X-ray response evaluation in subpixel level for X-ray SOI pixel detectors

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➢ Abstract

We have been developing Event-driven SOI Pixel Detectors, named "XRPIX" (X-Ray soiPIXel) based on the silicon-on-insulator (SOI) pixel technology, for future X-ray astronomical satellites. XRPIX has event trigger output function at each pixel and has CDS (Correlated Double Sampling) function to reduce electric noises and to acquire a good time resolution of a few μs. By surrounding XRPIX with shield counters and using anti-coincidence, we can remove NXB (Non X-ray Background) significantly. And we can be able to detect a wide energy range (0.5 – 40 keV).

In the previous work (Matsumura et al. 2015), X-ray beam of 8 keV narrowed to 10 μmϕ was irradiated from the circuit layer side of the device to XRPIX1b at Spring-8. As a result, it was found that the relative detection efficiency decreased to about 20% in the vicinity of the boundary compared with central part of a pixel. This was due to the influence on the electric field structure of the sensor layer by the layout of the pixel circuits. Therefore, we have developed a new device whose layout of pixel circuits was revised.

In this work, we irradiated 2-5 keV X-ray beam narrowed to 4 μmϕ to the device XRPIX3b with improved pixel circuit layout at 6 μm pitch from the sensor layer side. Then, we evaluated the relative detection efficiency in subpixel level of XRPIX3b. As a result, we confirmed that in XRPIX3b, improvement of charge collection near the boundary of a pixel, and improvement of the relative detection efficiency to about 75%.

➢ Introduction

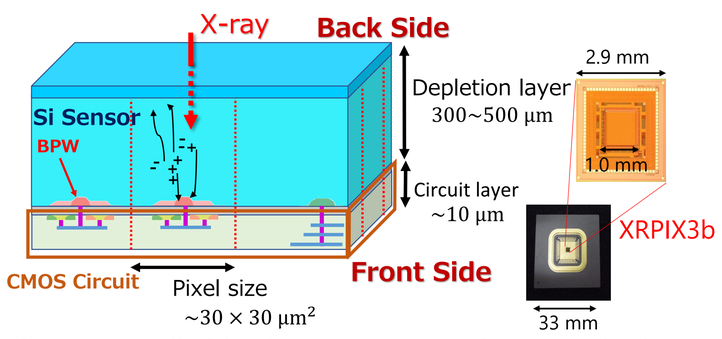


Figure 1 : (left) The structure of XRPIX (BI) (right) Photograph of the device

- **XRPIX** (**X**-**R**ay soi**PIX**el) ：A CMOS image sensor in which a sensor part (X-ray detection part) and a readout circuit part are integrated.
- **BPW** (Buried P-Well) ：A thin P layer. It is formed in the sensor part right under the CMOS circuit to suppress the back-gate effect.

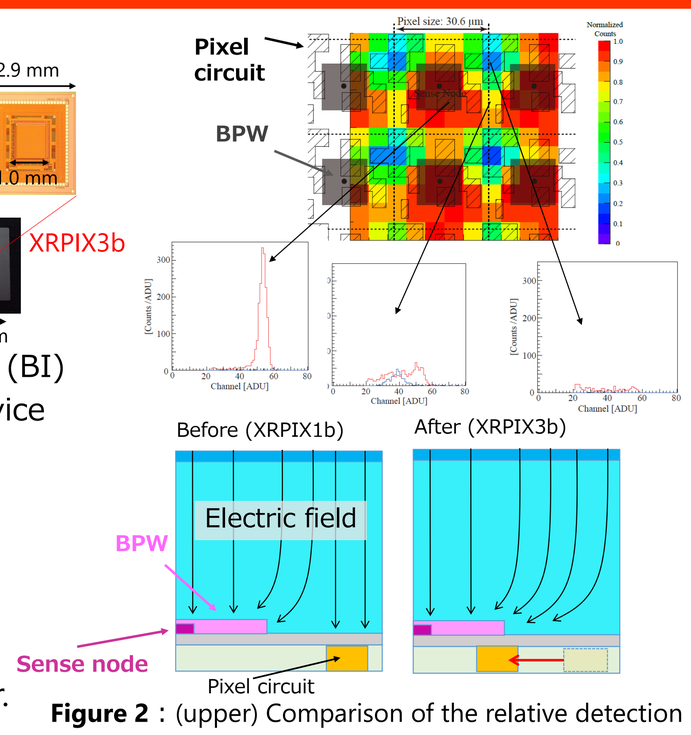


Figure 2 : (upper) Comparison of the relative detection efficiency and pixel circuit when XRPIX1b was irradiated with 8 keV X-rays. (lower) Cross-sectional view of XRPIX before and after layout change.

- According to the previous work (Matsumura et al. 2015), in **XRPIX1b**, the detection efficiency in the pixel was worse as the location of the pixel circuit farther from the BPW, and it was about 20% at the boundary of 4 pixels.
- At the boundary of 2 and 4 pixels, the shape of the spectrum was collapsed and the charge could not be completely collected.
- As a result of the electric field simulation, it turned out that the electric field structure of the sensor layer was distorted by the influence of the pixel circuit.
- Therefore, we have created a new device **XRPIX3b**, whose layout has been changed so that the pixel circuit is directly above the BPW.

We also conducted an experiment to investigate the difference in relative detection efficiency at the subpixel level for **XRPIX3b**.

➢ Improvement of relative detection efficiency

- In April 2017, we conducted an experiment at Beamline BL-11B in photon factory (KEK - PF) of High Energy Accelerator Research Organization.

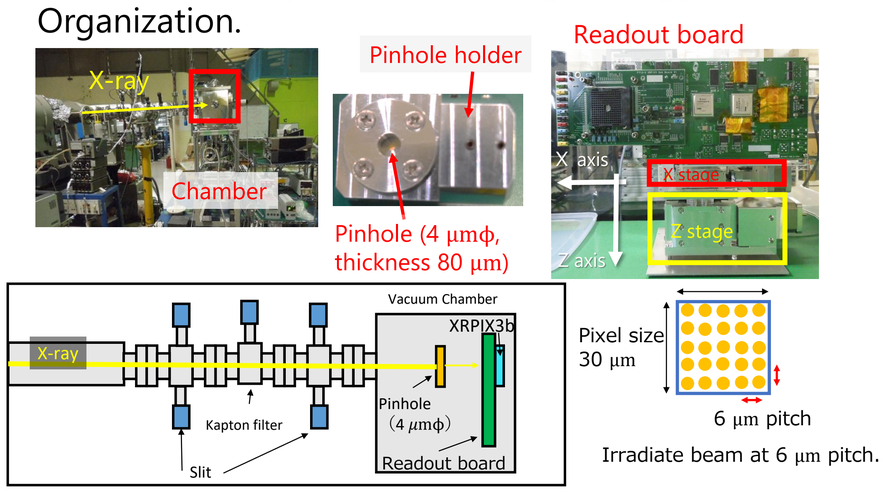
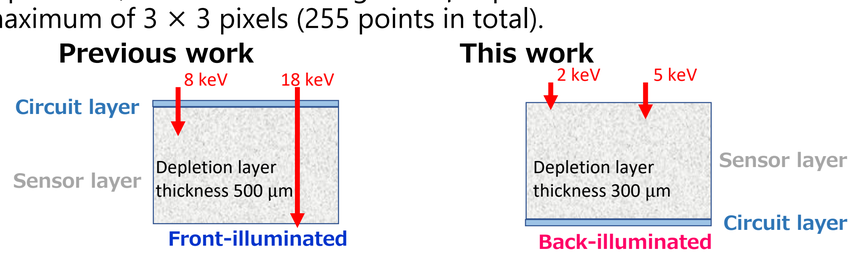


Figure 3 : Experiment setup picture of BL-11B and schematic view seen from the top. XRPIX3b was irradiated with a beam focused at 4 μmϕ using pinhole. In this experiment, we moved the stage at 6 μm pitch and irradiated the beam at a maximum of 3 × 3 pixels (255 points in total).



	Previous work		This work	
Location	SPring-8		KEK-PF BL-11B	
Device	XRPIX1b		XRPIX3b	
Depletion layer [μm]	500		310	
Direction	Front-illuminated		Back-illuminated	
Energy [keV]	8.0	17.7	2.1	5.0
Attenuation length [μm]	70	500	2	20
Distance from circuit layer[μm]	60		300	280

Figure 4 : Comparison of measurement conditions

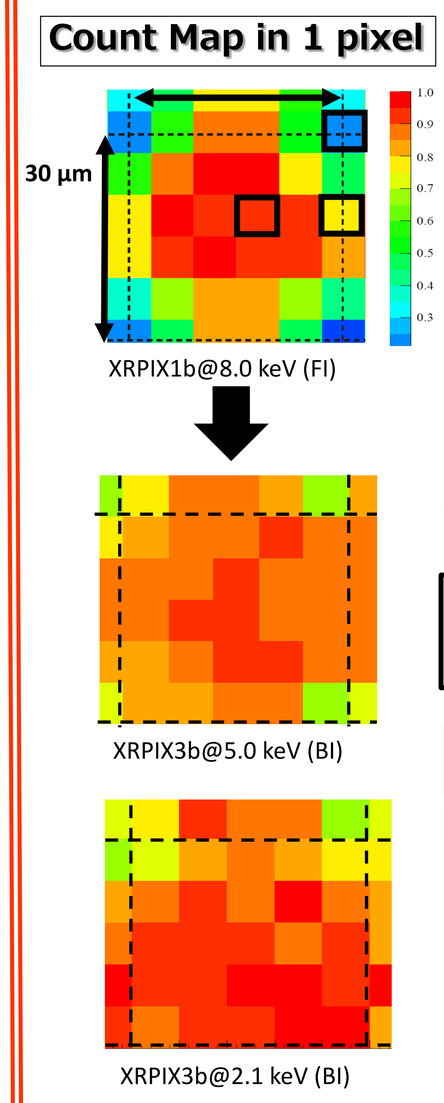


Figure 5 : Two-dimensional map of total counts. Standardized with the maximum value as 1.

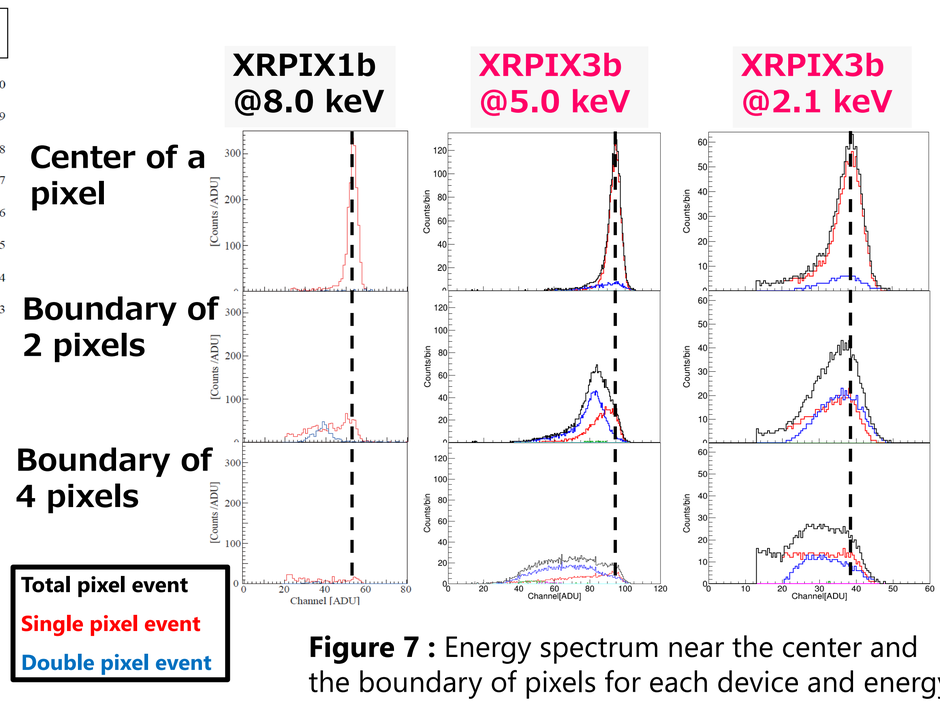


Figure 7 : Energy spectrum near the center and the boundary of pixels for each device and energy.

	XRPIX1b @ 8.0 keV	XRPIX3b @ 5.0 keV	XRPIX3b @ 2.1 keV
Boundary of 2 pixels	81.1 ± 2.8%	97.9 ± 2.3%	89.4 ± 4.1%
Boundary of 4 pixels	22.4 ± 1.2%	76.3 ± 1.9%	74.0 ± 3.2%

- At boundary of 2 pixels (@5.0 keV), detection efficiency was not deteriorated.
- At boundary of 4 pixels, the relative detection efficiency improved to about 75%.
- Compared with XRPIX1b, the shape of the energy spectrum improved in XRPIX3b.
  → Improvement of charge collection

➢ Conclusions

- Compared to XRPIX1b used in previous research, XRPIX3b with a new pixel circuit layout improved charge collection near the boundary of pixels.
- The energy spectrum was obtained even at boundary of 4 pixels, and the relative detection efficiency improved from 22% to about 75%.
- Further improvement is expected in the latest device XRPIX6 which improves the layout of the device.