Development of CdTe Pixel Detector with Window Comparator ASIC for High Energy X-Ray Application

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Outline

- Concepts of a new detector
- Design of readout (ASIC)
- Fabrication and Performances of detector
- Results of beam test
- Summary

Concepts

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

⇒ Experiments which requires high energy X-ray (-100keV) is one of the important experiments in SPring-8.

Concepts

Detector that is suite for SPring-8….

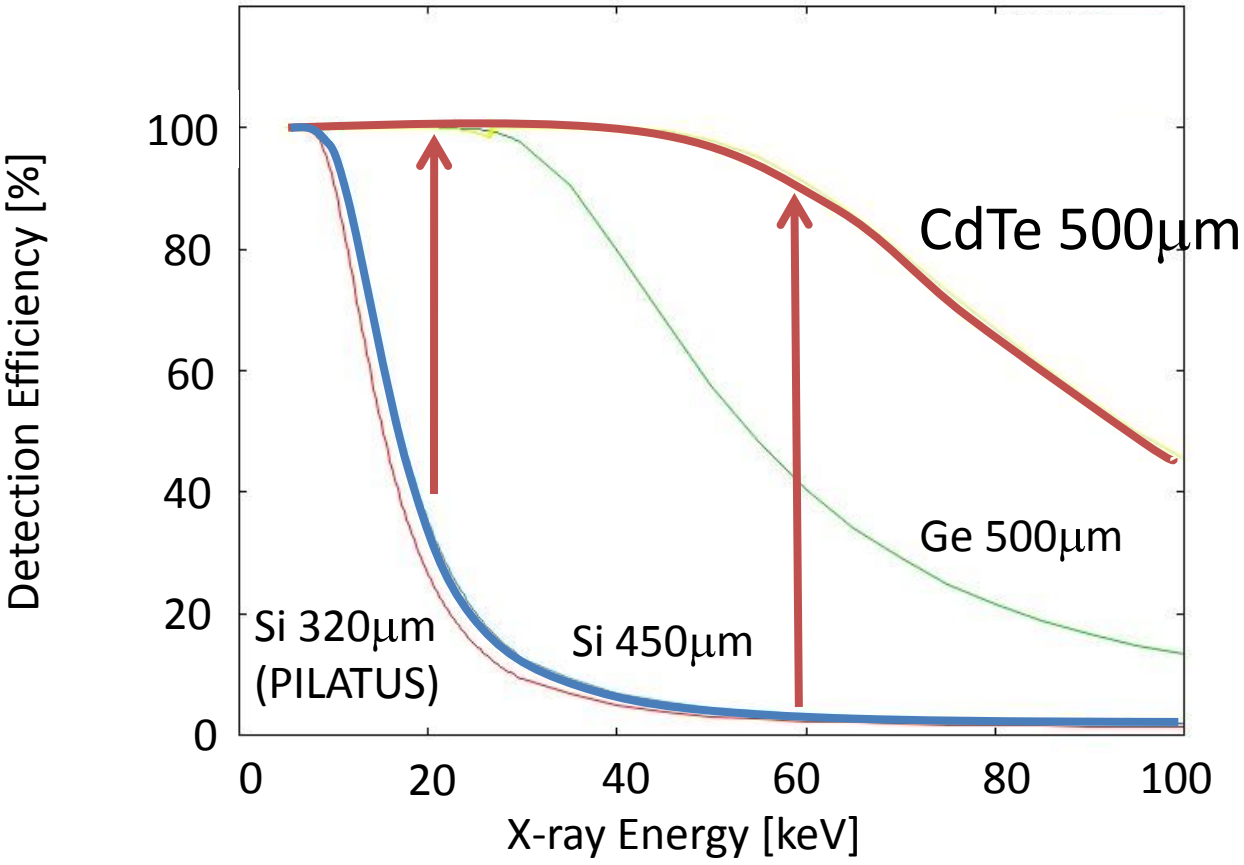
- Photon-counting large-area-imaging hybrid pixel detector, like PILATUS, which are very powerful for SR experiments.
- High sensitivity in high energy X-ray region (15 - 100keV)

  ⇒CdTe sensor
- Function to cut high energy X-ray

  ⇒Readouts with a window-type comparator

Concepts

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%

Concepts

Detector that is suite for SPring-8….

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

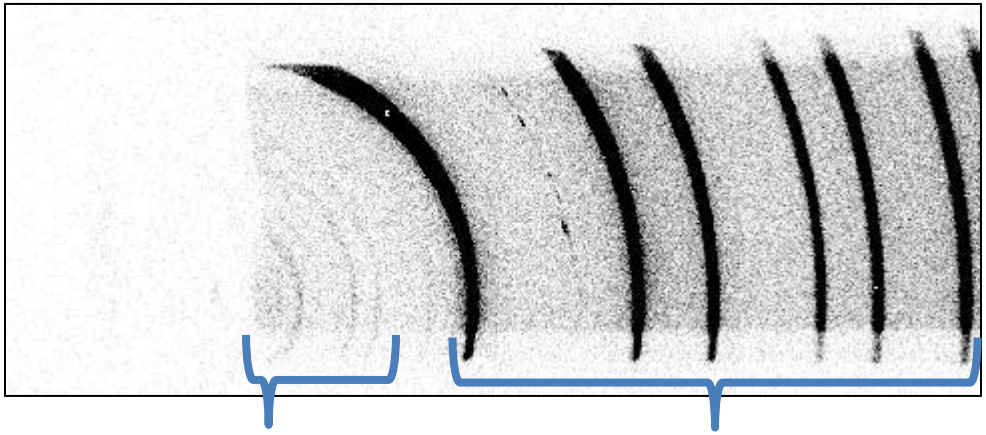
  ⇒CdTe sensor
- Function to cut high energy X-ray

  ⇒Readouts with a window-type comparator

Concepts

- Diffraction pattern of Si with lower-energy comparator only (without higher-energy comparator)

Lower energy comparator at 30.8keV
Monochromator at 37.8keV



113keV
(3rd order of 37.8keV)

37.8keV
(Target energy)

- Without higher-energy comparator, higher order X-ray from monochromator was mixed with the target energy X-ray in the detected image.

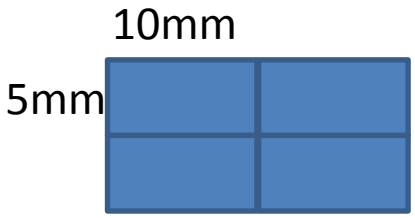
⇒Window-type comparator is required for low background images

Concepts

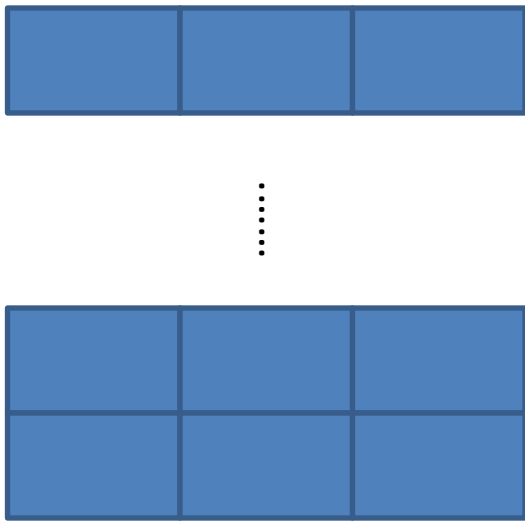
3 steps to realize a large area imaging detector

	SP8-01	SP8-02	SP8-03 (final design)
Pixel size	: 200um x 200um	180um x 180um	
Number of pixel	: 16 x 16 pixels	32 x 16 pixels	
Chip size	: 5mm x 5mm	10mm x 5mm	

Single chip



2 x2 chips/module



Small chip, large pixel
ASIC with many
parameter switches
2 side buttable
Nov. 2008-2010

Multi-chip module, small pixel
Optimized ASIC
3 side buttable
2010-2011

Large multi-chip module
4 side buttable
2012-2013

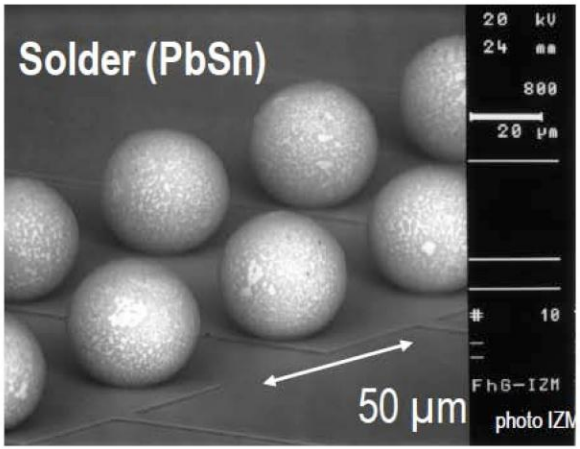
Concepts

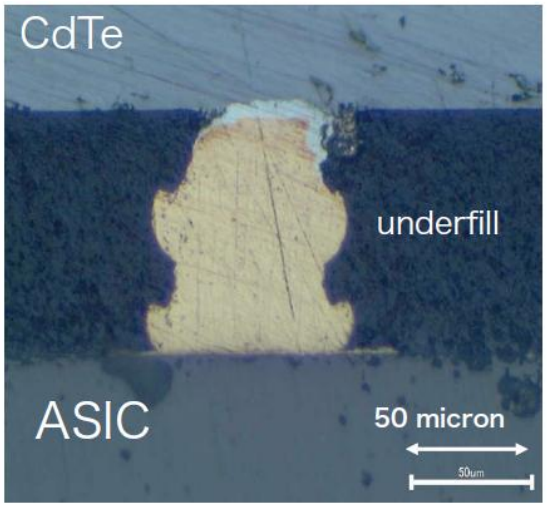
Specification of SP8-01

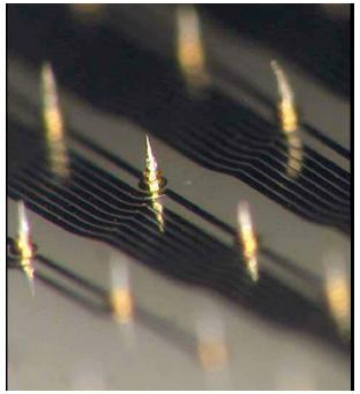
- Sensor
  - CdTe
  - 200 x 200 um/pixel, 16 x16 pixels/chip
- Contacts of sensors
  - In/CdTe/Pt-pixel, Al-pixel/CdTe/Pt, Pt-pixel/CdTe/Pt
  - **Gold-stud bonding**
- Readout with..
  - Analog amp. with time constant less than 100nsec
  - Readable both positive and negative charge
  - Switchable and adjustable gain: 15keV-40keV, 30keV-100keV
  - Poll-zero circuit and offset adjustor
  - Window-type comparator
  - 20 bits counter

Concepts

Gold-stud bonding







- Bump bonding
  - Wafer level process
  - High temperature and high pressure
  - ◎ Si
  - △ CdTe
- In/Au stud bonding (Developed by JAXA)
  - Chip level process
  - low temperature and soft process
  - ◎ **CdTe**

Concepts

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  - Gold-stud bonding
- Readout with..
  - Analog amp. with time constant less than 100nsec
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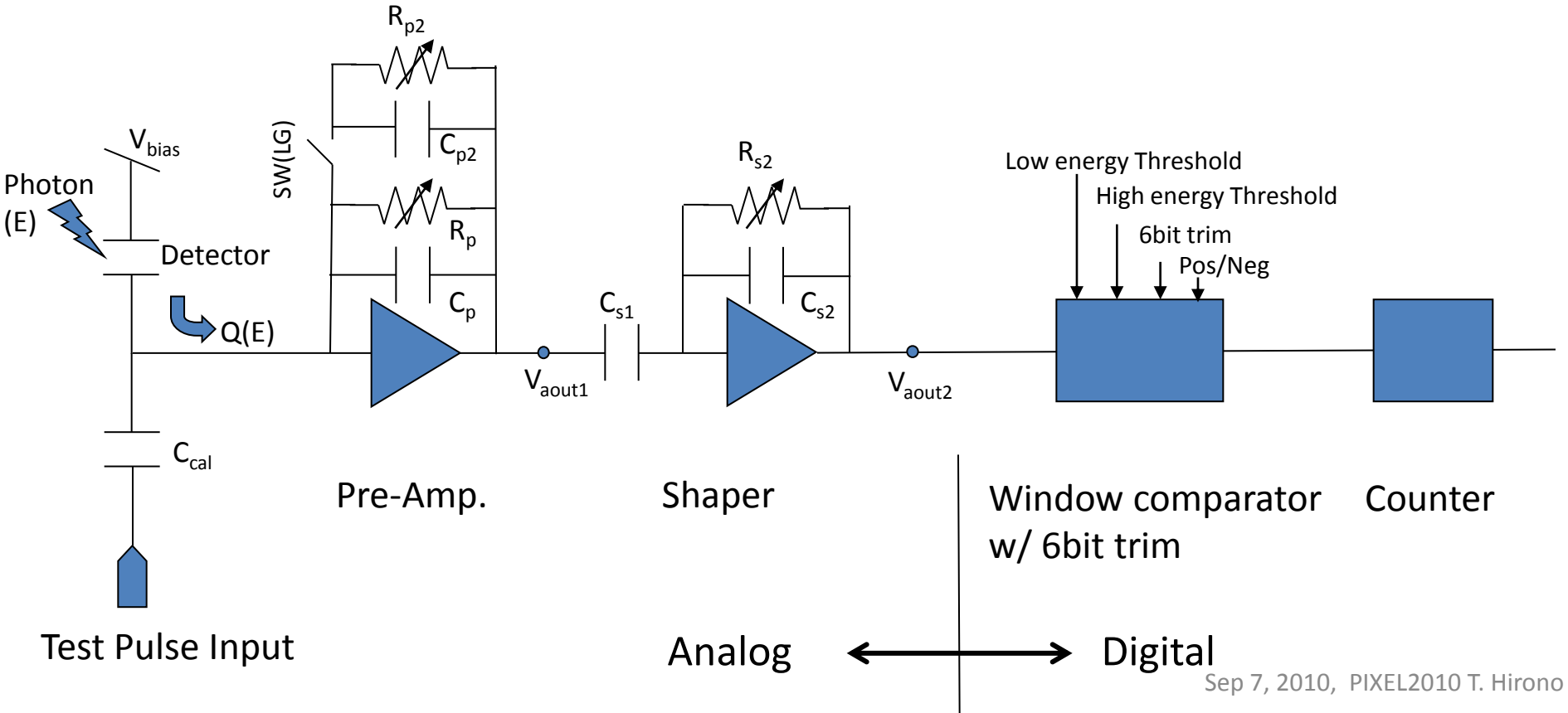
  - Poll-zero circuit and offset trim
  - Window-type comparator
  - 20 bits counter

Design of ACIS

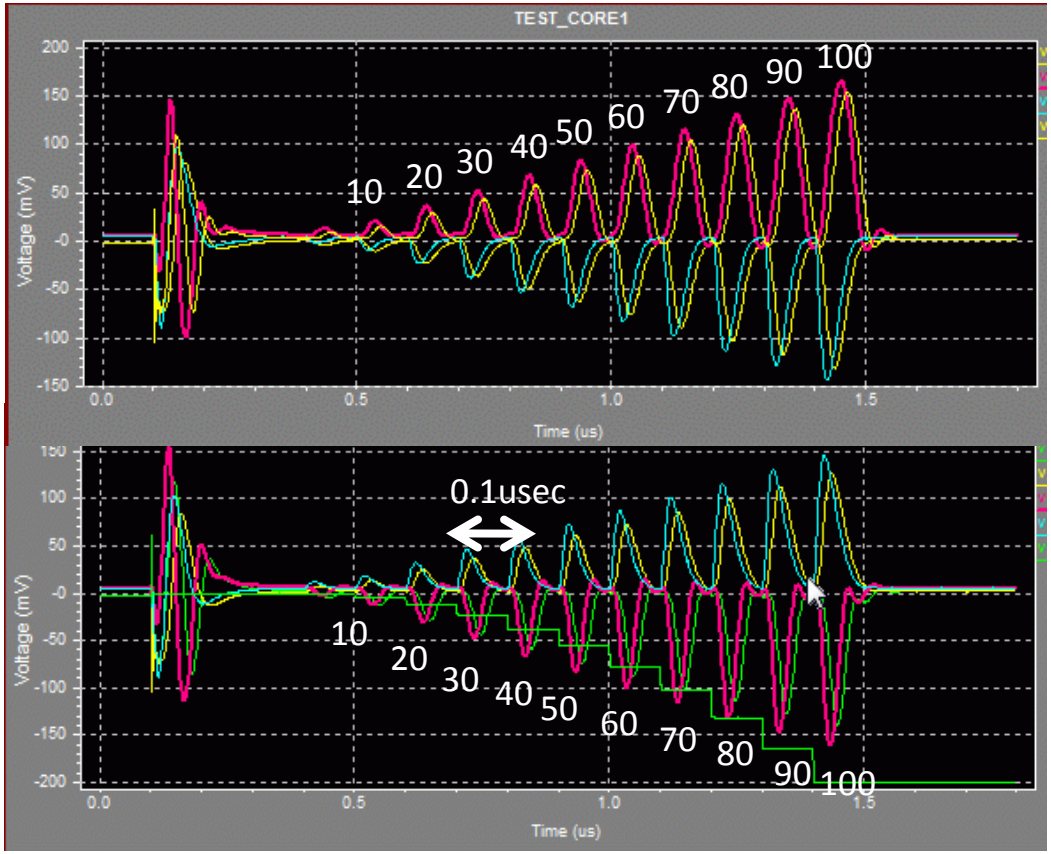
- To realize all the requirements of the readout,
  ⇒ Custom-designed ASIC for SP8-01 was developed

Block diagram of readout for 1 pixel



Design of ASIC

Result of Simulation of Analog Amp.



Pre-amp output

Shaper output

+charge, low gain

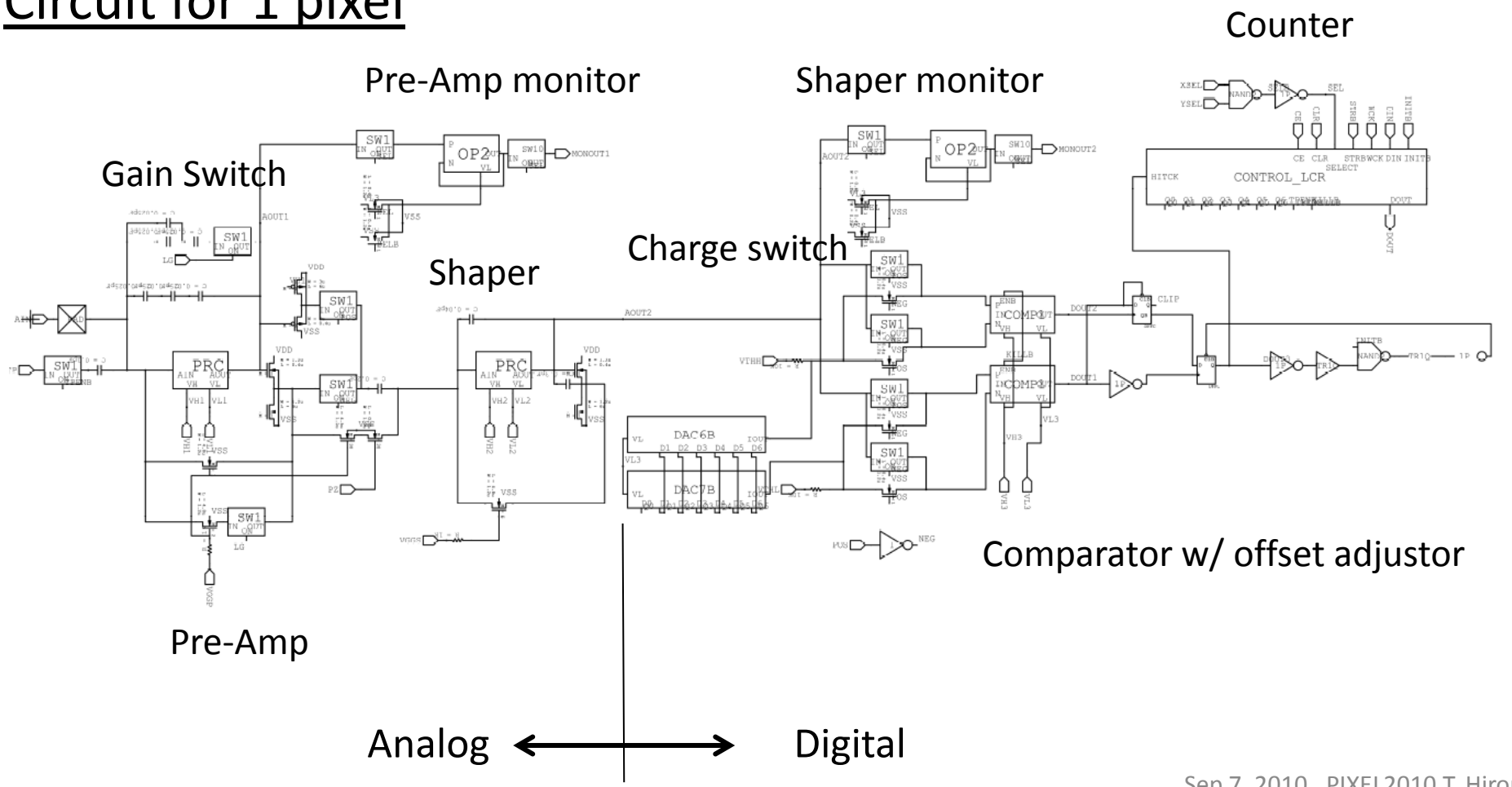
-charge, low gain

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

⇒All the parameter s of circuit was fixed to match requirements.

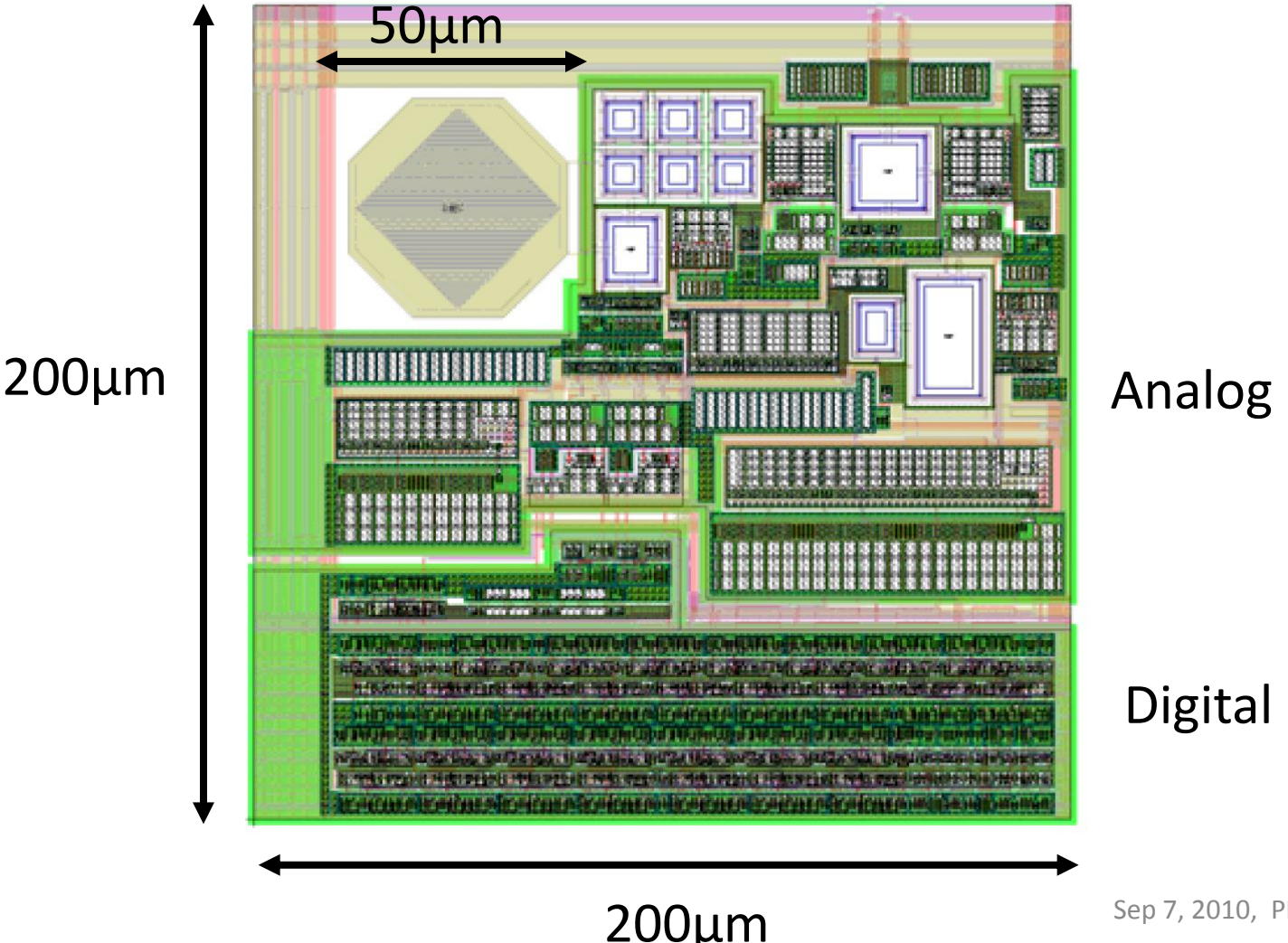
Design of ASIC

Circuit for 1 pixel



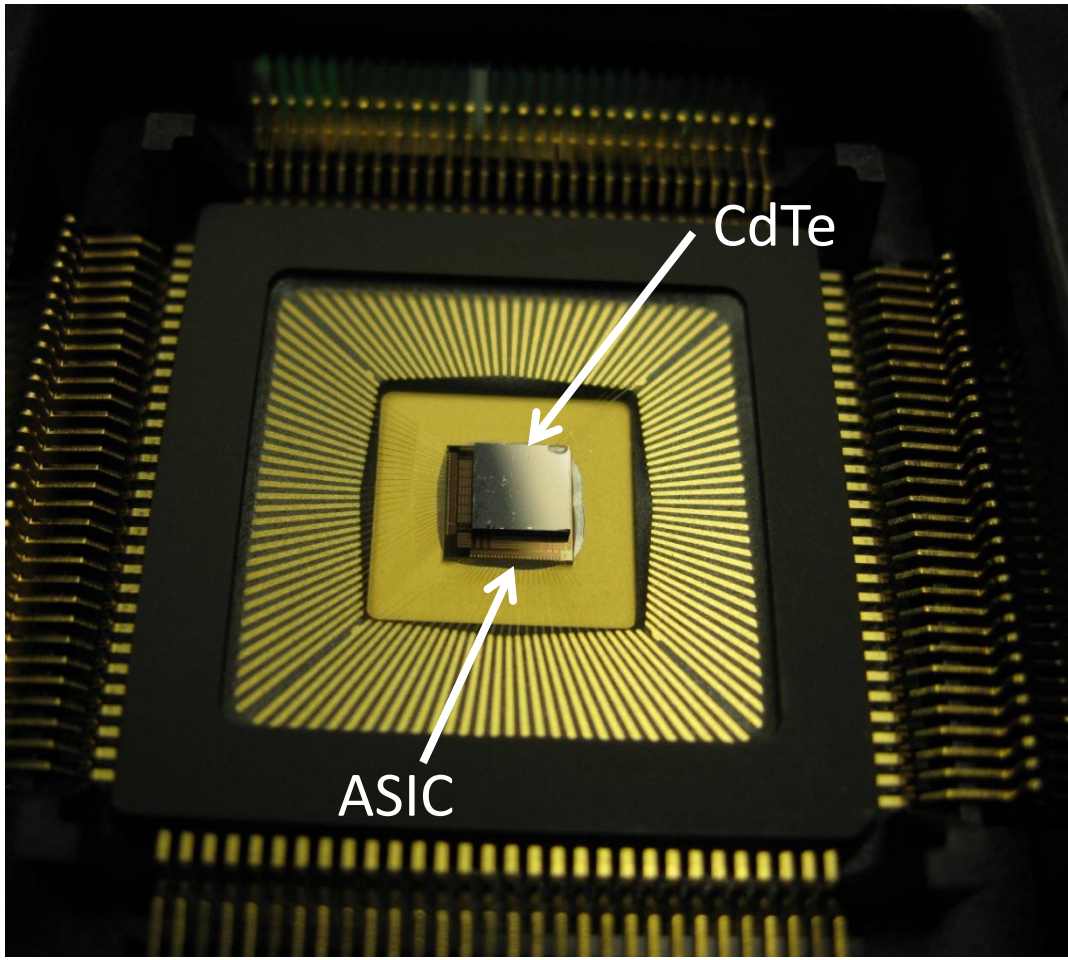
Design of ASIC

- Layout of a single pixel

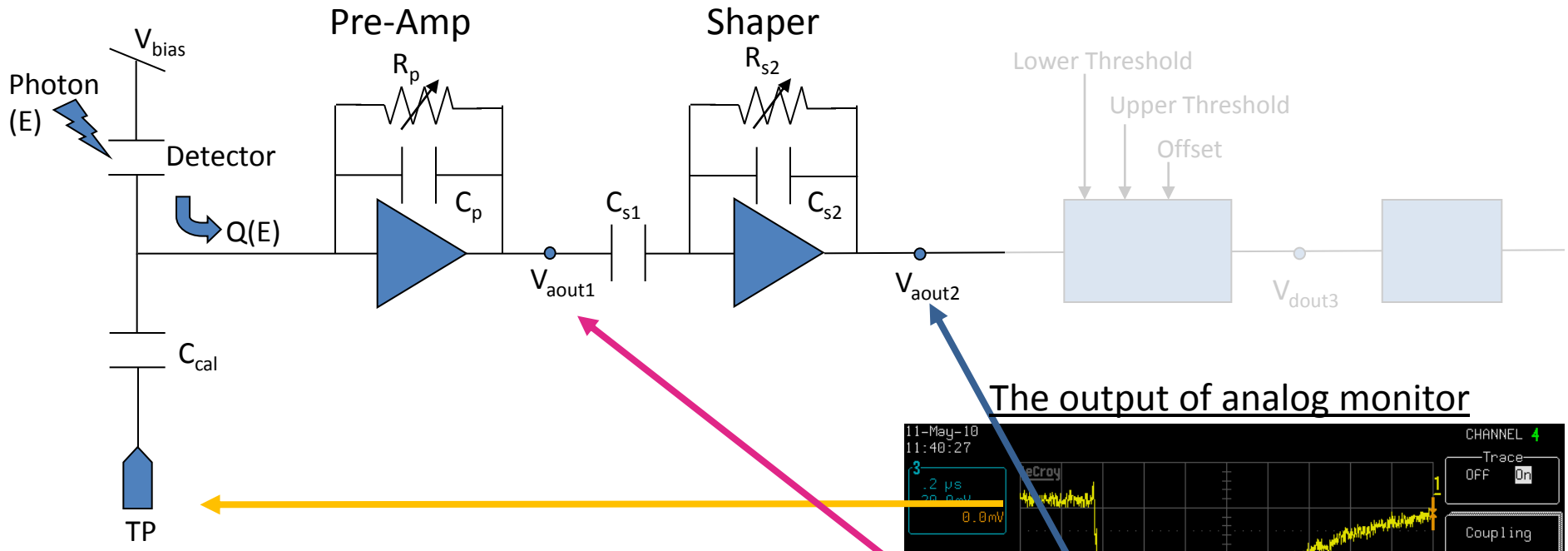


Fabrication of Detector

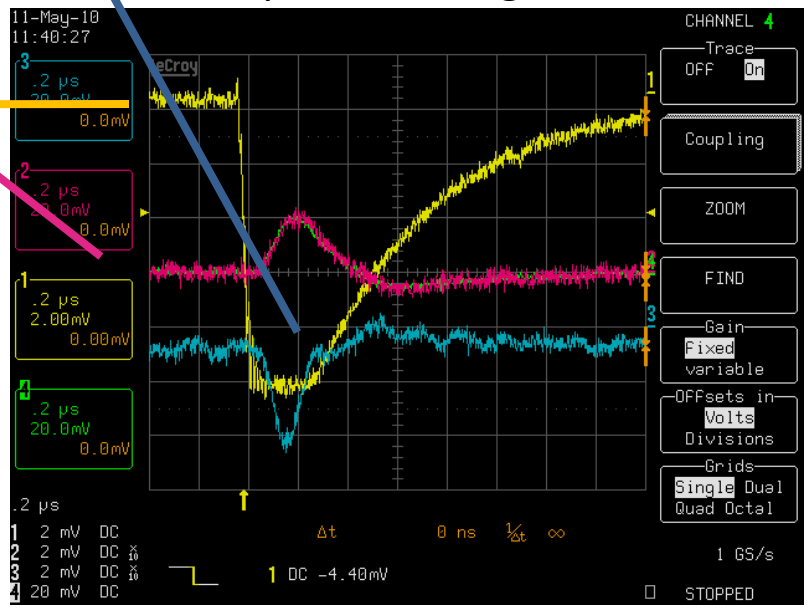
- ASIC was fabricated
  - TMC 0.25um
  - 5mm x 5mm
- and CdTe was bonded to the ASIC.
  - 500um thick
  - Gold-stud bonding
  - 3 types of electrode
    - Pt-pixel/CdTe/Pt
    - Al-pixel/CdTe/Pt
    - In/CdTe/Pt-pixel



Performance of ASIC



The output of analog monitor



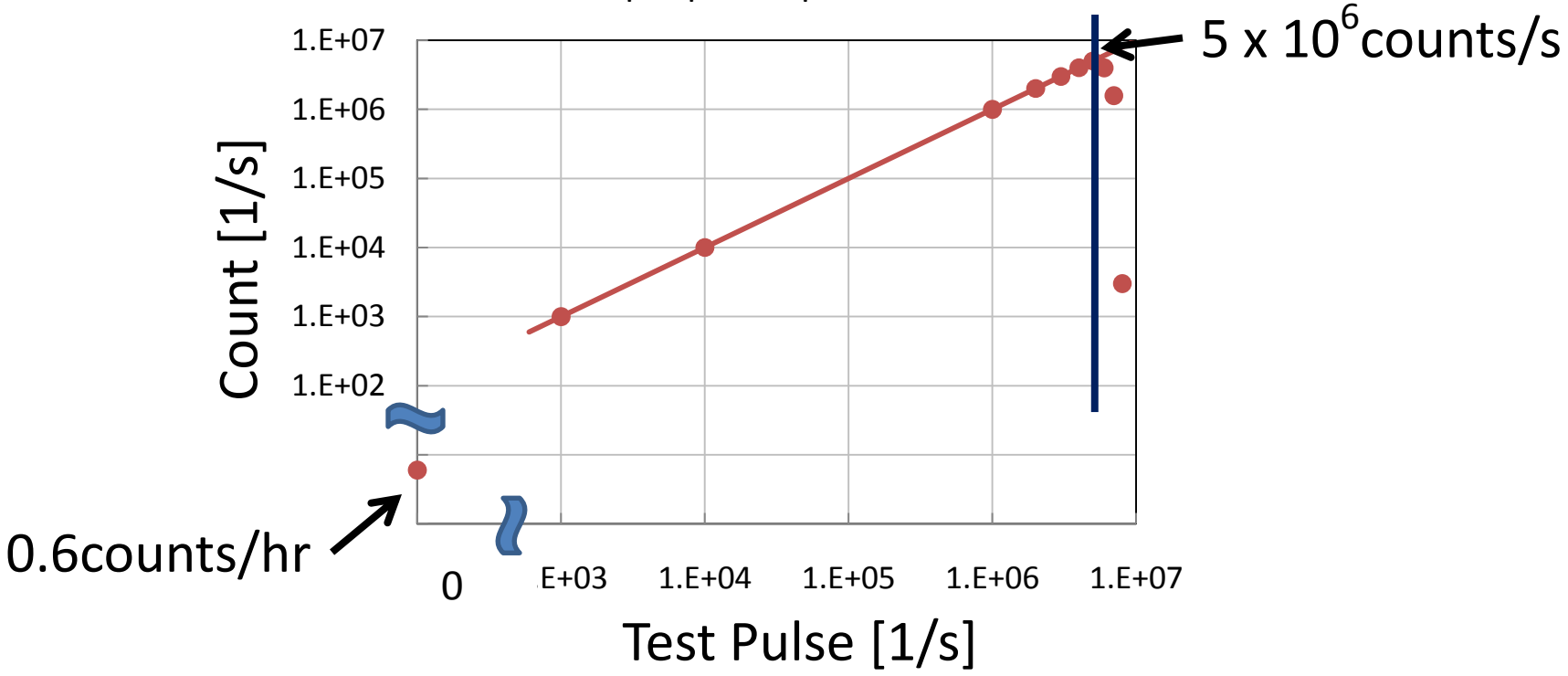
We input test pulse correspond to 30keV –charge, and observed pre-amp and shaper monitors

⇒We could observe pulse outputs from ALL of pixels

Performance of ASIC

Time Constant of Readout

- Test pulse was counted by changing test pulse frequency.
- Counts of counter was as same as input pulse up to 5Mcounts/s

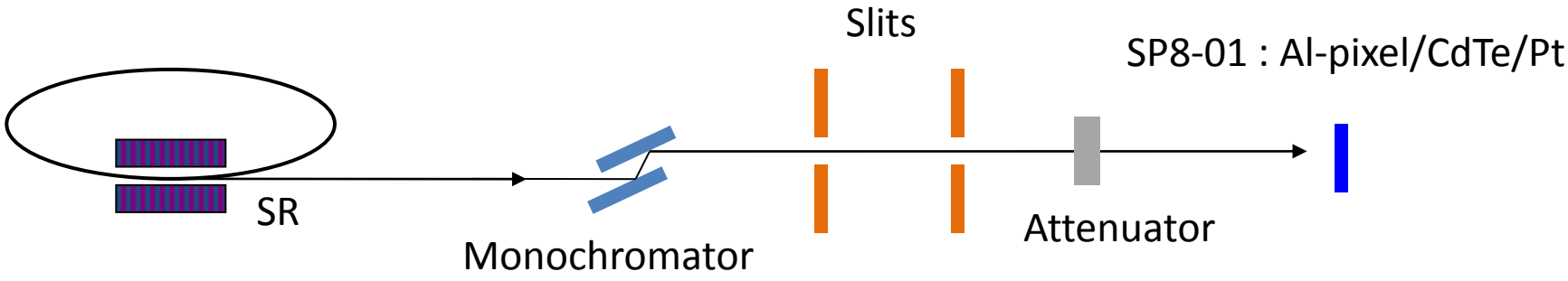


⇒Time constant was 200 nsec c.f. designed =100 nsec

⇒Background noise 0.6 counts/hr/pixel with window-comparator 20-30 keV

Results of Beam Test

- Beam test was performed at BL46XU, BL14B2/SPring-8



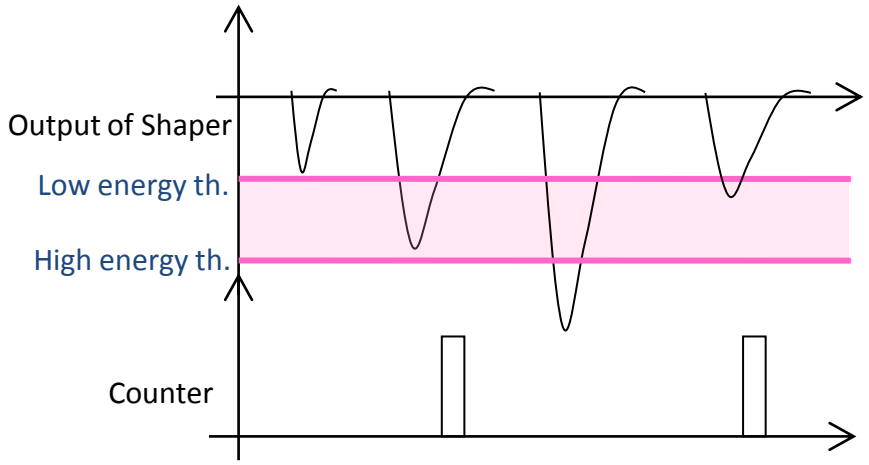
X-ray was resized into 50um□ by 2 slits placed after monochromator.

- Lower-energy threshold scan

⇒ to examine whether X-ray of 30 – 120 keV can be detected by SP8-01

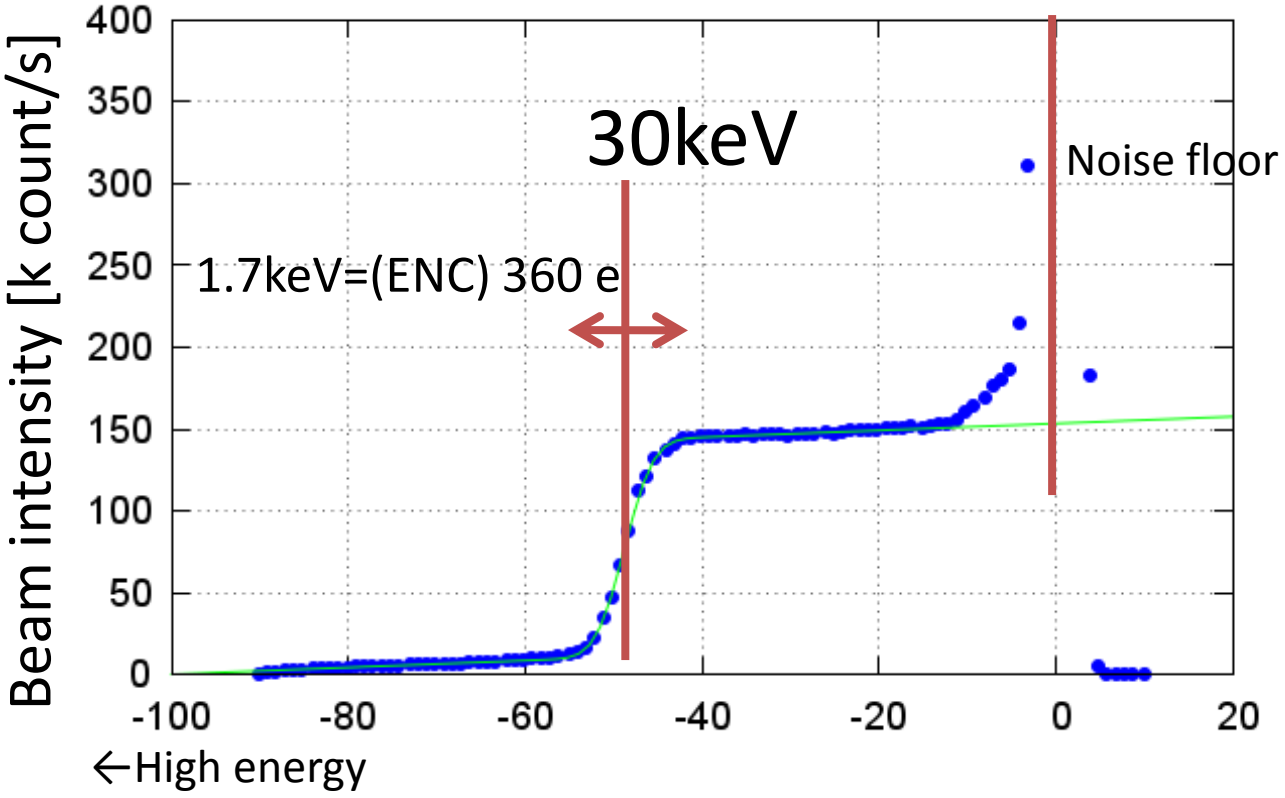
- Window scan

⇒ to demonstrate window comparator



Results of Beam Test

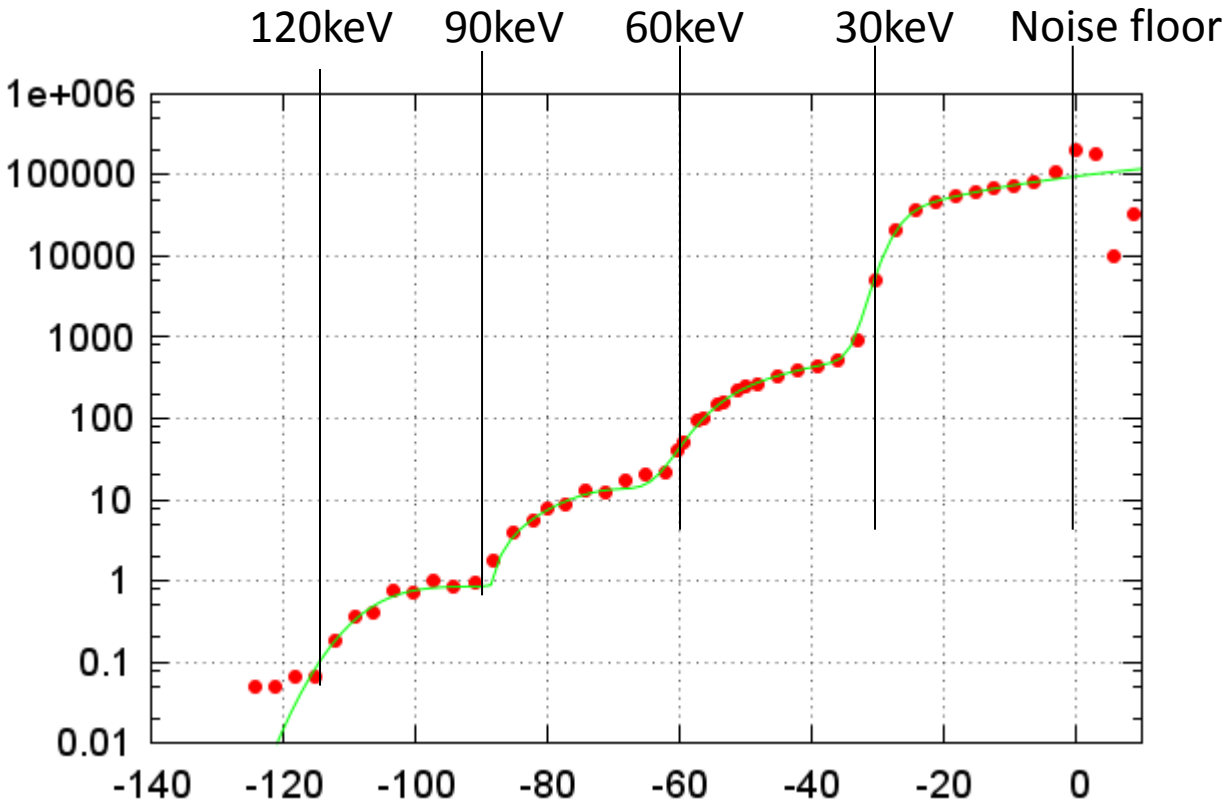
- Lower-energy threshold scan at 30keV
  - S-curve at -49.5mV ⇒30keV
  - The slop at 30keV corresponds to Equivalent Noise Charge of 360 e-



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

Result of Beam Test

Lower threshold scan



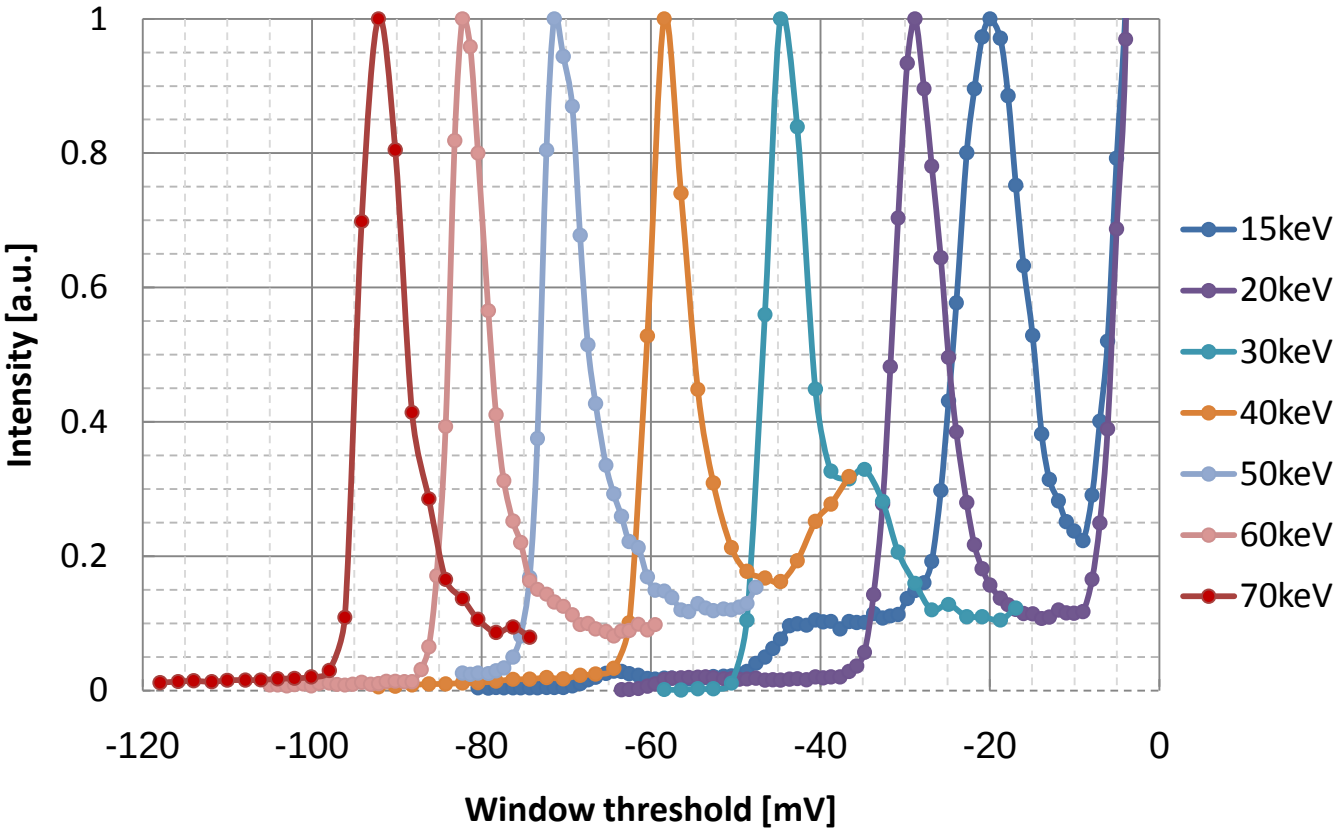
Al/CdTe/Pt (-charge)
HV : -500V
Gain : Low ,
(-66mV,-66mV)
Exp time: 5, 60sec

→X-ray up to 120keV was detected by SP8-01

Results of Beam Test

Window scan

– Higher/lower energy th. was scan both in same time.

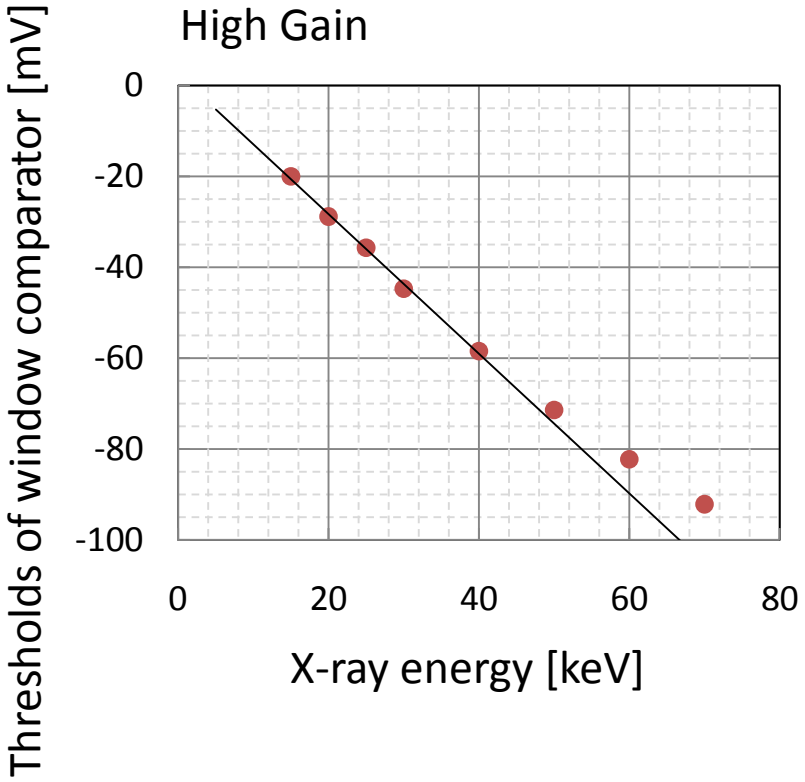


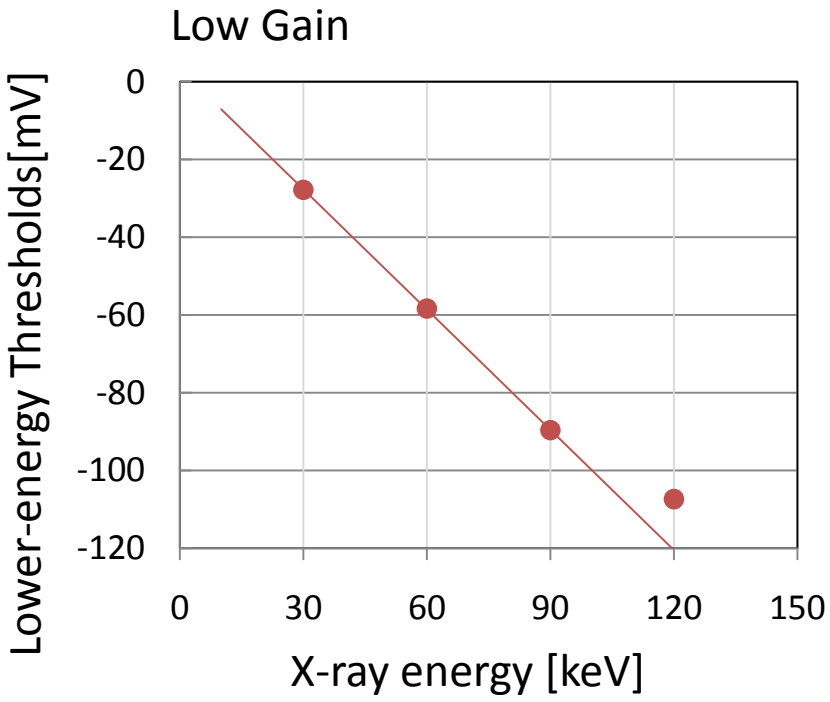
Al-pix/CdTe/Pt (-charge)
Gain : Hig Gain
HV: -300V
Exposure time : 1s
Window width :5mV
(3.2keV)
Intensity was normalized at peak.

⇒Window comparator worked fine.

Results of Beam Test

Energy linearity of readout





Linearity of high gain in 15-40 keV : 98%

low gain in 30-120keV: 90%

Summary

- New pixel detector, SP8-01, was developed for high energy X-ray SR experiment.
  - 200 x 200 um/pix, 16 x 16 pix/chip of CdTe sensor
  - Custom-designed ASIC with window-comparator
- SP8-01 was performed as X-ray detector.
  - Time constant: 200ns
  - ENC : 360 e-, Background noise: 0.6cnt/hr/pix
  - SP8-01 detected X-ray
    - High Gain : 30keV-120keV
    - Low Gain : 15keV-70keV (linearity of 98% in 15-40keV)

⇒Design of SP8-02 (small pixel, multi-chip module) was started.