The X-ray CCD camera of the MAXI Experiment on the ISS/JEM

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Abstract

MAXI, Monitor of All-sky X-ray Image, is the X-ray observatory on the Japanese experimental module (JEM) Exposed Facility (EF) on the International Space Station (ISS). MAXI is a slit scanning camera which consists of two kinds of X-ray detectors: one is a one-dimensional position-sensitive proportional counter with a total area of $\sim 5000 \text{ cm}^2$, the Gas Slit Camera (GSC), and the other is an X-ray CCD array with a total area $\sim 200 \text{ cm}^2$, the Solid-state Slit Camera (SSC). The GSC subtends a field of view with an angular dimension of $1^\circ \times 180^\circ$ while the SSC subtends a field of view with an angular dimension of $1^\circ$ times a little less than $180^\circ$. In the course of one station orbit, MAXI can scan almost the entire sky with a precision of $1^\circ$ and with an X-ray energy range of $0.5–30 \text{ keV}$.

We have developed the engineering model of CCD chips and the analogue electronics for the SSC. The energy resolution of EM CCD for Mn K$\alpha$ has a full-width at half maximum of $\sim 182 \text{ eV}$. Readout noise is $\sim 11 \text{ e}^{-}\text{rms}$.

1 Introduction

The charge coupled device (CCD) is a standard X-ray detector due to its high X-ray detection efficiency, moderate X-ray resolving power, and high spatial
resolving power. The Solid-state Imaging Spectrometer, SIS, onboard ASCA is the first CCD camera used as a photon counting detector and equipped on board the satellite ([1]). Following SIS, many satellites such as HETE ([2]), Chandra ([3]), XMM ([4]), and Astro-E ([5]) carry a X-ray CCD camera on their focal planes.

2 MAXI

The International Space Station (ISS) will be placed in a nearly circular, high inclination (51.6°), low Earth orbit having a 96 minute orbital period with respect to a point in the sky. ISS will rotate synchronously with its orbit so that one side will always point toward the center of the Earth and the opposite side will permanently view the sky. A payload is attached to the main structure of the JEM which rotates and has unpredictable disturbances. Therefore, pointed observations are very difficult on the JEM. On the other hand, synchronous rotation with orbital revolution provides access to the entire sky in one orbit without a moving mechanism. Considering these characteristics, we conclude that a monitoring mission or survey of a large field of the sky is suitable, and can produce significant scientific results.

The schematic view of MAXI is shown in figure 1. MAXI can scan almost the entire sky with a precision of 1°. MAXI carries two kinds of X-ray detectors: a one-dimensional position-sensitive proportional counter (GSC) and an X-ray CCD camera (SSC). Combining these two cameras, MAXI can monitor X-ray sources with an energy band of 0.5−30 keV. The total weight of MAXI is about 500 kg. Simulations of the data expected from MAXI have been performed in ([6]). A detailed description of MAXI can be found in ([7], [8]).

3 SSC

The SSC is an X-ray CCD camera system. The SSC consists of two X-ray CCD cameras, each comprising 16 CCD chips. The block diagram of the SSC camera is shown in figure 2. The SSC consists of three parts: two CCD cameras, analogue electronics (SSCE), and a digital processing unit (DP). Detailed specifications of the SSC are shown in table 1.

The CCD is fabricated by Hamamatsu Photonics K.K. (HPK). The CCD chip is three-side buttable with full-frame transfer and has 1024 × 1024 pixels of 24µm×24µm size with two phase gate structures. The CCD chip is covered by ∼2000Å Al to block optical light. The CCD is operated at −60°C, which
is achieved by using a passive cooling system and a Peltier cooling system (TEC). TEC is supported with glasses to hold out the launch shock.

The SSCE is developed by Meisei Electronics. There are several CCD signal processing techniques ([9] and references therein). To measure the voltage of each charge packet, we need a reference voltage between the floating level and the signal level. The correlated double sampling technique is widely used for this purpose. In practice, it is advantageous to integrate or take the sum of the signals rather than merely spot sample floating and signal levels. Thus, a delay-line circuit is used in SIS/ASCA and an integrated circuit is introduced for SXC/HETE, ACIS/Chandra and XIS/Astro-E. We plan to develop all these circuits for the SSC and will select the one that possesses the lowest readout noise.

Since the data rate of CCD is fairly high, an onboard data reduction system is important. We developed an efficient reduction system based on our experiences with SIS/ASCA and XIS/Astro-E. There are three parts in DP: the control unit, the event handling unit (EHU), and the telemetry unit. Two CPU boards (RAD 6000) on the VME bus will be used for EHU and another CPU board will be used for the control unit, the telemetry unit, and GSC data processing.

There are two interfaces between MAXI and JEM Exposed Facility (EF): medium-speed interface (10Base-T ethernet) and low-speed interface (MIL1553B). All CCD data will be downlinked through the ethernet whereas part of health and status (HS) data will be transferred through MIL1553B.

Based on the SIS/ASCA, we have learnt much about radiation damage on the CCD ([10]). One serious problem is the increase in dark current and its non-uniformity. To minimize the effects of radiation damage on the CCD, we allocate a dark level buffer for every pixel. The dark level for each pixel is updated for every frame based on the pulse height of pixel of interest. For the recovery of the radiation damage, we use an annealing process. However, we think that the radiation damage would be small because the lifetime of MAXI is two years (might be extended) and the orbit is lower than other missions (≃ 400km).

Since the SSC is a one-dimensional X-ray camera, we use the spatial resolving power of the CCD only for the horizontal axis. Thus, we operate CCD in the parallel summing mode (same as the fast mode for SIS/ASCA). The vertical axis of the CCD corresponds to the time. The binning number can be changed as $2^n$ (n=2~8). 16 CCD chips in one camera are read cyclically using a multiplexer.
4 SSC Engineering Model

The engineering model (EM) of the CCD chip has been completed and tested at the Osaka University X-ray CCD laboratory. EM of CCD is shown in figure 3 where CCD is fixed on the Al plate. Two cables connected to the CCD are used for the Peltier cooler.

There are three types of CCD produced for EM: a standard chip (standard), a deep depletion type I (deep-I), and a deep depletion type II (deep-II). There is a difference both in the depletion layer and in the dark current among these three types of CCDs. The details of these three chips can be referred to in Miyaguchi et al. (1999, [11]).

EM of the SSCE has been fabricated by MEISEI on the VME board. The function test of the EM SSCE is underway.

5 X-ray Responsivity

5.1 Experimental Setup and Analysis

We evaluated the X-ray responsivity of deep-I EM CCD. We cooled the CCD chip down to $-100^\circ$ with a He cryogenic system in the vacuum chamber. We used the C4880 CCD camera system, which is the X-ray CCD data acquisition system manufactured by HPK. Exposure time was set at 5 seconds.

CCD frame files were transferred to a workstation through the ethernet with FITS format after they were acquired by C4880. HK information was collected with a workstation and stored in a hard disk.

Dark current image was constructed with several CCD frame files using the same algorithm as that of XIS/Astro-E ([5]). Before the X-ray event extraction, the dark current image was subtracted from each frame.

5.2 Results

Figure 4 shows the energy spectrum of X-rays from $^{55}\text{Fe}$ for single-pixel events. The split threshold is $\simeq 70$ eV. Mn K$\alpha$ and K$\beta$ lines are clearly separated. The energy resolution of Mn K$\alpha$ has a full-width at half maximum of $\simeq 182$ eV. Readout noise is $\simeq 11$ e$^{-}$rms.
Since the energy resolution of HPK CCD is $\sim$40\% less than that obtained by CCDs fabricated by the MIT Lincoln Laboratory (e.g. [5]). HPK plans to improve the CCD to achieve performance comparable to those of other X-ray CCD devices.

6 Conclusion

MAXI is an X-ray all-sky monitor on the International Space Station and is due for flight in 2003. It is designed to scan almost the entire sky with a precision of $1^\circ$ and with an X-ray energy range of 0.5–30 keV in the course of one station orbit.

We have developed the engineering model of the analogue electronics and the CCD chips for the X-ray CCD camera, SSC. We evaluated the X-ray responsivity of the EM CCD chip. The energy resolution of Mn K\(\alpha\) X-rays has a full-width at a half maximum of 182 eV. Based on the EM results, we will improve the performance of CCD and its electronics.

References

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| Specification                          | Value                     |
|---------------------------------------|---------------------------|
| **CCD type**                          | HPK CCD (Frame transfer; two phase) |
| Number of cameras                     | 2                         |
| Number of CCD chips per camera        | 16                        |
| Number of CCD pixels                  | 1024 (H) × 1024 (V)       |
| Pixel size                            | 24 μm × 24 μm             |
| Effective depletion depth (target)    | 30 – 50μm                 |
| Field of view                         | ≈ 1° × 180°               |
| Angular resolution                    | ≈ 1°                      |
| CCD operating temperature (target)    | −60°C                     |
| Annealing temperature                 | up to 20°C                |
| Clocking mode                         | Normal (diagnostics) and P-sum (observation) |
MAXI Instrumentation

Solid-state Slit Camera (SSC)
CCD (25 mm × 25 mm). 0.5-10 keV
16 chip (100 cm²) × 1 camera × 2 views.

Visual Star Camera (VSC)

Radiators for CCD

Gas Slit Camera (GSC)
1dim position sensitive proportional counters. 2-30 keV.
500 cm² × 6 cameras × 2 views.

Grapple Fixture for robot arm

Electronics

1m

Fig. 1. Schematic view of MAXI
Fig. 2. Block diagram of the SSC
Fig. 3. Photo of EM CCD chip
Fig. 4. $^{55}$Fe spectrum obtained with the EM SSC camera