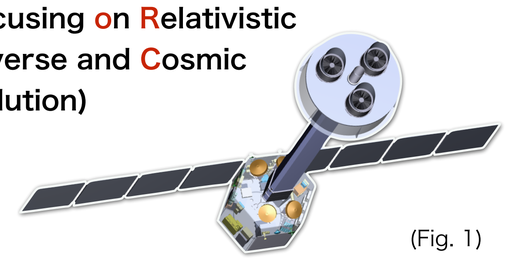
Evaluation of Kyoto's Event-Driven X-ray Astronomical SOI Pixel Sensor with a Large Imaging Area

Hideki Hayashi, T. G. Tsuru, T. Tanaka, H. Uchida, H. Matsumura, M. Itou, S. Ohmura, K. Tachibana, S. Harada (Kyoto Univ.), A. Takeda, K. Mori, Y. Nishioka, N. Takebayashi, S. Yokoyama, K. Fukuda (Univ. of Miyazaki), Y. Arai, I. Kurachi (KEK), S. Kawahito, K. Kagawa, K. Yasutomi, S. Shrestha, S. Nakanishi (Shizuoka Univ.), H. Kamehama (Okinawa National College of Technology), T. Kohmura, K. Hagino, K. Tamasawa, K. Negishi, K. Oono, K. Yarita (Tokyo Univ. of Science)

Introduction

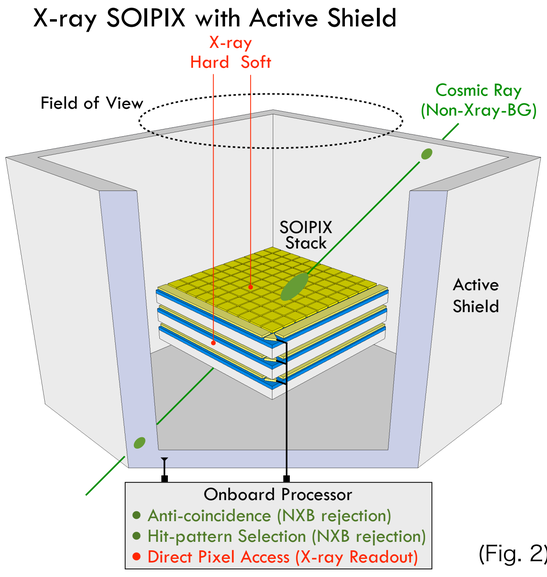
We have been developing monolithic active pixel sensors, named "XRPIX", based on the silicon-on-insulator (SOI) pixel technology for future X-ray astronomy satellites such as "FORCE" (Fig. 1) [1]. XRPIX contains a comparator circuit in each pixel for hit trigger (timing) and two-dimensional hit-pattern (position) outputs. The function allows us readout of pulse heights only from hit pixels on trigger output timing, which is referred to as the event-driven readout mode [2]. Thus, XRPIX offers a good time resolution better than 10 μs and a high throughput reaching > 1 kHz in addition to the imaging and spectroscopic capabilities comparable to those of an X-ray CCD. Taking advantage of the good time resolution, we can significantly reduce non-X-ray backgrounds (NXB) by introducing an anti-coincidence technique (Fig. 2).
Recently, we processed XRPIX5b with the largest imaging area in our XRPIX series. In this poster, we report the first evaluation results of XRPIX5b, especially whether the performance changes due to its large size.

Future X-ray Astronomy Satellite "FORCE" (Focusing on Relativistic universe and Cosmic Evolution)



(Fig. 1)

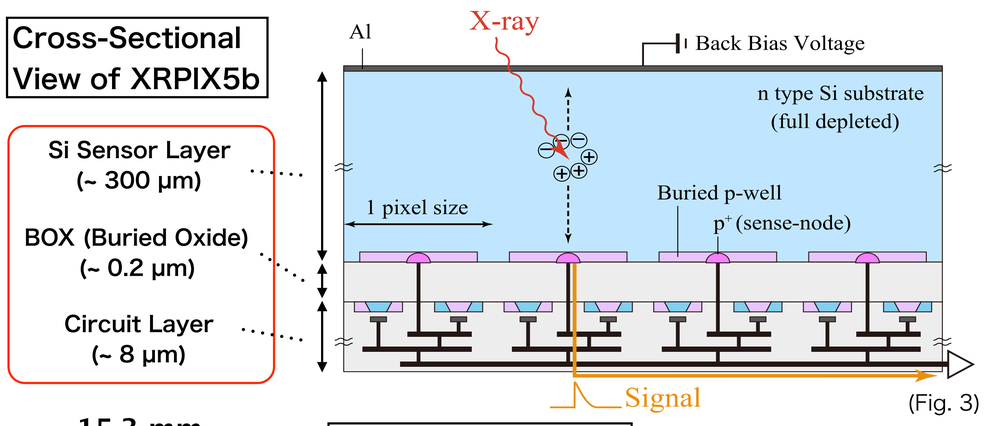
X-ray SOIPIX with Active Shield



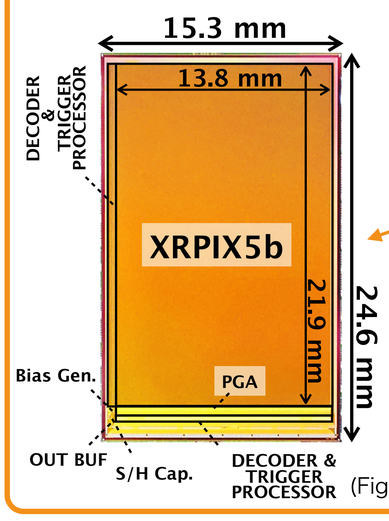
(Fig. 2)

Device Description of XRPIX5b

Cross-Sectional View of XRPIX5b

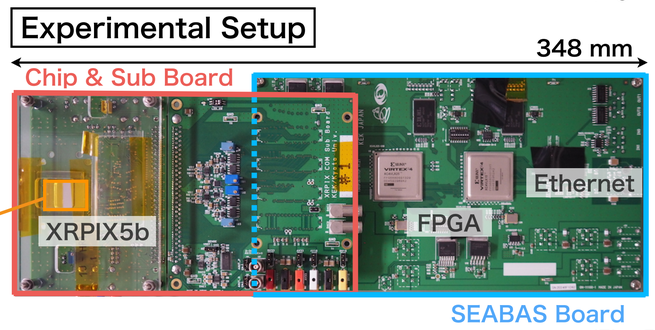


(Fig. 3)



(Fig. 4)

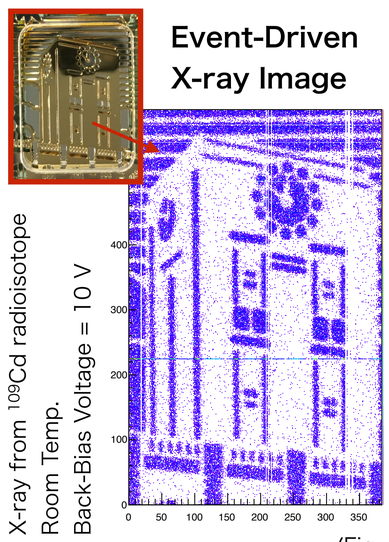
Experimental Setup



(Fig. 5)

- Pixel size : 36 μm × 36 μm
- Pixel format : 608 × 384
- Thickness of sensor layer : 300 μm
- Wafer type : Floating Zone

X-ray Image



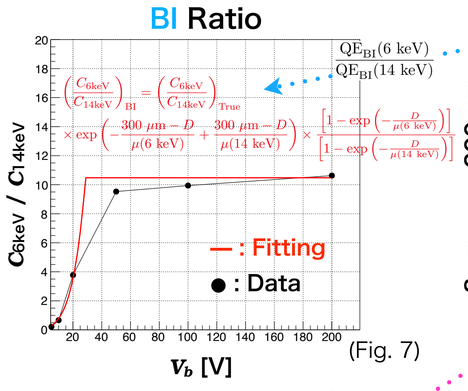
(Fig. 6)

- We sucessfully obtained the X-ray Image with XRPIX5b in the event-driven readout mode.
  → We confirmed all the pixels correctly output X-ray hit addresses.

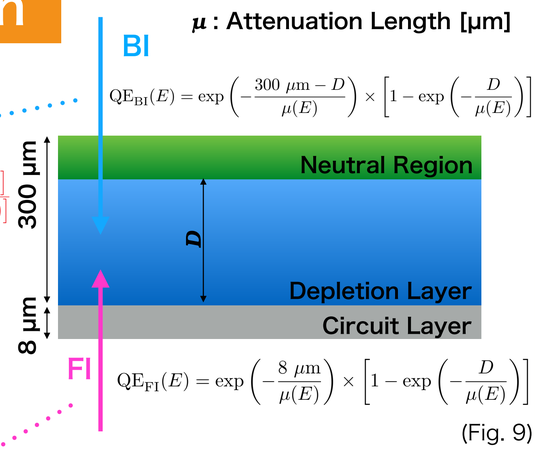
Depletion Depth

QE : Quantum Efficiency
μ : Attenuation Length [μm]

BI Ratio

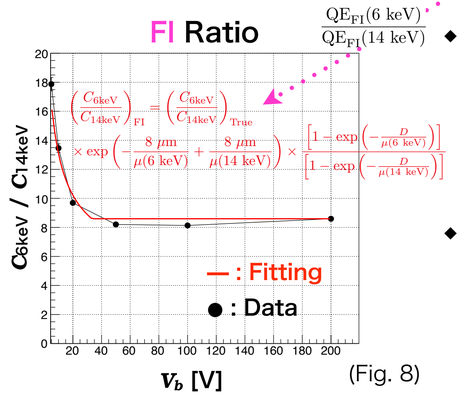


(Fig. 7)



(Fig. 9)

FI Ratio



(Fig. 8)

(0 μm ≤ D ≤ 300 μm)

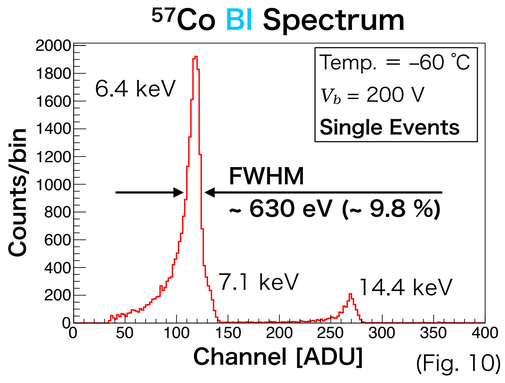
- In order to measure the depletion depth, we obtained ^{57}Co X-ray spectra and ratios of 6.4 keV and 14.4 keV X-ray counts with several back-bias voltages (V_b) from 5 V to 200 V.
- We fitted the data with the models descrived in the left two figures.
  → The sensor layer is fully depleted (300 μm) at V_b ≥ 50 V.
  → The resistivity of the sensor layer is 8-10 kΩ·cm.

Spectral Performance

＊ By Frame Mode (Not Event-Driven)

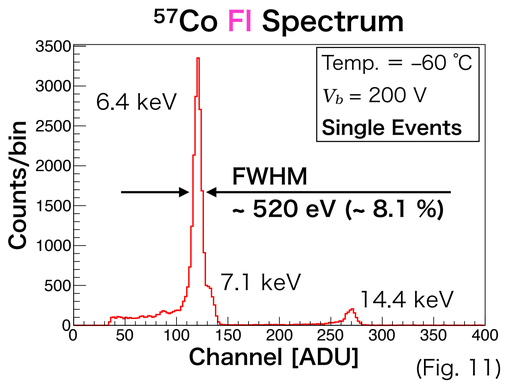
BI : Gain ~ 18.6 μV/e⁻
Readout Noise ~ 46 e⁻ (rms)
FI : Gain ~ 18.4 μV/e⁻
Readout Noise ~ 47 e⁻ (rms)

^{57}Co BI Spectrum



(Fig. 10)

^{57}Co FI Spectrum



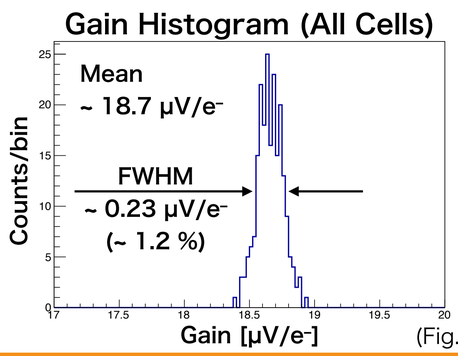
(Fig. 11)

- Fig. 10 and 11 show ^{57}Co spectra obtained with the central 32 × 32 pixels with the back-illumination (BI) and the front-illumination (FI) using the identical device.
- In spite of the large size, the spectral performance is comparable to XRPIX3b with a small imaging area of 1 mm × 1 mm, which has almost the same pixel circuit as XRPIX5b [3].
- The low-energy tail degrades the energy resolution of the BI spectrum.
  → Significant charge loss in the BI configuration.
  → We need to examine the electronic fields in the sensor layer to clarify the cause [4].

Gain Uniformity

- Fig. 12 and 13 show a histogram and a map of gains of pixels in each location of the sensor. The gains shown here are obtained by fitting ^{57}Co BI spectra from 32 × 32 pixels, which we refer to as a cell hereafter.
- The cells away from the analog output pad have lower gains.
  → The possible cause would be resistance and parasitic capacitance of the trace.

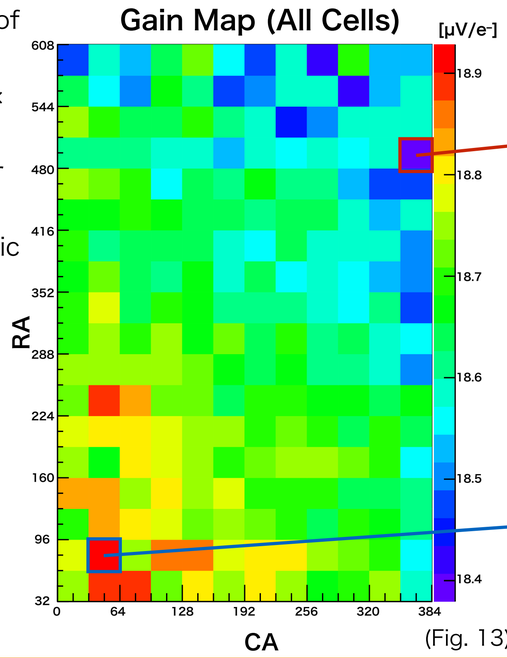
Gain Histogram (All Cells)



(Fig. 12)

RA means row address, and CA means column address.

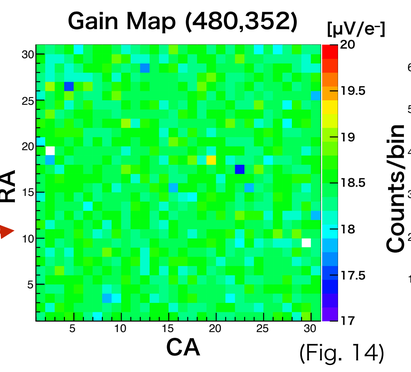
Gain Map (All Cells)



(Fig. 13)

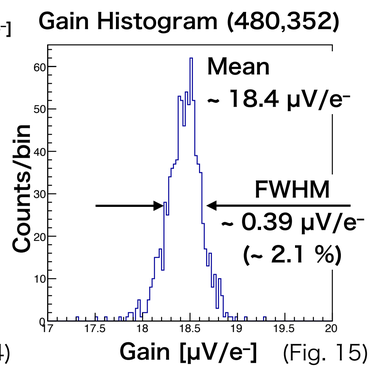
(RA,CA) = (480,352)

Gain Map (480,352)



(Fig. 14)

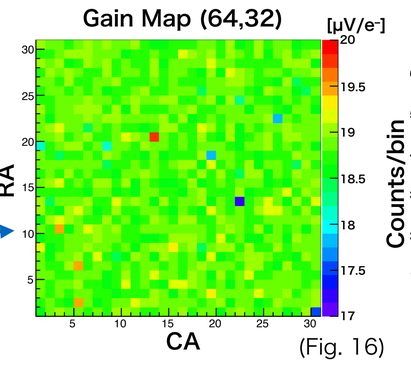
Gain Histogram (480,352)



(Fig. 15)

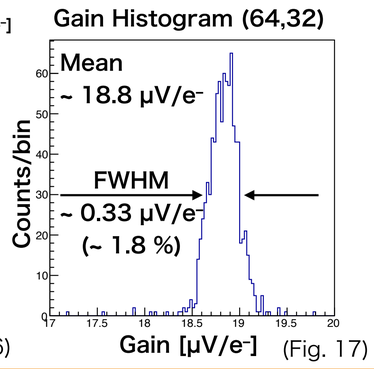
(RA,CA) = (64,32)

Gain Map (64,32)



(Fig. 16)

Gain Histogram (64,32)



(Fig. 17)

＊ The statistical errors of gains obtained by fitting spectra (< 0.1 μV/e⁻) are negligible to the gain variation.

- We investigated the pixel-to-pixel gain variation in the two cells enclosed by the solid square in Fig. 13.
- The gain variation in a cell is ~ 2 % (FWHM), which probably reflects the gain variation of amplifiers in each pixel.
  → The gain variation of ~ 2 % has little effect on the energy resolution of ~ 8 % (Fig. 11).

Summary

- **We have been developing XRPIX for future X-ray astronomy satellites, which realizes a good time resolution better than 10 μs.**
- **We processed XRPIX5b with a large imaging area of 21.9 mm × 13.8 mm and successfully obtained X-ray spectra from all the pixels, but the low-energy tail degrades the energy resolution of the BI spectrum.**
- **The sensor layer is fully depleted (300 μm) at V_b ≥ 50 V.**
- **The gain variation of ~ 2 % (FWHM) has little effect on the energy resolution of ~ 8 % @ 6.4 keV (FWHM).**

Reference

[1] T.G.Tsuru et al., Proc. SPIE 9144 (2014) 914412.
[2] A.Takeda et al., IEEE TNS. 60 (2013) 586.
[3] A.Takeda et al., JINST, 10 (2015) C06005
[4] H.Matsumura et al., Nucl. Instrum. Methods Phys. Res. A 794 (2015) 255.