Soft X-ray Trigger Performance of X-ray Astronomy SOI Pixel Sensors, “XRPIX”

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Introduction

We have been developing X-ray Silicon-On-Insulator (SOI) pixel sensors, called “XRPIX” for the next generation X-ray astronomy satellite “FORCE” [1]. XRPIX has the event trigger output function which achieves a time resolution of 10 μs. This time resolution is five orders of magnitude better than that of X-ray CCDs, used as the main detectors in the current X-ray astronomy satellites.

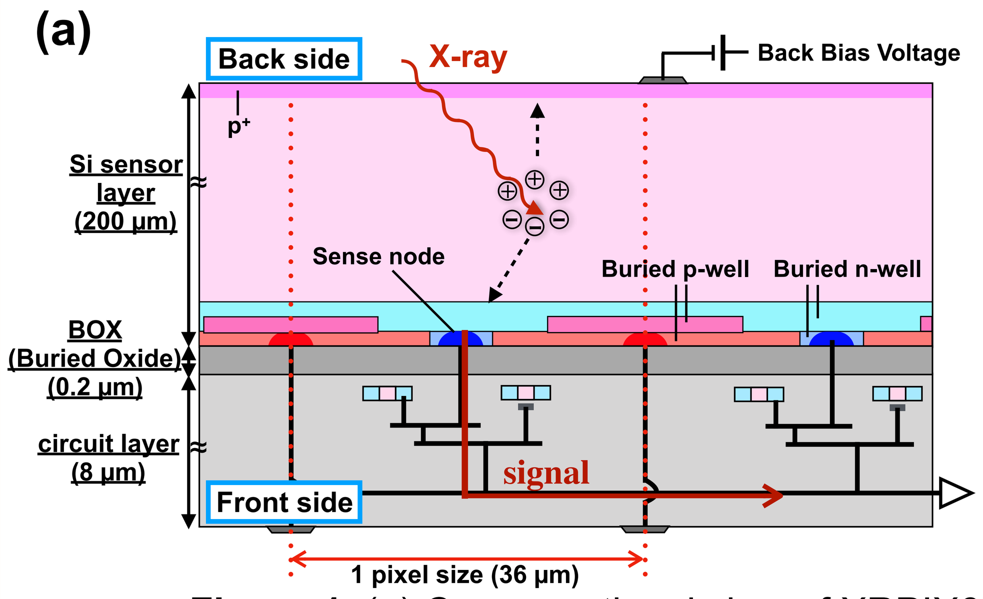
In order to improve spectroscopic performance, we have developed a test device, "XRPIX6E". It has a pinned depleted diode (PDD) structure minimizing the parasitic capacitance at the sense node and the dark current to lower the read out noise [2]. We already achieved an energy resolution of 264 eV (FWHM) for 6.4 keV X-rays with XRPIX6E [3]. We evaluate the trigger and the spectral performance for soft X-rays.

Device Discription of XRPIX6E with the PDD Structure

Figure 1 shows the cross section and the potential map of XRPIX6E with the PDD structure.

- The highly-doped buried p-well acts as an shield to suppress the electrical interference between sense node and circuit layer.

(a)



Pixel size	36 μm
Number of Pixels	48x48
Wafer type	Floating zone
Thickness of Sensor	200 μm

(b)

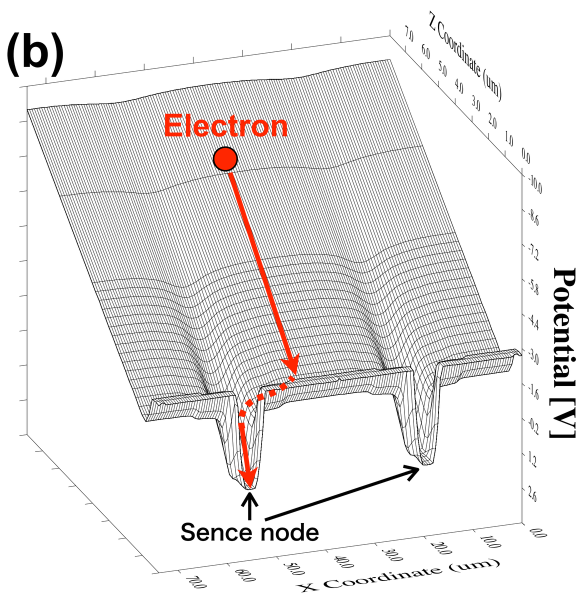


Figure 1. (a) Cross-sectional view of XRPIX6E. (b) Designed potential inside XRPIX6E [4].

XRPIX has **Event-Driven readout mode** (using trigger output), and **Frame readout mode** (not using trigger output).

- In event-driven readout mode, when the pulse height of the event exceeds the threshold, a trigger outputs, and then the pulse height is read out.
- In frame readout mode, we read out all pixels serially like a CCD.

Experimental Set-up

- We irradiated XRPIX6E with ^{57}Co(6.4, 7.1, 14.4 keV), Al-K(1.5 keV), F-K(0.68 keV) in order to investigate linearity between X-ray and trigger threshold voltage, lowest possible trigger threshold level, and soft X-ray spectral performance.
- Back-bias voltage of -200 V is applied.
- The chip is cooled at -50 ℃.

Linearity between Energy and Threshold Voltage

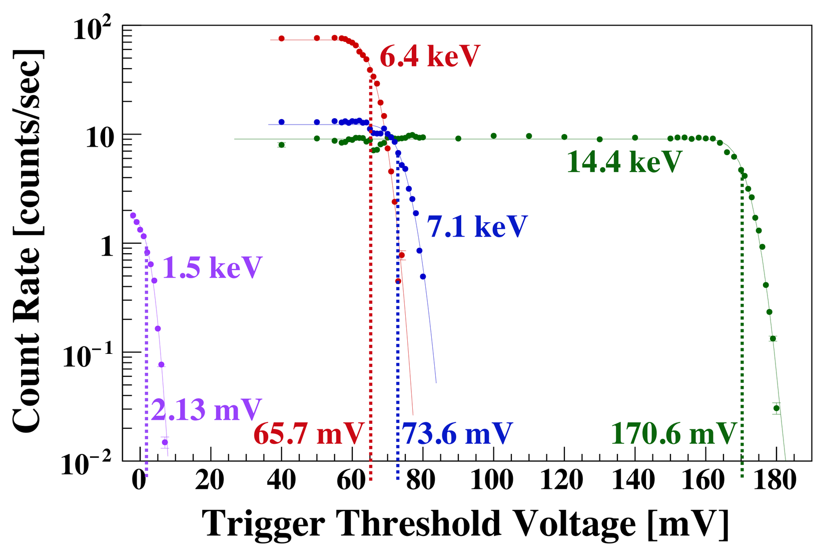


Figure 2. X-ray count rate V.S. trigger threshold voltage.

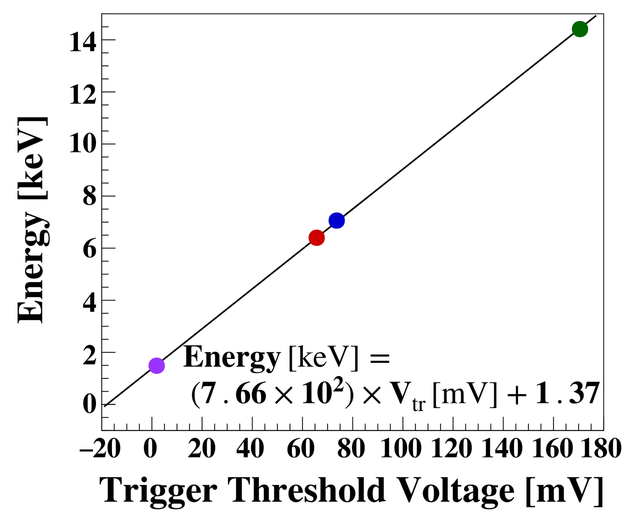


Figure 3.Relationship between X-ray energy and trigger threshold voltage.

We investigated the count rates of several X-rays as a function of trigger threshold voltage.

- Figure 2 shows that the trigger rates decrease with increasing threshold voltage, which can be well fitted with error functions.
- Figure 3 shows the linear relationship between the energy and the trigger threshold voltage. Each value of threshold voltage is corresponding to the half value of the count rate obtained from error function in Figure 2.
- Although overall linearity is good (the residual is less than 2.2%), there is an offset equivalent to 1.4 keV.

Lowest Possible Threshold Level

We determine the lowest possible trigger threshold voltage.

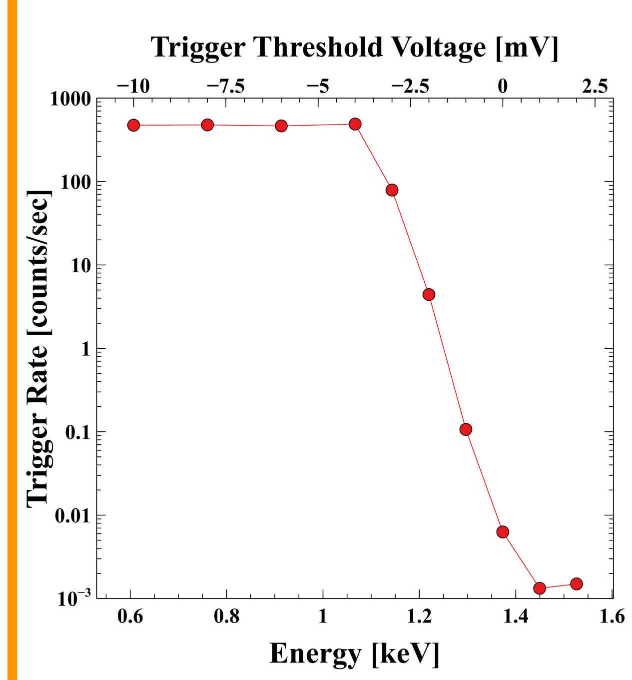


Figure 4. The count rate triggered by noise as a function of trigger threshold voltage.

If we lower the trigger threshold in order to detect soft X-ray, electrical noise fires triggers. We measured noise trigger rates with several trigger threshold levels without X-ray illumination. Figure 4 shows the result.

- X-rays above 1.5 keV can safely be detected almost without triggers fired by noise.
- If we allow noise trigger rate of 10 Hz, we can detect X-rays with energies down to 1.2 keV.

Spectral Performance for Soft X-rays

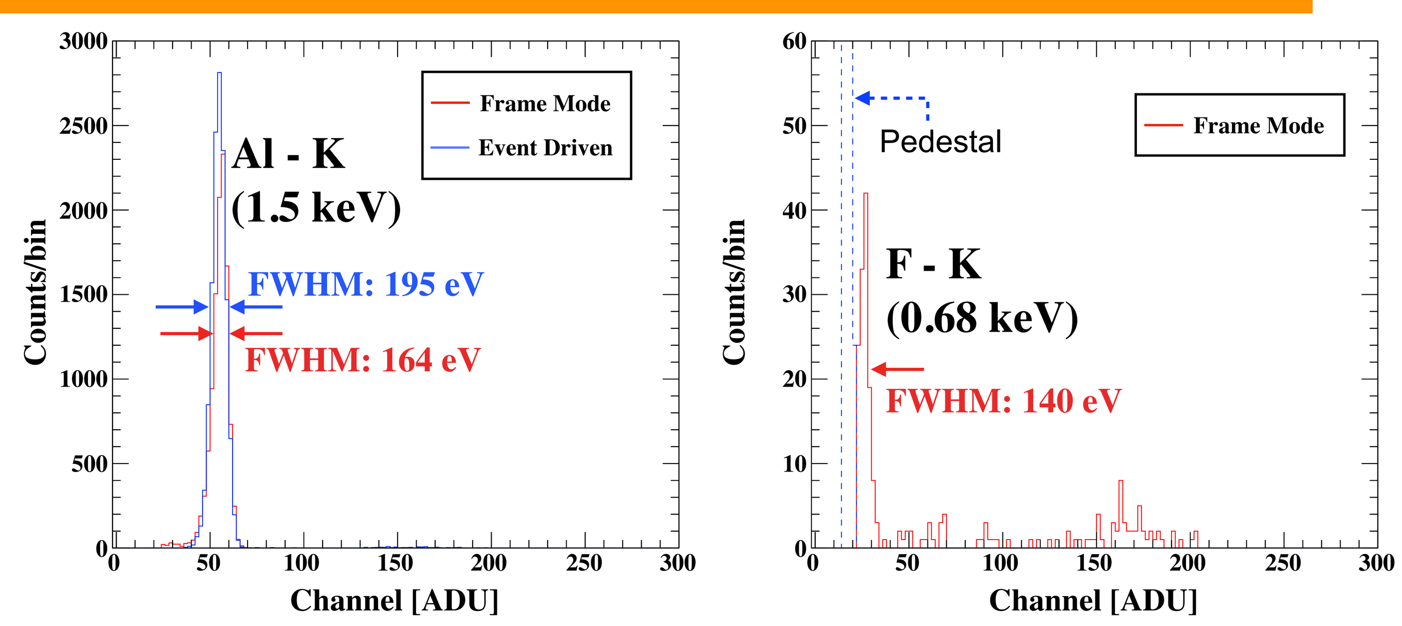


Figure 5. Soft X-ray spectra (Al - K & F - K).

- We successfully obtained Al-K spectrum from event-driven readout mode.
- Energy resolution of Al-K line in event-driven readout mode is not as good as in frame readout mode.
- F-K line can be detected in frame readout mode, which indicates that the signal level of F-K is higher than readout noise level. In event-driven readout mode, however, we can’t detect the line because of the trigger circuit noise. Therefore, further noise reduction is necessary.

Summary

- We have been developing XRPIX for future X-ray astronomy satellites, which realize a time resolution of 10 μs.
- Linearity between energy and threshold voltage is good, however, there is an offset equivalent to 1.4 keV.
- The lower limit of detectable energy with event-driven mode is 1.2 keV.
- We successfully obtained Al-K spectrum from event-driven mode.
- Although F-K can be detected in frame readout mode, it can’t be detected because of the noise of trigger circuit in event-driven readout mode.

Reference

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[2] H.Kamehama et al., Sensors 18 (2017) 27.
[3] K.Kayama, et al., JINST 14 (2019) C06005.
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