Development of X-ray SOI pixel sensors for future X-ray wide field cameras

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Abstract

We have been developing XRPIX for X-ray wide field cameras using two-dimensional coded masks. XRPIX is a monolithic active pixel sensor based on the silicon-on-insulator (SOI) pixel technology. XRPIX contains a comparator circuit in each pixel. Thus, XRPIX offers a good time resolution better than 10 μs in addition to the imaging and spectroscopic capabilities comparable to those of X-ray charge-coupled devices. Recently, we have developed XRPIX5, which has a large imaging area of 21.9 mm $\times$ 13.8 mm and the format of 608 $\times$ 384 pixels. We successfully obtained X-ray spectra from almost all regions of XRPIX5 in the frame mode. We found that the readout noise is $\sim$ 37 e^- (rms) and the energy resolution is $\sim$ 710 eV (FWHM) at 13.95 keV. Furthermore, we confirmed that the gain of various regions of XRPIX5 is 18.4–18.8 μV/e^-.

Key words: monolithic active pixel sensor, SOI pixel technology, X-ray, imaging, spectroscopy

1. Introduction

X-ray charge-coupled devices (CCDs) are standard imaging spectrometers widely used for focal plane detectors in modern X-ray astronomy satellites. CCDs have good performance because of their small pixel sizes ($\sim$ 20 μm sq.) and good energy resolution almost at the Fano limit ($\sim$ 130 eV in FWHM at 6 keV). However, CCDs suffer from problems such as poor time resolution (a few seconds) and a high non-X-ray background (NXB) especially above 10 keV due to interactions of cosmic rays. Therefore, we have been developing XRPIX with high-speed readouts and low background. XRPIX is a monolithic active pixel sensor based on the silicon-on-insulator (SOI) pixel technology [1]. Fig. 1 shows the cross-sectional view of XRPIX. XRPIX contains a comparator circuit in each pixel for hit trigger (timing) and two-dimensional hit-pattern (position) outputs in addition to the imaging and spectroscopic capabilities comparable to those of CCDs. The function allows us to read out analog signals only of hit pixels, which is referred to as the event-driven readout mode. Thus, XRPIX offers a good time resolution better than 10 μs and a high throughput reaching $>$ 1 kHz. We can also reduce the NXB by applying the anti-coincidence technique because of the good time resolution. In our previous studies, we successfully demonstrated the X-ray detection by the event-driven readout [2].

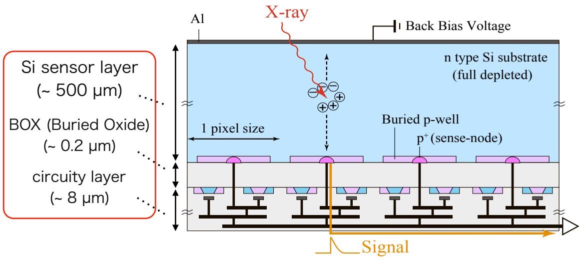

Fig. 1. Cross-sectional view of XRPIX.

2. Proposal of X-ray wide field cameras using XRPIX

MAXI has opened up the all-sky monitor and time-domain astronomy in the soft X-ray band below 10 keV. In order to push out the frontiers, we propose X-ray wide field cameras using XRPIX with two-dimensional coded masks. The cameras can reduce the NXB and perform fast timing observation because XRPIX has a much better time resolution than that of CCDs. The angular resolution in principle reaches 2.5 arcmin by adopting the same pitch size for the coded mask and the distance between of 10 cm XRPIX and the mask. Furthermore, the field of view reaches 65° × 45° by adopting the XRPIX size of 44 mm × 28 mm (This size is about the same size of 4 chips of XRPIX5, which is described later.) and the coded mask size of 88 mm × 56 mm.

3. Evaluation of XRPIX5

Large size chips are essential for the wide field cameras. Recently, we successfully processed XRPIX5, which has a large imaging area of 21.9 mm × 13.8 mm and the format of 608 × 384 pixels. The pixel size is 36 μm × 36 μm. XRPIX5 has high resistivity floating zone wafer ($\rho > 2$ kΩ cm) with a thickness of 500 μm. XRPIX5 features the largest imaging area in the XRPIX series. In this chapter, we report the first evaluation results of XRPIX5, especially whether the performance changes due to its large size.

Fig. 2 shows the ^{241}Am X-ray spectrum and the gain calibration curve using ^{241}Am, ^{109}Cd and ^{55}Fe X-rays. We use only single pixel events for the spectrum. We took the data using the frame mode in which we read out assigned 8 × 8 pixels in each frame. For the present data, we read out 8 × 8 pixels around [ra, ca] = [304, 192] ("ra" means row address, and "ca" means column address.). We found that the readout noise, the energy resolution and the gain are ~ 37 e$^-$ (rms), ~ 710 eV (FWHM) at 13.95 keV and 18.8 μV/e$^-$, respectively. This performance is nearly the same as XRPIX3b, which has the best spectral performance in the XRPIX series [3].

We successfully obtained X-ray spectra from the 5 regions shown in Fig. 3. This suggests that we can obtain X-ray spectra from the entire region of the sensor. We evaluated differences in gain of various regions. As shown in Fig. 3, the gain is found almost uniform (18.4–18.8 μV/e$^-$).

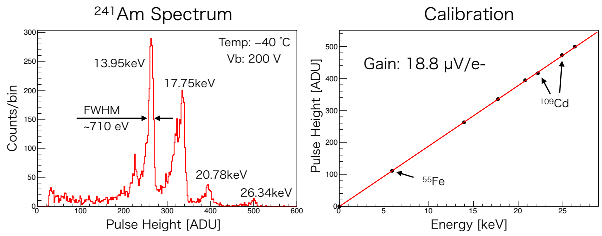

Fig. 2. X-ray spectrum of an ^{241}Am radioisotope and output pulse height as a function of X-ray energy. The pulse height is shown in analog digital units (ADU). 1 ADU is 244 μV.

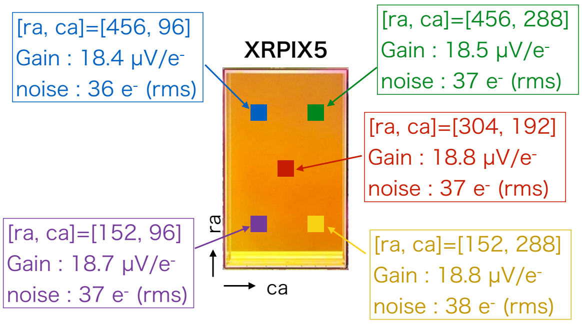

Fig. 3. Gain of various regions of XRPIX5.

4. Summary

We develop XRPIX and propose X-ray wide field cameras using XRPIX with two-dimensional coded masks. In principle, we can realize the small size and fast timing cameras which have angular resolution of 2.5 arcmin and field of view of 65° × 45°. We successfully processed XRPIX5 with a large imaging area and obtained X-ray spectra from various parts of XRPIX5. The readout noise is ~ 37 e$^-$ (rms) and the energy resolution is ~ 710 eV (FWHM) at 13.95 keV. The gain is found almost uniform (18.4–18.8 μV/e$^-$). At present, we conclude that the performance does not degrade despite the large chip size. We will further evaluate XRPIX5 including the verification of the event-driven mode.

References

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