Development of p-channel CCDs for NeXT

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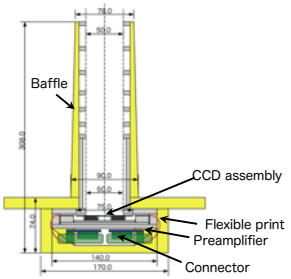
(Abstract) We develop an X-ray CCD camera system (SXI: Soft X-ray Imager) as a focal plane detector of an X-ray telescope onboard NeXT, the next Japanese X-ray astronomical satellite mission. We develop p-channel CCDs as the goal of SXI. We report the test results of two p-channel CCD devices, Pch-15 and Pch-teg. Pch-15 is a front illuminated CCD consisting of 512 x 512 pixels with a pixel size of 24 μm x 24 μm. Pch-15 was fabricated on an n-type silicon wafer of 600 μm thickness. The thickness of depletion layer of Pch-15 was evaluated to be 290±33 μm from the detection efficiency of 22.4 and 24.9 keV emission lines from ^{109}Cd. Pch-teg consists of 328 x 320 pixels with a pixel size of 14.5 μm x 15 μm. Pch-teg was designed as a fully depleted front illuminated CCD with wafer thickness of 200 μm. The thickness of depletion layer of Pch-teg was evaluated to be 172±13 μm. We detected the oxygen K line at 527 eV with Pch-teg and evaluated the energy resolution to be 81±1 eV of FWHM at 527 eV. We evaluated the energy resolution, readout noise, and charge transfer inefficiency for both the devices by ^{55}Fe irradiation.

1. SXI: Soft X-ray Imager

The SXI is an X-ray CCD camera system onboard NeXT, the next Japanese X-ray astronomical satellite mission. The SXI is required to cover X-ray energy range in the 0.5-12 keV.

Energy band	**0.5 - 12 keV**
Pixel size	**24 μm× 24 μm**
Image array	**2048 × 2048**
Storage array	**2048 × 2048**
Image area	**50 mm×50 mm**
FOV	**19 '×19 '**
Readout node	**8**
Energy resolution	**< 135 eV at 5.9keV**
Readout noise	**< 5 e$^-$**
CTI	**< 5 × 10^{-6}**

Requirements for SXI



2. P-channel CCD

	Baseline	Goal
Wafer	**P-type (N channel)**	**N-type (P channel)**
Depletion layer	**70~100 μm**	**200 μm**
Illumination method	**Front illuminated**	**Back illuminated**

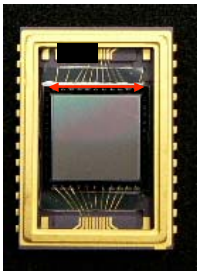
We develop p-channel CCDs as the goal of the SXI. Although n-channel CCDs have been employed for previous X-ray astronomical satellites, we set p-channel CCDs as the goal of the SXI because p-channel CCDs could have thicker depletion layer than n-channel CCDs.

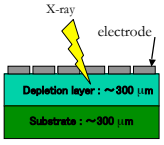
$$d \sim (\mu\rho V)^{0.5}$$

d thickness of depletion layer
μ mobility of major carrier
ρ resistivity of wafer
V bias voltage

The mobility of the electron ,the major carrier of n-type silicon wafer for p-channel CCD, is three times larger than that of the hole, the major carrier of p-type silicon wafer for n-channel CCD. Besides, it is easy to obtain n-type silicon wafer with high and uniform resistivity compared to p-type silicon wafer.

3. Test device Pch-15

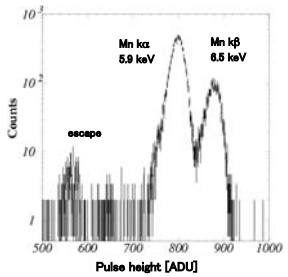




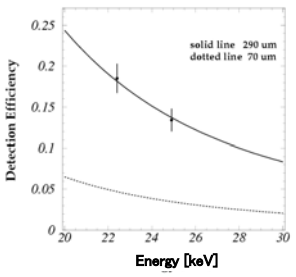
Specification	
Pixel size	24μm x 24μm
Format	512 x 512
Wafer thickness	600μm
Illuminated method	FI

Performance	
Energy resolution	202±6 eV at 5.9 keV
Readout noise	18 electrons
CTI (horizontal)	(1.0±0.1) × 10^{-5}
CTI (Vertical)	< 10^{-6}
Depletion layer	290±33 μm

Operation temp −110°C
Readout speed 67 kHz



X-ray histogram of ^{55}Fe obtained with Pch-15. The energy resolution was (202±6) eV of FWHM. The readout noise was 18 electrons (r.m.s).

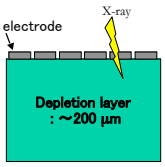


Detection efficiency for 22.4 and 24.9 keV emission lines from ^{109}Cd obtained with Pch-15. The thickness of depletion layer was calculated to be 290±33 μm.

4. Test device Pch-teg

4.1 Specification

Schematic of cross section

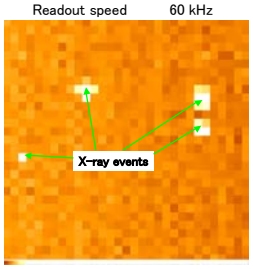


Specification	
Pixel size	14.5 μm x 15 μm
Format	328 x 320
Wafer thickness	200 μm
Illuminated method	FI (Front illuminated)

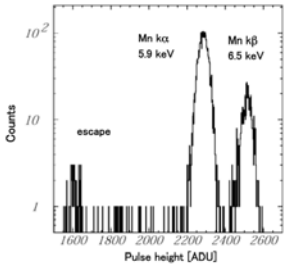
Performance	
Energy resolution	143±3 eV at 5.9 keV
Readout noise	7 electrons
CTI (horizontal)	< 10^{-5}
CTI (Vertical)	< 10^{-5}
Depletion layer	172±13 μm

4.2 ^{55}Fe irradiation

Operation temp −70°C
Readout speed 60 kHz

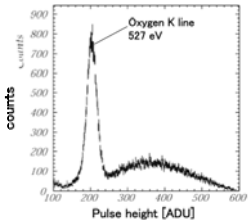


Iimage of X-ray events with a pixel size of 14.5μm×15μm



X-ray histogram of ^{55}Fe obtained with Pch-15. The energy resolution was 143±3 eV of FWHM, and the readout noise was 7 electrons (r.m.s).

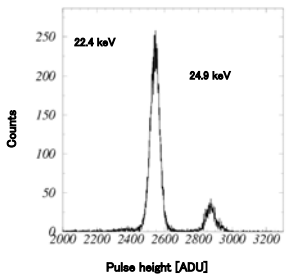
4.3 Low energy responsivity



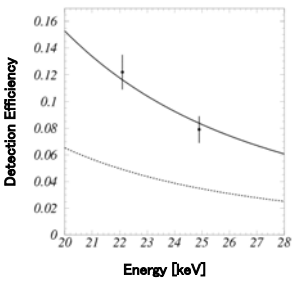
We investigated low energy responsivity by irradiation with Oxygen K lines generated by an X-ray generator.

Energy resolution was 81±1 eV of FHWM at 527 eV.

4.4 Thickness of depletion layer



X-ray histogram of ^{109} Cd obtained with Pch-teg. Ag Kα (22.4 keV) and Kβ (24.9 keV) emission lines are resolved.



Detection efficiency for 22.4 and 24.9 keV emission lines from ^{109}Cd obtained with Pch-teg. The thickness of depletion layer was calculated to be 172±13 μm.

Reference
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