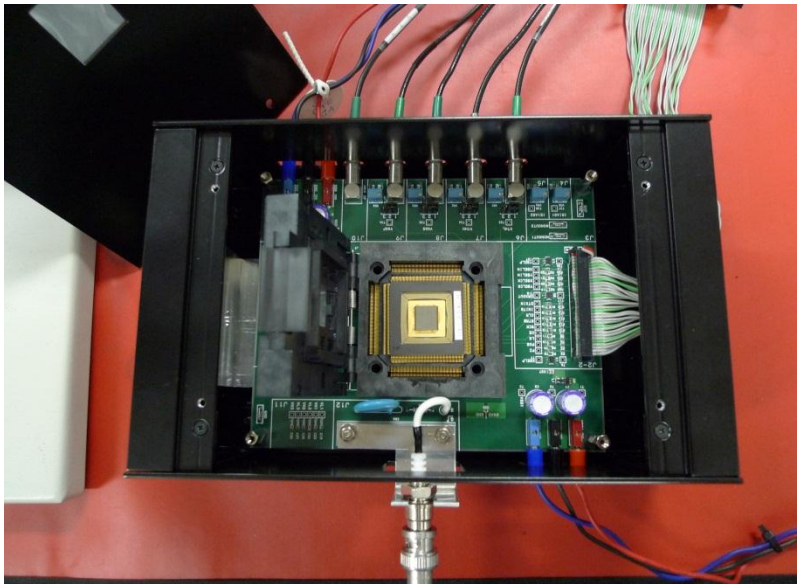


In/Au-stud bonding

SP8-02B detector chip



Test board



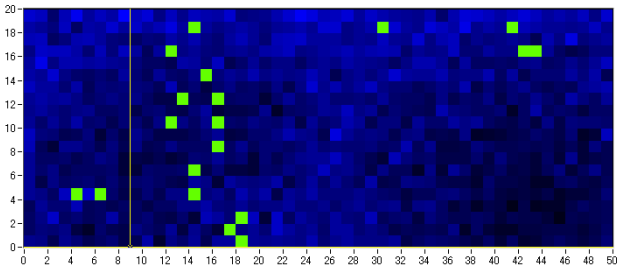
Performances of SP8-02B

Bonding of SP8-02B

5 single-chips, 3 dual-chips were fabricated on Aug 22, 2012
A single chip detector and a dual chip detector were checked by ^{241}Am (60keV).
A pixel without any signals at the lower threshold of 30keV counted as a defective pixel

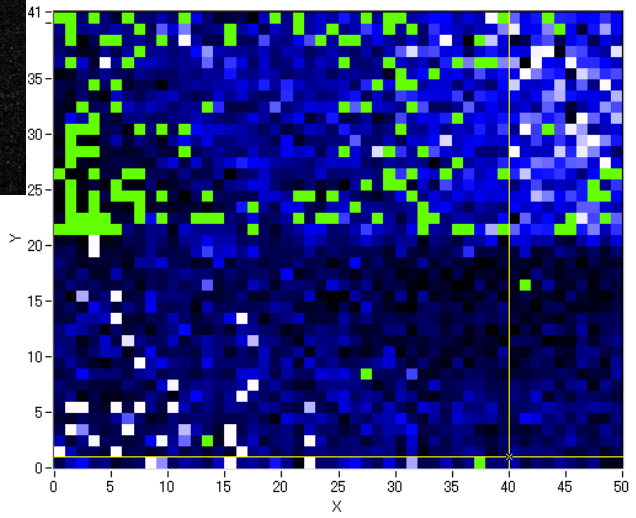
SP8-02B

Defective pixels



98% (19 defective pixels)

SP8-02B Dual Chip Detector

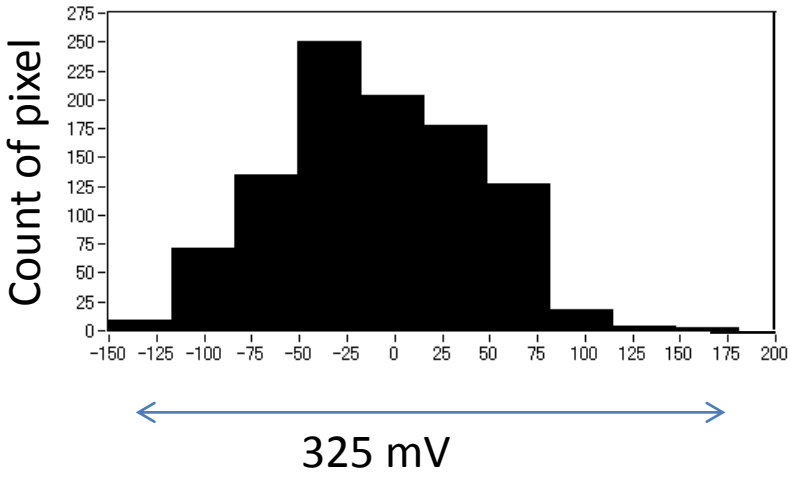


93% (143 defective pixels)

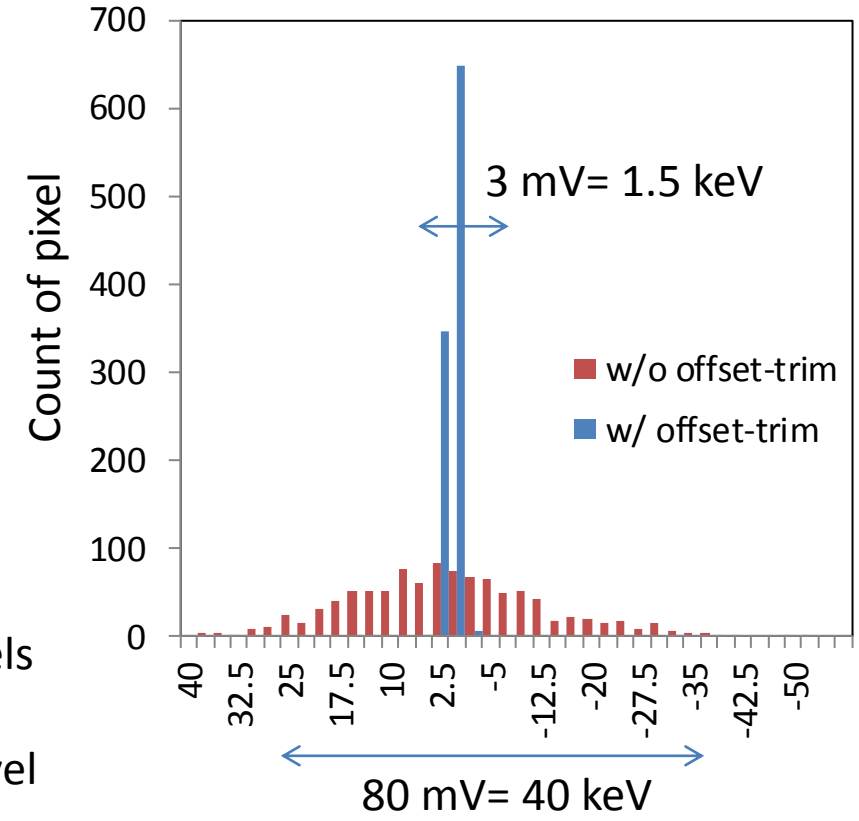
Performances of SP8-02B

- Dispersion of the threshold-level

SP8-02 (old ASIC)



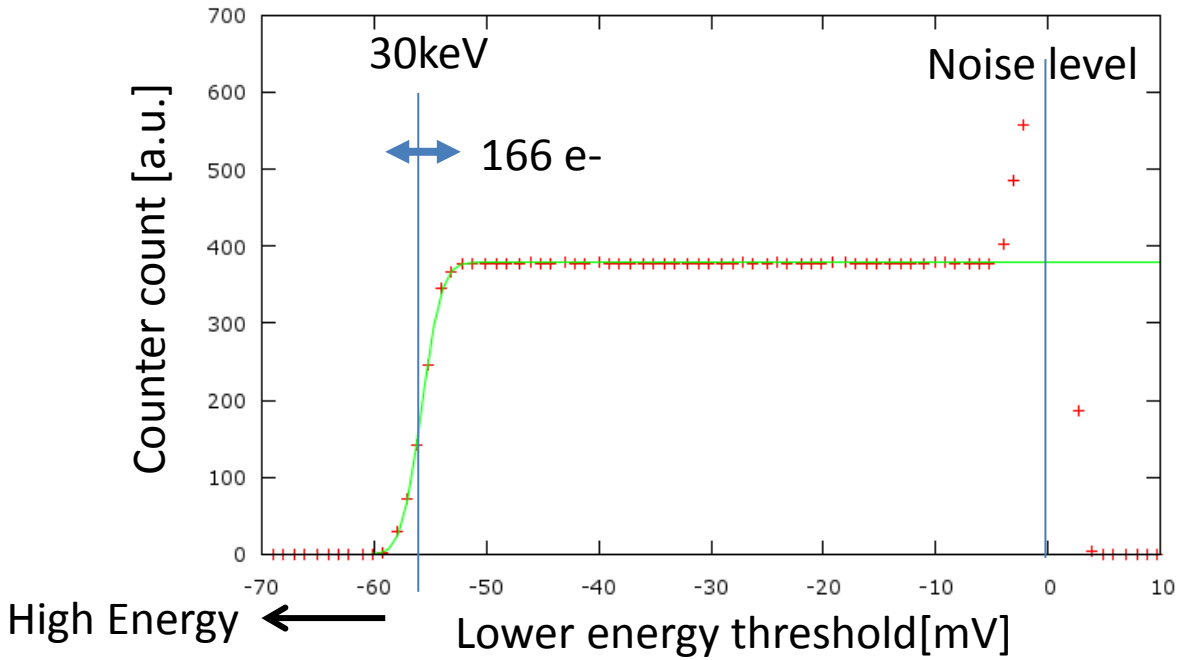
SP8-02B (new ASIC)



Dispersion of the threshold-level between pixels is much smaller than that of SP8-02
The offset-trim unifies the pixel's threshold-level as small as 1.5 keV

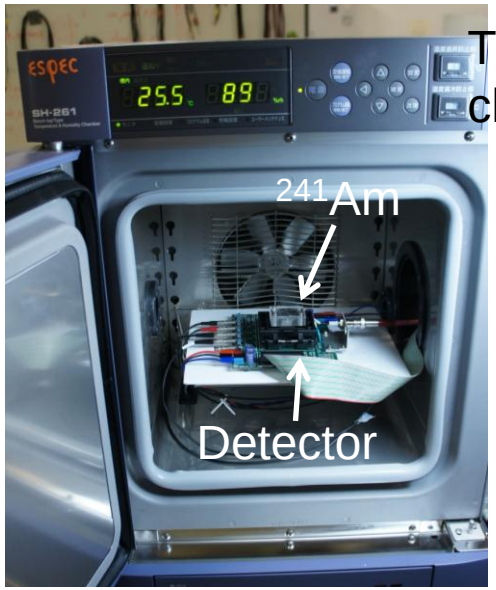
Performance of SP8-02B

- Equivalent Noise Charge with sensor
  - An s-curve of test pulse corresponds to 30keV by scanning the lower-energy threshold with higher-energy threshold open
  - The s-curve edge slop of test pulses ⇒ENC =166 e-
    cf SP8-01(old ASIC) ENC=360e-
  - Noise count ∝ $Exp(-1/ENC^2)$ ⇒ < 0.1 count/hr/mm^2 can be expected

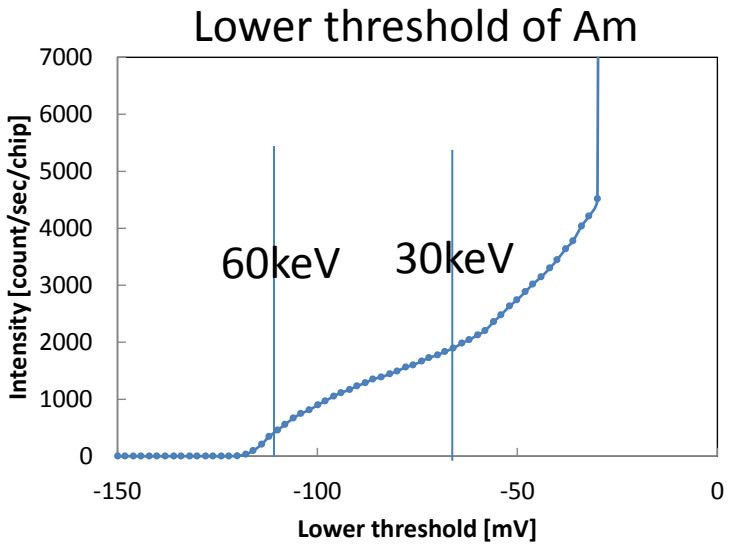


Stability Test

- Stability test was performed with a SP8-02B single chip irradiated by ^{241}Am
- Temperature was controlled between -20 ~ +26 degrees.
- Humidity was downed to less than 30% at the room temperature and kept at this condition at the low temperature.
- Images with the lower-energy threshold at 30 keV were taken continually. The exposure time was 10 sec.



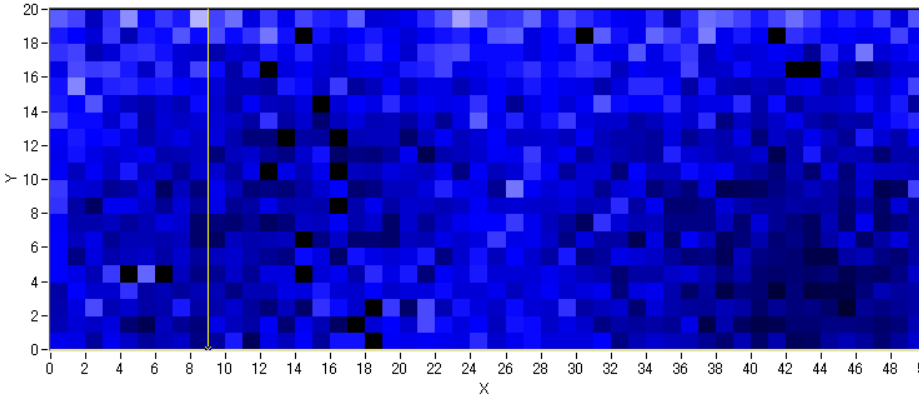
Thermostatic chamber



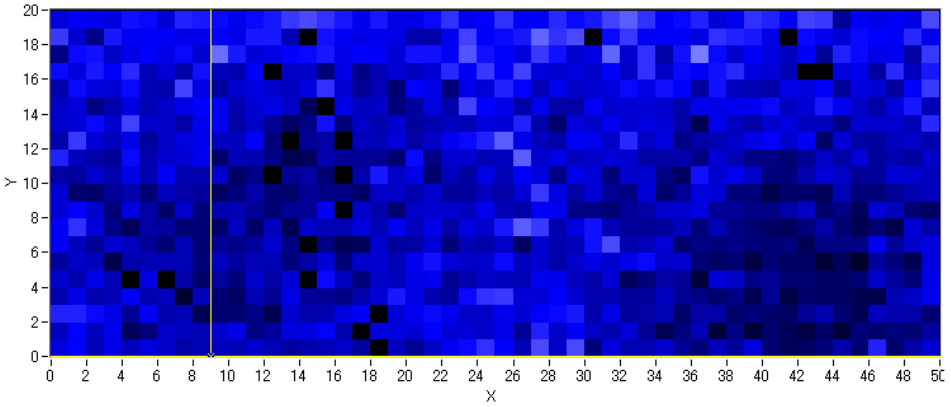
Stability Test

- Stability of the single chip detector at the room temperature (26C)
  - Sensitivity degrades
  - Noisy pixels emerge

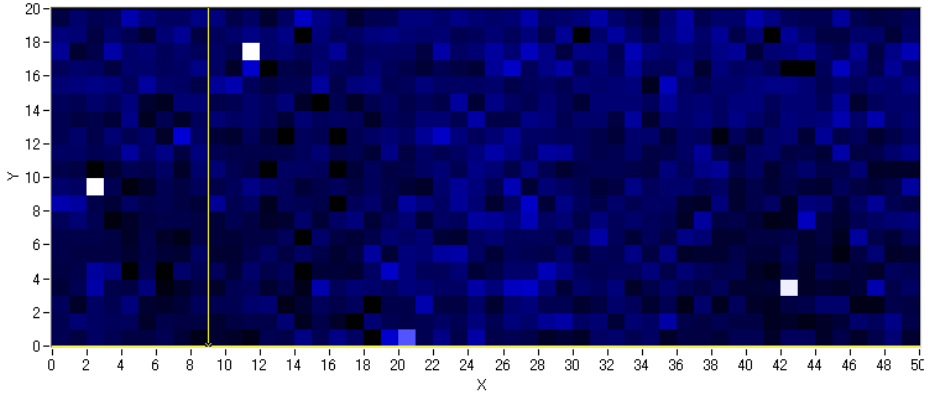
0hr after HV on



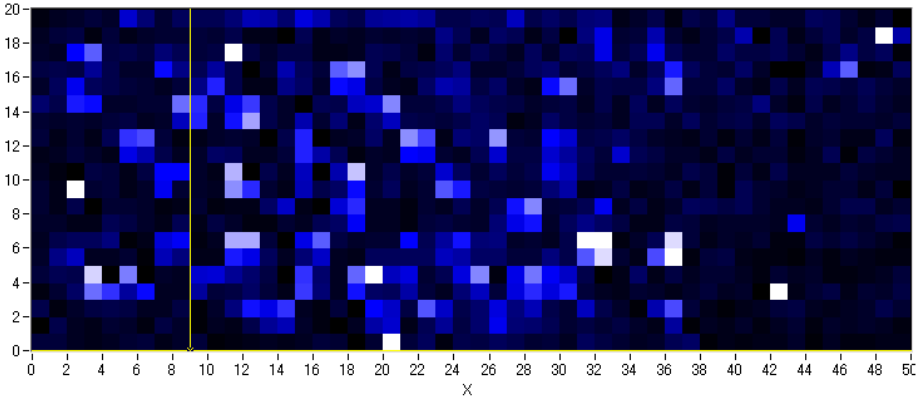
1hr after HV on



6hr after HV on

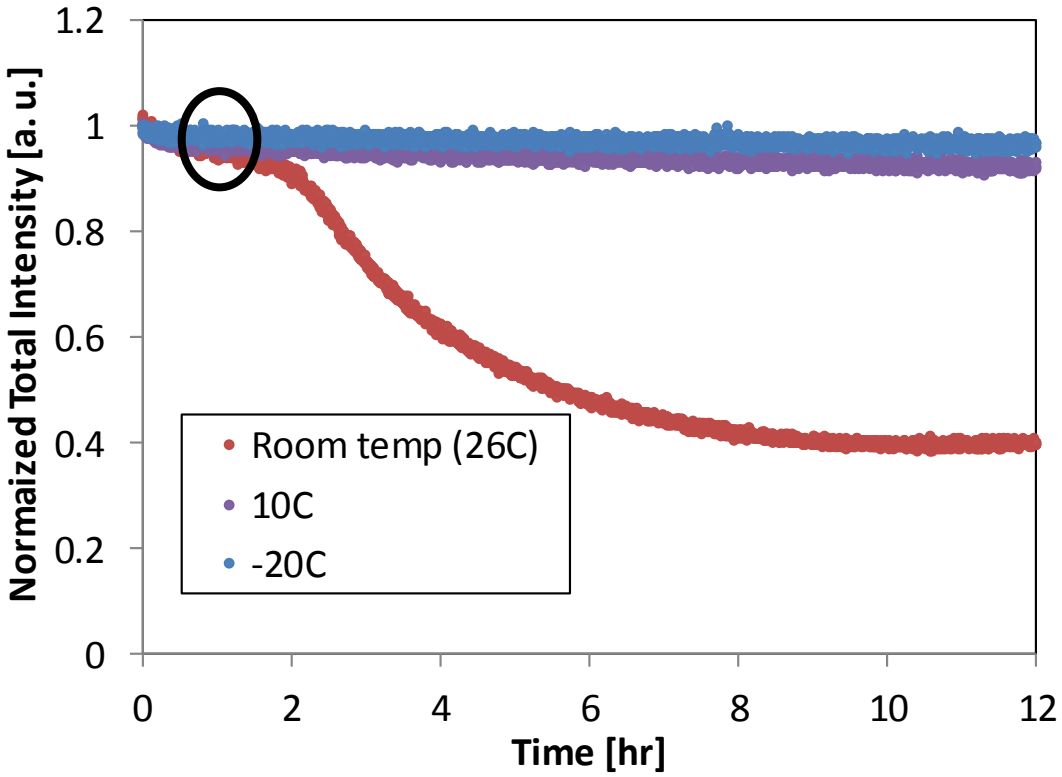


20hr after HV on



Stability Test

- Total counts of the SP8-02B single chip detector
  - Degradation of the detector was 15%/hr at the room temperature (26°C)
  - 0.9%/hr with coolant -20 °C



Chip: SP8-02B
HV: -300 V
Exp: 10 sec
Offset-trim: 60 keV
Source: ^{241}Am
Intensity was normalized at 0 hr

Summary

- CdTe detector have been developed for X-ray SR experiments.
- SP8-02B, 3nd prototype, was fabricated.
  - 200 x 200 um/pix, 50 x 20 pix and 50 x 40 pix/module
  - Custom-designed ASIC which is optimized from SP8-01/02
- Properties of SP8-02B were improved in comparison with SP8-01/02
  - Dispersion of threshold: 80mV(40keV) w/o offset-trim
    3mV(1.5keV) w/ offset-trim
  - ENC: 166 e-
  - Time Stability: 15%/hr at the room temperature(26°C)
    0.9%/hr at -20°C

Future Plan

- Trail runs for Au/In bonding are planned to decrease the defective pixels and increase uniformity of the sensitivity
- Properties of SP8-02B will be tested using SR of 15-100 keV
- We are fabricating 2 x 4 ASICs assembly with one sensor (SP8-02B OCM, 40 x 200 pixels) and then building multi-module detector with a cooling system (SP8-02B MMD, 4 x 2 module, 160 x 400 pixels).
- We plan to make a larger ASIC in SP8-03 (40mm x 40 mm).

SP8-02 OCM

(octal chip module)

Future Plan

- Trail runs for Au/In bonding are planned to decrease the defective pixels and increase uniformity of the sensitivity
- Properties of SP8-02B will be tested using SR of 15-100 keV
- We are fabricating 2 x 4 ASICs assembly with one sensor (SP8-02B OCM, 40 x 200 pixels) and then building multi-module detector with a cooling system (SP8-02B
- We plan to make a larger ASIC in SP8-03 (40mm x 40 mm).

SP8-03 OCM

(octal chip module)


Thank you for your attention