Design and Development of an Event-driven SOI Pixel Detector for X-ray Astronomy

Ayaki Takeda (Univ. of Miyazaki)

K. Mori, Y. Nishioka, N. Takebayashi, S. Yokoyama, K. Fukuda (Univ. of Miyazaki),
T. G. Tsuru, T. Tanaka, H. Uchida, H. Matsumura, K. Tachibana, H. Hayashi, S. Harada (Kyoto Univ.),
T. Kohmura, K. Hagino, K. Oono, K. Negishi, K. Yarita (Tokyo Univ. of Sci.), Y. Arai, I. Kurachi (KEK/IPNS)
S. Kawahito, K. Kagawa, K. Yasutomi, S. Shrestha (Shizuoka Univ.), H. Kamehama (Okinawa National College of Technology)

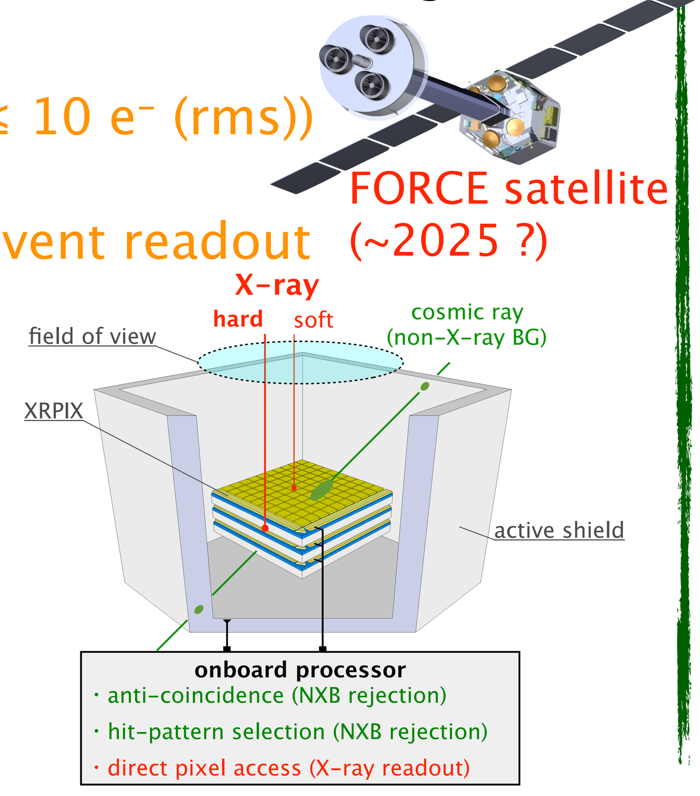
SOIPIX for X-ray Astronomy

We have been developing monolithic active pixel detectors based on the SOIPIX for future X-ray astronomical satellite missions (e.g. FORCE).

The performance is required …

- FWHM ≤ 140 eV @ 6 keV (Readout Noise ≤ 10 e^- (rms))
- Spatial resolution : ≤ 100 μm pitch pixel
- Coincidence time resolution : ~10 μs per event readout
- Wide energy range : 0.5 – 40 keV

-> **We have been developing "XRPIX device."**



Event-driven Readout mode

We realize the spectroscopic system on the right figure.
(anti-coincidence method between hit signals and external active shield detectors)

Our Works with XRPIX

We have designed 8 devices and shown some basic performances.

- X-ray response of XRPIX (SOIPIX) -> XRPIX1/1b [1], [2]
- Dependency on pixel size and structure -> XRPIX2 [3]
- Event-driven readout mode -> XRPIX1b [4], XRPIX2b [5]
- Improvement of Spectroscopic Performance -> XRPIX3b [6]
- Large-area Device -> XRPIX5 (H. Hayashi's poster presentation)

The basic function of XRPIX has been already realized.
Recently, we showed that increasing the conversion gain of the sense-node is effective for improving the spectroscopic performance [6].

➡ We applied a new approach to the XRPIX device.

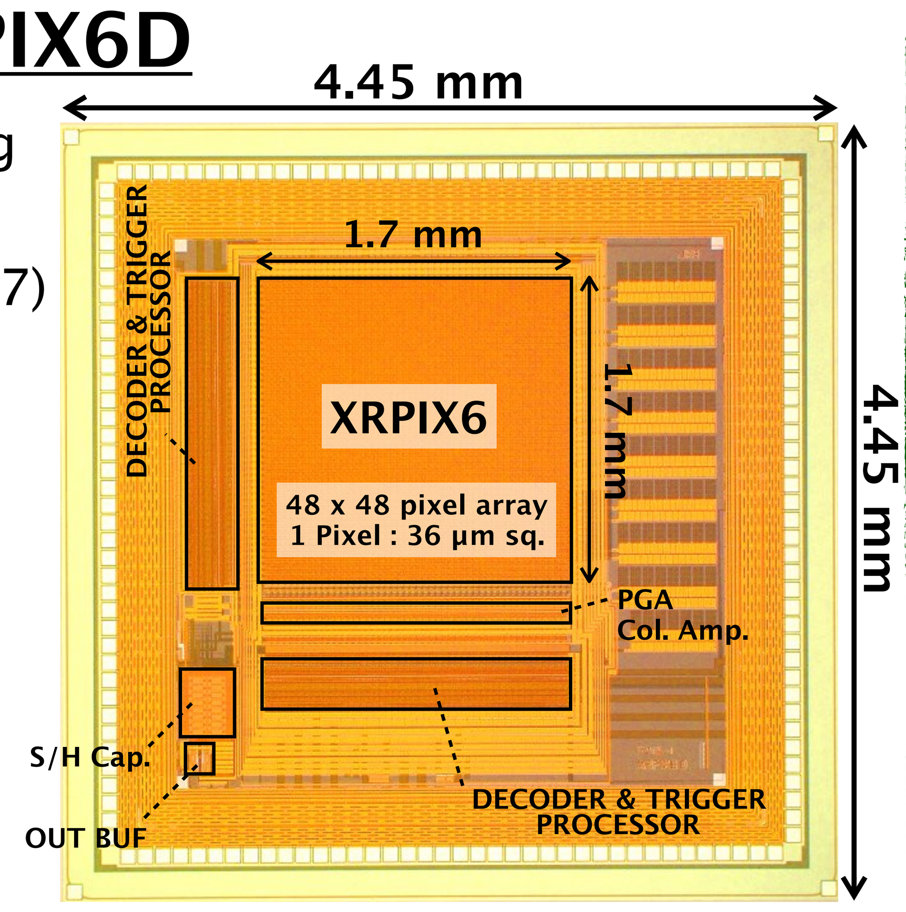
Our New Device -> "XRPIX6D"

Design Specification of XRPIX6D

XRPIX6D is the new prototype for improving spectroscopic performance by introducing Double-SOI structure. (Fabricated Jan., 2017)

Components

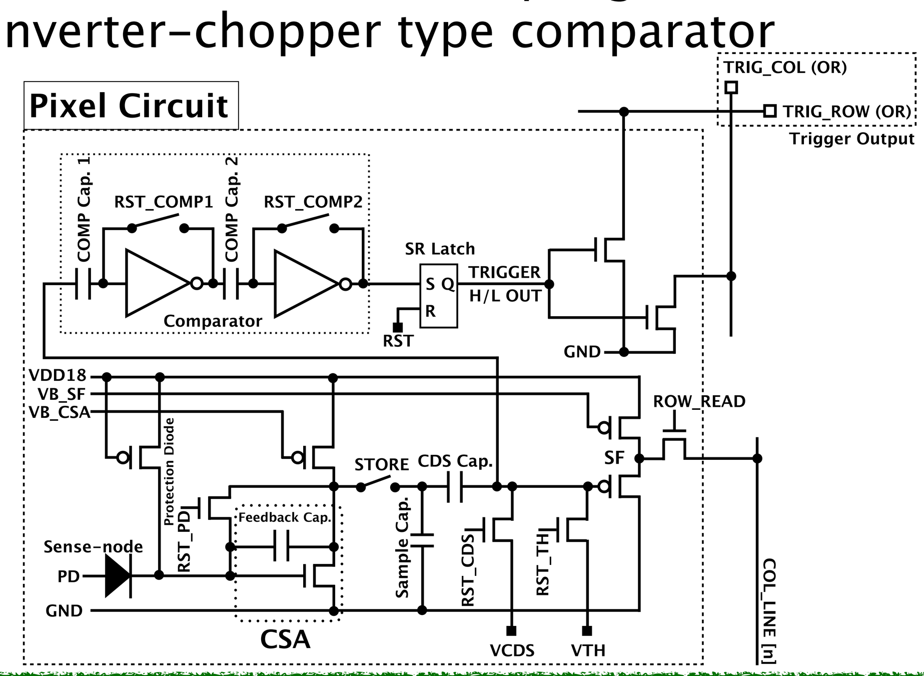
- Chip Size : 4.45 mm sq.
  (Effective Area : 1.7 mm sq.)
- Pixel Size : 36 μm sq.
- # of Pixel : 48 x 48 (= ~2.3k)
- Thickness of Sensor Layer : ~300 μm
- Sensor Wafer : ~1kΩ cm (PCZ wafer)
  * Double-SOI wafer



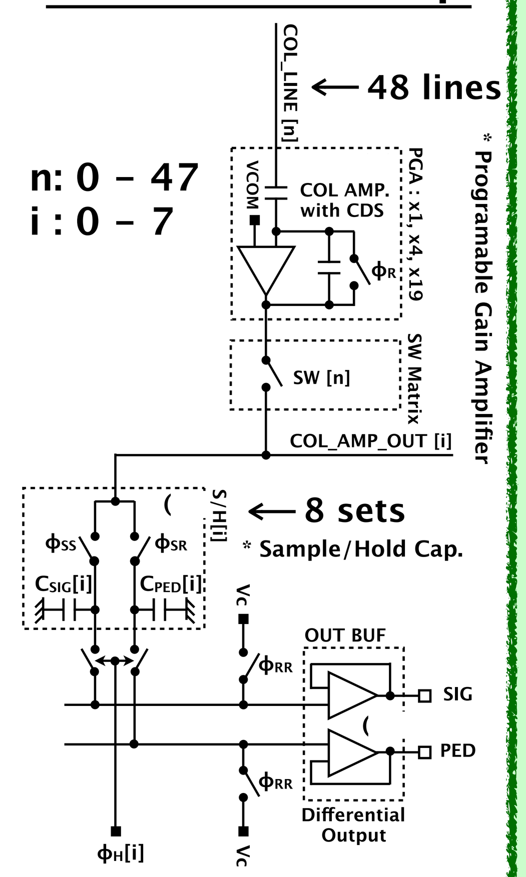
XRPIX6D Analog Circuit

Pixel Circuit consists of …

- Charge-sensitive amplifier (CSA)
- Correlated Double Sampling
- Inverter-chopper type comparator



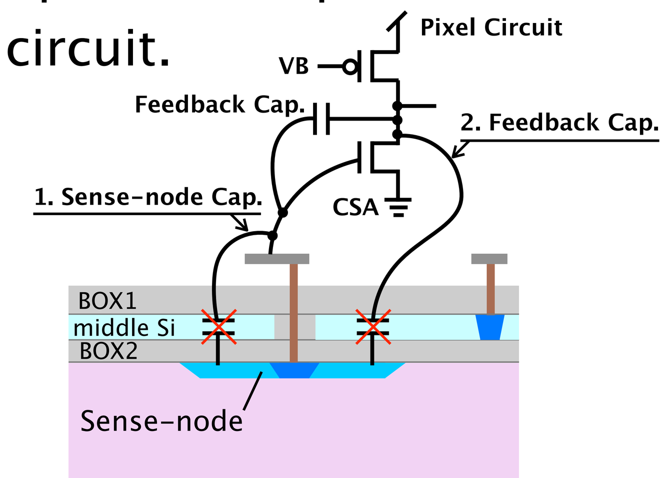
After Column Amp.



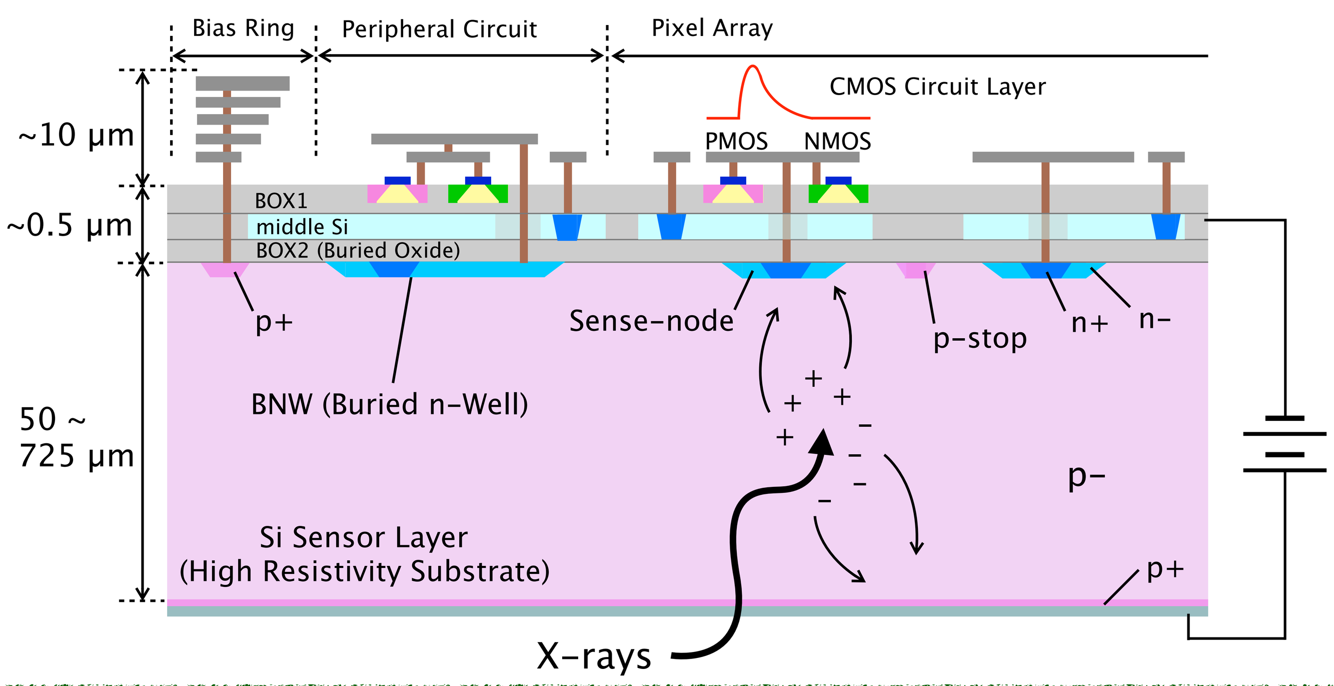
Introduction of Double-SOI Structure

The Double-SOI structure reduce parasitic capacitance between sense-node and CMOS circuit.

1. Sense-node Capacitance
-> Increase conversion gain
2. Feedback Capacitance
-> Increase closed loop gain



The spectroscopic performance improves by increasing the sense-node gain [6].
Therefore, we introduced Double-SOI structure at XRPIX6D.
Furthermore, Double-SOI structure can suppress electrical crosstalk between sense-node and CMOS circuit.



Improvement of spectroscopic performance

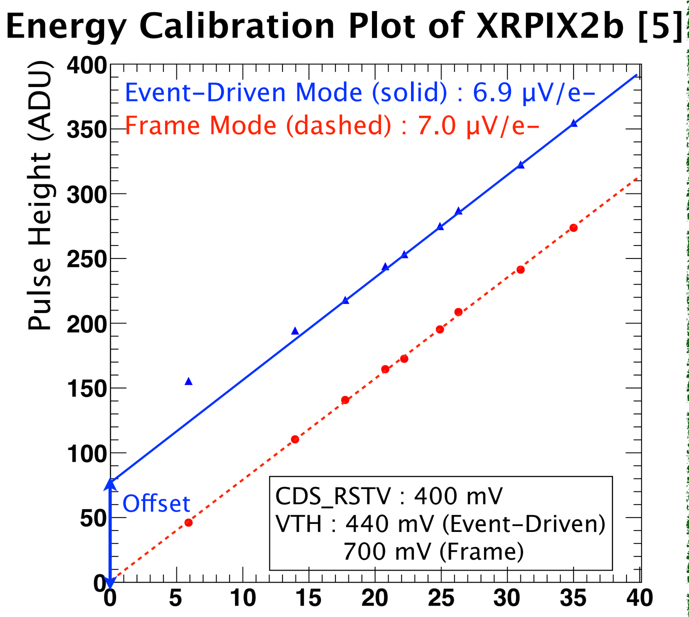
Our Previous Study

We showed the following issue in event-driven mode from our previous studies [5].

- Offset of pulse height to signal level (the right plot).
- Deterioration of spectroscopic performance.
  (comparison of frame readout mode)

We concluded that the behavior of the comparator affects the analog CMOS circuit as electrical crosstalk to the sense-node.

Energy Calibration Plot of XRPIX2b [5]

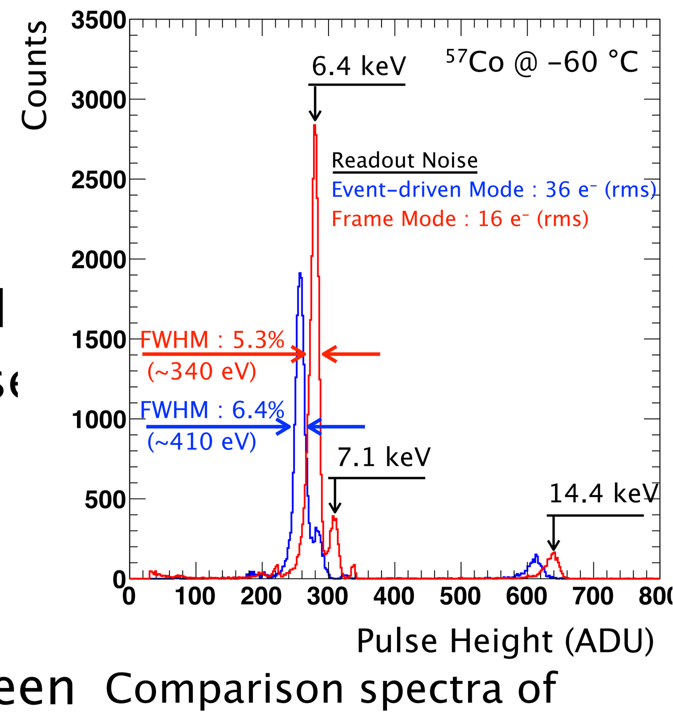


* Analog Digital Unit (ADU) = 244 μV

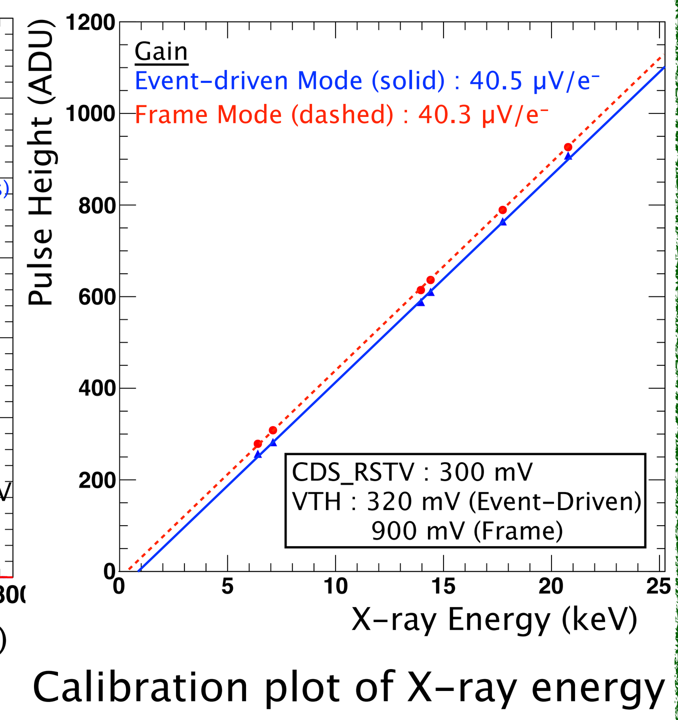
This Work

We evaluated and compared the frame and event-driven mode of XRPIX6D.
Compared with conventional our devices, the gain increase and the spectroscopic performance improved.

We observed suppression of the electrical crosstalk between the sense-node and CMOS circuit.



Comparison spectra of the frame and the event-driven mode.



Calibration plot of X-ray energy and signal pulse height.

Summary

- We have been developing SOIPIX for future X-ray astronomical satellite mission.
- A new device, "XRPIX6D" was designed for improving spectroscopic performance.
  -> Introduction of Double-SOI structure.
- We succeeded in improving the spectroscopic performance and suppressing the electrical crosstalk between sense-node and CMOS circuit by "XRPIX6D".
  Frame -> ~340 eV (FWHM) @ 6.4 keV, Event-driven -> ~410 eV (FWHM) @ 6.4 keV

Reference

[1] S.G.Ryu *et. al.*, *IEEE TNS.*, **Vol.58**, Issue:5, pp.2528-2536, 2011.
[2] S.G.Ryu *et. al.*, *IEEE TNS.*, **Vol.60**, Issue:1 , pp.465-469, 2013.
[3] S.Nakashima *et. al.*, *Phys. Procedia*, **Vol.37C**, pp.1392-1399, 2013.
[4] A.Takeda *et. al.*, *IEEE TNS.*, **Vol.60**, Issue:2, pp.586-591, 2013.
[5] A.Takeda *et. al.*, *PoS (TIPP2014)138*, 2014.
[6] A.Takeda *et. al.*, *JINST.*, **10**, C06005, 2015.

Please contact us if you are interested. -> http://rd.kek.jp/project/soi/
mail: takeda @ astro.miyazaki-u.ac.jp (Ayaki Takeda)

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