Development of fully-depleted and back-illuminated charge coupled devices for Soft X-ray Imager onboard the NeXT satellite

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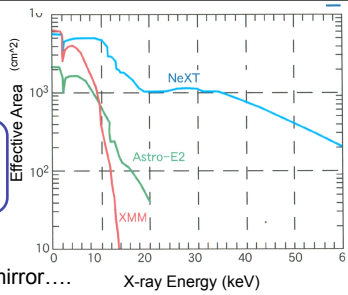
1. Introduction

1-1 NeXT satelite

- Launch in around 2012
- Multi-layer Super Mirror
- Large Effective Area in 0.1-80keV



To detect all X-rays collected by this super mirror….

Focal plane detector should be sensitive in the wide energy band.

1-2 Soft X-ray Imager (SXI) and Hard X-ray Imager (SXI)

X-ray CCD and CdTe pixelized detector

To match the wide energy range of NeXT, we have been developing two different types of focal plane detectors…

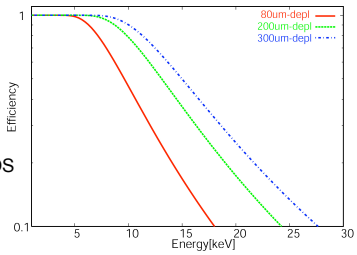
X-ray CCD ⇒ Soft X-ray Imager
- ○ Good Spatial & Energy Resolution
- × Low Sensitivity at the higher energy band

CdTe detector ⇒ Hard X-ray Imager
- ○ High Sensitivity in the wide energy band
- × Low Spatial Resolution (>200um)
- × Low Energy Resolution for Soft X-rays

Soft X-rays: detected by X-ray CCD, Hard X-rays: detected by CdTe

2. CCD for Soft X-ray Imager

High Sensitivity for hard X-rays
⇒The key parameter is thickness of the depletion layer



Established X-ray MOS CCD
(Chandra ACIS, XMM-Newton EPIC-MOS and Suzaku XIS)
⇒～80um-thickness of depletion layer (～5%@20keV)

We challenge to develop Pch Back-illuminated (BI) CCD which has the thick depletion layer of over 200um (～15%@20keV).

To achieve such device…

We changed the type of wafer from P-type semiconductor (which is conventionally used) to N-type one (over 10kΩcm resistivity).

We have already confirmed…

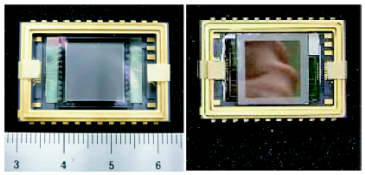
The thickness of depletion layer of test devices of Pch CCD reach 300um (Kamata et.al. 2004, Matsuura et.al. 2006).
The wafer can be mechanically thinned down to < 150um without any mechanical damage and performance degradation (Takagi et al. 2005).

⇒We can expect to fabricate the fully-depleted and back-illuminated CCD with the thick depletion layer.

We develop fully-depleted and back-illuminated Pch CCD for SXI.

3. Test model of fully-depleted BI-CCD

3-1 Specification



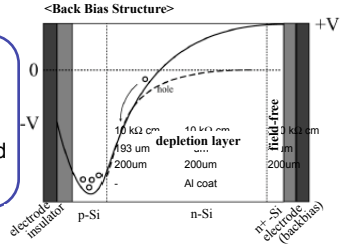
(left) BI 15-14 and BI 15-06. (Right) BI 15-22 . Due to Al coating, The hand of the photographer is reflected in the surface.

Table 1. Specification and typical performance of test models

Type No.	BI 15-14	BI 15-22	BI 15-06
Format	512 x 512		
Pixel size	24um x 24um		
Clock phase	2 phase		
Transfer method	Full Frame Transfer		
Illuminated method	Back Illuminated (Full depleted)		
Wafer Resistivity			
Depletion Layer			
Wafer *			

Remarks
#: not measured. * :Nominal value reported by HPK

- Depletion thickness = 200um
- Fully depleted
- Back illumination
- Backbias electrode (see right Fig.)
- ⇒ to restrain the size of charge cloud
- ⇒ to safely apply large voltage gap



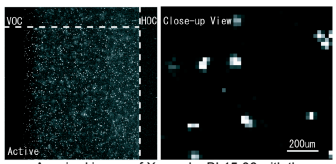
Schematic view of the potential well of back bias structure

3-2 Basic Characteristics

- The detection efficiency of BI15-14 is 12%@22keV (^{109}Cd) .

⇒equivalent to 193um-thickness of depletion layer, as we expected.

- Table 2 shows the characteristics of BI 15-06 in various back bias voltages of 1, 5, 10, and 20V. We clearly see there are not few changes in the performance dependent on the back bias voltage.



Acquired image of X-rays by BI 15-06 with the back bias voltage of 20V.

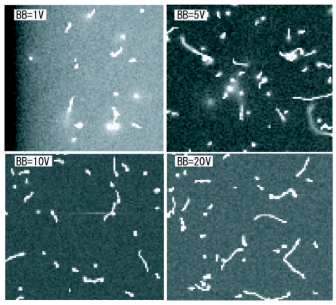
Table 2. Comparison of characteristics of BI 15-06 in various back bias voltages.

V_{BB}	Sv*	CTIx*	CTIy*	I_{dark}*
[V]	[uV/e]	[10^{-5}/transfer]	[10^{-5}/transfer]	[e-/sec/pix]
1	2.0	2.1(1.9-2.4)	0.6(<1.2)	0.08
5	2.0	2.8(2.3-3.1)	0.84(<1.4)	0.13
10	2.0	2.4(2.1-2.8)	0.52(<1.1)	0.17
20	2.0	0.6(<1.1)	1.1(<1.9)	0.22

Parentheses indicate the 1-sigma confidence limit.
*: Voltage applied to back bias electrode.
#: Node sensitivity.
$, %: Charge transfer inefficiency of horizontal(x) and vertical(y) transfer.
&: Dark current at -98 degC

3-3 β-ray Image

- The tracks of β-ray (^{90}Sr: 546keV) are seen more clearly and the charge distribution of tracks becomes narrower, as the voltage level of the back bias electrode increased.
- This suggests the size of the hall cloud is successfully restrained at the high back bias voltage level as we expected.
- These narrow charge distribution of β-ray tracks also suggest these devices are fully depleted.



Images of β-ray from ^{90}Sr detected by BI 15-06 with the back bias voltage

4. Summary

- We fabricated the test devices of the fully-depleted and back-illuminated CCD on the high resistivity N-type wafer, which thinned down to 200 um.

⇒We confirmed these devices successfully detected X-rays and were almost fully-depleted by the measurement of the detection efficiency for ^{109}Cd and the shape of the β-ray track

- We formed a back bias electrode on the backside surface of these test devices in order to intensify the electric field in a depletion layer.

⇒We confirmed there are not few changes in the spectroscopic performance dependent on the back bias voltage and the size of the hall cloud is successfully restrained at the high back bias voltage level from the image of the β-ray events.

References

[1] Kamata, Y., et al., Proc. of SPIE, 5499, pp. 210-218, 2004
[2] Matsuura, D., et al., Proc of SPIE, submitted (in this volume)
[3] Takagi, S., et al., NIMA, 541, pp. 385-391, 2005