Si/CdTe Semiconductor Compton Camera

Shin Watanabe, Takaaki Tanaka, Kazuhiro Nakazawa, Takefumi Mitani, Kousuke Oonuki, Tadayuki Takahashi, Takeshi Takahama, Hiroyasu Tajima, Yasushi Fukazawa, Masaharu Nomachi, Shin Kubo, Mitsunobu Onishi and Yoshikatsu Kuroda

Abstract—We are developing a Compton camera based on Si and CdTe semiconductor imaging devices with high energy resolution. In this paper, results from the most recent prototype are reported. The Compton camera consists of six stacked double-sided Si Strip detectors and CdTe pixel detectors, which are read out with low noise analog ASICs, VA32TAs. We obtained Compton reconstructed images and spectra of line gamma-rays from 80 keV to 662 keV. The energy resolution (FWHM) is 10 keV and 16 keV at 356 keV and 511 keV, respectively.

Index Terms—Compton camera, Compton telescope, Si strip detector, CdTe pixel detector

I. INTRODUCTION

A COMPTON camera is the most promising approach for the gamma-ray detection from several hundred keV to MeV, especially in high energy astrophysics. In order to achieve high sensitivity observations, the background rejection becomes very important in this energy region. The Compton camera can provide us efficient background rejections if clear Compton reconstructed images are available [1]. Therefore, imagers used in the Compton camera must have high energy resolution and high position determination due to the nature of Compton reconstruction technique.

We have proposed the concept of Si/CdTe Compton camera for gamma-ray observations. Silicon (Si) is used as a scatterer, and cadmium telluride (CdTe) is used as an absorber. Advantages of using semiconductors in Compton cameras are high energy resolution and high position determination. Additionally, the high position determinations enable us to make Compton cameras compact. Compact semiconductor Compton cameras provide high detection efficiencies. The combination of Si and CdTe is suitable for several ten keV to MeV gamma-ray detections. The photo absorption cross section of Si is small, and the Compton cross section becomes relatively large because of small atomic number of Si ($Z = 14$). On the other hand, CdTe has high photo absorption efficiency for gamma-rays of this energy region, due to its large atomic numbers of 48 and 52.

We have been developing Compton cameras consisting of double-sided Si strip detectors (DSSDs) and CdTe pixel detectors. Based on our recent developments, DSSDs and CdTe detectors come to have high energy resolutions [2]–[4]. With the first prototype composed of one DSSD and two CdTe pixel detectors, we have obtained Compton reconstructed images from 80 keV to 356 keV [5], and have demonstrated a polarization detection [6].

In this paper, we report the results from our latest prototype of the Si/CdTe Compton camera. The prototype consists of six stacked DSSDs and three $8 \times 8$ CdTe pixel detectors.

II. SETUP OF THE MOST RECENT PROTOTYPE

A. Stacked DSSDs

As scatterer detectors, we use DSSDs with an area of $2.56 \times 2.56$ cm and a thickness of 300 $\mu$m. The strip pitch of the DSSD is 400 $\mu$m and 64 strips are made in each side. The signals from the strips are processed by the front-end-cards (FECs) on which two low noise analog ASICs, VA32TAs [2] are mounted. More detailed setup of the DSSD, the FEC, and VA32TA are reported in previous papers [5], [7]. Fig. 1 shows a spectrum obtained with the p-side strips of the DSSD. The energy resolution of 1.26 keV (FWHM) at 59.5 keV is achieved at the temperature of $-10^\circ$C.

In order to increase an efficiency of Compton scattering, we stacked six DSSDs compactly. A picture of the six stacked DSSD is shown in Fig. 2. A stack pitch of 5.4 mm for DSSDs is obtained by utilizing the specially designed ceramic package.

B. CdTe pixel detectors

We use $8 \times 8$ CdTe pixel detectors as the absorbers in the Compton camera. This CdTe pixel detector is based on the Schottky CdTe diode device, utilizing indium as the anode and platinum as the cathode [4]. Fig. 3 shows the picture of the pixel detector. The detector has dimensions of $18.55 \times 18.55$ mm and a thickness of 500 $\mu$m. The indium side is used as a common electrode and the platinum side is divided into 8 by 8 pixels and a guard ring with a width of 1 mm. The pixel size is $2 \times 2$ mm, and the gap between each pixel is 50 $\mu$m. Each pixel is connected to a fanout board by our bump bonding technology [8], and the signal from each
Fig. 1. A spectrum of $^{241}\text{Am}$ obtained with the DSSD p-side strips. The operating temperature is $-10\,^\circ\text{C}$. The energy resolution is 1.26 keV (FWHM) at 59.5 keV.

Fig. 2. The six stacked DSSDs. The pitch between DSSD layers is 5.4 mm. The signal from each pixel is fed into the VA32TA on-board the FEC. The VA32TA and FEC design are the same as that used in DSSD readout.

The spectrum obtained with one of the CdTe pixel detectors is shown in Fig. 4. The $\Delta E/\langle E \rangle \sim 2\%$ energy resolution is achieved.

C. Compton camera setup

By combining the stacked DSSDs and three CdTe pixel detectors, we constructed a Compton camera. The picture of the Si/CdTe Compton camera is shown in Fig. 5. Two CdTe pixel detectors are placed underneath the DSSDs, and another is arranged on the side of the DSSDs.

The readout schematic diagram is shown in Fig. 6. Signals from all detectors are read out by VA32TAs on FECs. Fifteen FECs are connected to the interface card (IFC). The IFC
provides analog bias currents/voltages, and digital and analog signal repeater function. The readout card (ROC) performs analog-to-digital conversions and readout sequence controls. A packet of data is constructed event by event in the ROC, and is sent to an acquisition computer via IEEE 1355 Space Wire [9]. More detailed information on IFC and ROC is referred in the paper of [10]. In this Compton camera, the triggers are made from OR signals among six p-sides of DSSDs and three CdTe pixel detectors, and pulse height data of all channels are acquired.

III. DATA ANALYSIS AND RESULTS

Using radio isotopes, we acquired event data with the prototype to test the imaging and spectroscopy abilities. We placed the radio isotopes 350 mm above the surface of the top DSSD. The DSSDs and the CdTe detectors were cooled at −5°C.

For Compton reconstructions, data reduction is performed as follows. Firstly, “two-hit events”, one hit in a DSSD and one hit in a CdTe, were selected from all the data. Here, one hit in a DSSD means that only one channel that is connected to a DSSD has a pulse height above 12 keV, and one hit in a CdTe means that the only one channel that is connected to a CdTe detector has a pulse height above 25 keV. From each two-hit event, the information on the energy deposits detected in the DSSD ($E_{Si}$) and in the CdTe detector ($E_{CdTe}$) and their hit positions are obtained. Secondly, we calculate the incident gamma-ray energy ($E_\gamma$) and the scattering angle ($\theta_{comp}$). In the calculations, we assumed that incident gamma-rays are scattered in the DSSD and fully absorbed in the CdTe pixel detector. On this assumption,

$$E_\gamma = E_{Si} + E_{CdTe}, \quad (1)$$

and

$$\cos \theta_{comp} = 1 - \left( \frac{m_e c^2}{E_{CdTe}} - \frac{m_e c^2}{E_{Si} + E_{CdTe}} \right), \quad (2)$$

From the calculated scattering angle and the two-hit positions, the Compton cone is drawn on the sky event by event. We projected the cone at the plane at the distance of 350 mm, and obtained the image of the gamma-ray source.

Fig. 7 and Fig. 8 show the images obtained with the experimental data, in which the gamma-ray source position can be clearly identified. Fig. 7 is an image of 250–400 keV gamma-ray lines from a $^{133}$Ba, and Fig. 8 is an image of 511 keV gamma-rays from a $^{22}$Na.

The energy spectrum can be obtained from $E_\gamma = E_{Si} + E_{CdTe}$. Fig. 9 and Fig. 10 show the spectra of gamma-rays from $^{133}$Ba and $^{22}$Na, respectively. Black lines are spectra made from all two-hit events. In addition, we can perform the event selection by using the Compton reconstructed image. We selected events satisfying the condition that the drawn Compton cone meets at the source position. Red line spectra in Fig. 9 and Fig. 10 are made from the selected events. In these spectra, the gamma-ray peaks from the source are relatively enhanced. The archived energy resolutions are 10 keV and 16 keV (FWHM) at 356 keV and 511 keV, respectively.
Fig. 7. The Compton reconstructed image of 250–400 keV gamma-rays from $^{133}$Ba. The source is placed 350 mm above the DSSD.

Fig. 8. The Compton reconstructed image of 511 keV gamma-rays from $^{22}$Na. The source is placed 350 mm above the DSSD.

IV. CONCLUSION

We have constructed a prototype of Si/CdTe Compton camera, consisting of six stacked DSSDs and three $8 \times 8$ CdTe pixel detectors. By using this prototype, we have obtained Compton reconstructed images and spectra of gamma-rays from 80 keV to 662 keV. The achieved energy resolutions are 10 keV and 16 keV at 356 keV and 511 keV, respectively.

REFERENCES

2003.


