New CdTe Pixel Gamma-Ray Detector with Pixelated Al Schottky Anodes

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We developed a new Al Schottky CdTe pixel detector and measured its spectral performance. It has pixelated anodes made of aluminum and a common cathode made of platinum. Because of the low leakage current and the high bias voltage owing to the Schottky diode characteristic and the anode pixel configuration, a good spectral performance including a high energy resolution was achieved. When the pixel detector with a thickness of 0.75 mm was subjected to a bias voltage of 400 V and was operated at −20°C, the full-width-half-maximum (FWHM) energy resolution of 1.1 and 1.8 keV at 59.5 and 122 keV, respectively, were successfully obtained. The spectral performance obtained with the Al Schottky CdTe pixel detector exceeded that obtained with the conventional In Schottky CdTe pixel detector, which has an In common anode and Pt pixelated cathodes, under the same operating conditions.

KEYWORDS: gamma-ray detector, cadmium telluride (CdTe), pixel detector

1. Introduction

Hard X-ray and gamma-ray imaging spectrometers with good spatial and energy resolutions are desired for medical, industrial and astrophysical applications. Cadmium telluride (CdTe) and cadmium zinc telluride (CZT) are very promising materials as hard X-ray and gamma-ray imaging spectrometers, because they have a high detection efficiency comparable to that of NaI scintilators and have a good energy resolution comparable to that of Ge detectors. Although a weak point of CdTe and CZT was the degradation of energy resolution and peak detection efficiency owing to poor charge transport properties of their materials, several techniques have been developed to maintain good spectral performance.[1,2]

In recent years, we have successfully overcome the poor charge transport properties by adopting a thin CdTe diode device. The basic idea of using a CdTe diode is to utilize indium (In) as the anode electrode on a p-type CdTe wafer and platinum (Pt) as the cathode.[1,3,4] A high Schottky barrier formed on the In/p-CdTe interface leads us to the use of the detector as a diode. Using this type of detector with a thickness of 0.5 mm at an applied bias voltage as high as 1 kV, we have obtained high energy resolutions: 830 eV (full-width-half-maximum: FWHM) at 59.5 keV and 2.1 keV (FWHM) at 662 keV.[1,4]

On the basis of the In Schottky diode device, we have developed CdTe diode pixel detectors, utilizing In as the common anode and Pt as the pixelated cathode (In/CdTe/Pt-pixel).[4–6] Because of their Schottky diode characteristic, low leakage current and good energy resolution have been achieved from the In/CdTe/Pt-pixel configuration. Ideally, electrons, which have a larger mobility and a longer lifetime than holes in CdTe, have to be collected for high energy resolution, therefore, the anode side should be pixelated. However, with the current electrode technology, it is difficult to divide an In electrode into pixels.

Recently, as an electrode material, aluminum (Al) has been found to be a good alternative to In.[7,8] In addition to low leakage current and high energy resolution comparable to those of In/CdTe/Pt detectors, Al/CdTe/Pt detectors have an advantage that an Al anode can be divided into pixels. Therefore, it is possible to fabricate electron-collecting-type diode pixel detectors, utilizing Al as pixelated anodes and Pt as the common cathode (Al-pixel/CdTe/Pt).

We have constructed the first Al-pixel/CdTe/Pt detector using the same components as those used in our recent In/CdTe/Pt-pixel detectors. In this paper, we report the achieved performance of the Al-pixel/CdTe/Pt detector. A comparison between the Al-pixel/CdTe/Pt and In/CdTe/Pt-pixel detectors is also described.

2. Setup of the Al Schottky CdTe Pixel Detector

Figure 1 shows a picture of the Al-pixel/CdTe/Pt detector together with the In/CdTe/Pt-pixel detector. The CdTe device has a size of 13.35×13.35 mm^2 and a thickness of 0.75 mm. The CdTe crystal is manufactured by ACRORAD in Japan using the Traveling Heater Method (THM). The Pt side is used as the common electrode and the Al side is divided into $8 \times 8 = 64$ pixels. The pixel size is 1.35×1.35 mm^2, and the gap between the pixel electrode is 50 μm. Around the pixels, a guard ring electrode with a width of 1 mm is attached. Additionally, a thin layer of gold is evaporated on the Al pixel side to ensure a good bump bonding connectivity.

The procedure for the component mounting is the same as that for In/CdTe/Pt-pixel detectors.[6] ASIC for both pixel detectors readout is VA64TA, which was developed by this research team in conjunction with IDEAS and SLAC.[9]

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3. Spectral Performance of the Al Schottky CdTe Pixel Detector

In order to evaluate the spectral performance of the Al-pixel/CdTe/Pt detector, we operated the detector in a thermostatic chamber at −20°C. The applied bias voltage was −400 V for the Pt common cathode. Spectroscopy measurements were performed using gamma-rays from ^{241}Am and ^{57}Co sources.

The spectra obtained from one of the pixels with the best performance are shown in Fig. 2. High energy resolutions were obtained: 1.0 keV (FWHM) at 14.4 keV, 1.1 keV (FWHM) at 59.5 keV, and 1.8 keV (FWHM) at 122 keV. Figure 3 shows the distribution of energy resolution from all 64 pixels. The FWHM spread is within about 10% for almost all pixels. The energy resolutions in the summed spectrum of all 64 pixels were 1.3 keV (FWHM) and 2.0 keV (FWHM) at 59.5 keV and 122 keV, respectively. Additionally, it was found that the long-term stability in the spectrum is sufficient for practical use under our operating conditions. Any significant deteriorations in energy resolution and detection efficiency have not been observed for at least one hour after applying bias voltage.

4. Comparison between the Two Types of CdTe Diode Pixel Detectors

In order to study the effect of the spectral response on the difference in electrode configuration between the Al-pixel/CdTe/Pt and In/CdTe/Pt-pixel detectors, both types of CdTe device with the same dimension ($13.35 \times 13.35 \times 0.75$ mm^3) were prepared (Fig. 1). The detectors were operated at −20°C. We examined the changes of the spectral shape in the 122 keV peak from a ^{57}Co source at various bias voltages.

Figure 4 shows the peak shapes for 122 keV gamma-ray photons obtained using the two types of pixel detector. The sums of the spectra from all pixels are shown. The applied bias voltages are from −100 to −400 V for the Al-pixel/CdTe/Pt detector, and from 100 to 1000 V for the In/CdTe/Pt-pixel detector. The energy scales of the two detector are calibrated on the basis of the spectra of −400 and 1000 V bias, respectively.

In order to quantify the peak heights and the lower tail amounts, the ratios of 120–124 keV count rate to 110–124 keV count rate are plotted as a function of applied bias voltage in Fig. 5. The filled circles and the open circles show the data of Al-pixel/CdTe/Pt and In/CdTe/Pt-pixel detectors, respectively. A higher ratio means a sharper peak and a smaller tail.

Compared with the case of using the In/CdTe/Pt-pixel detector, a small tail and a high peak can be obtained with the Al-pixel/CdTe/Pt detector under the same bias voltage condition. The peak obtained with the Al-pixel/CdTe/Pt detector under the bias voltage of −400 V is almost equivalent to the peak obtained with the In/CdTe/Pt-pixel detector under the bias voltage of 800 V. The spectral difference should be caused by the $\mu\tau$ product difference between electrons and holes in the CdTe crystal (μ, mobility; τ, lifetime). In the THM CdTe crystals manufactured by ACRORAD, the $\mu\tau$ product of electrons is 10–30 times larger than that of holes.[10] In the case of using the Al-pixel/CdTe/Pt detector, because electrons incoming to the pixel electrodes produce a large part of the signal, there is an advantage in spectral performance. On the other hand, in the case of using the In/CdTe/Pt-pixel detector, small $\mu\tau$ holes should be moved to the cathode pixels. Therefore, a higher bias voltage was required for obtaining a good spectral performance.

5. Conclusions

We have constructed a new type of CdTe pixel diode detector with a Pt common cathode and Al pixelated anodes. The construction procedure was the same as that for our conventional CdTe pixel diode detector with an In common anode and Pt pixelated cathodes. When we applied a bias voltage of 400 V to a 0.75-mm-thick detector and operated at −20°C, the pixel detector worked successfully and a good energy resolution was achieved. The obtained energy resolutions of one pixel were 1.1 keV (FWHM) at 59.5 keV and 1.8 keV (FWHM) at 122 keV under these conditions. Additionally, we compared the spectral performance between the Al-pixel/CdTe/Pt and In/CdTe/Pt-pixel detectors. It was found that a better energy resolution can be obtained with the Al-pixel/CdTe/Pt detector than with the In/CdTe/Pt-pixel detector under the same bias voltage condition.

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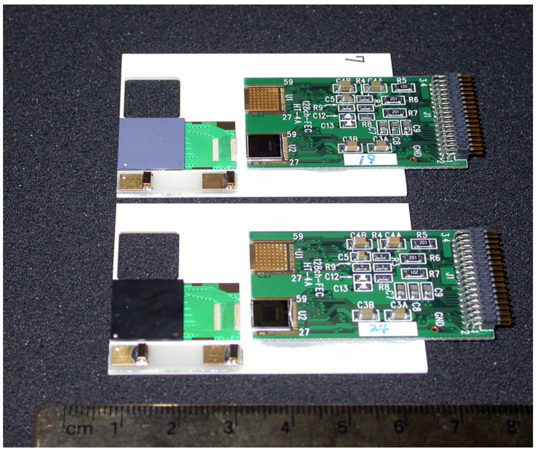

Fig. 1. Picture of the CdTe pixel detectors. The bottom shows the Al-pixel/CdTe/Pt detector and the top shows the In/CdTe/Pt-pixel detector.

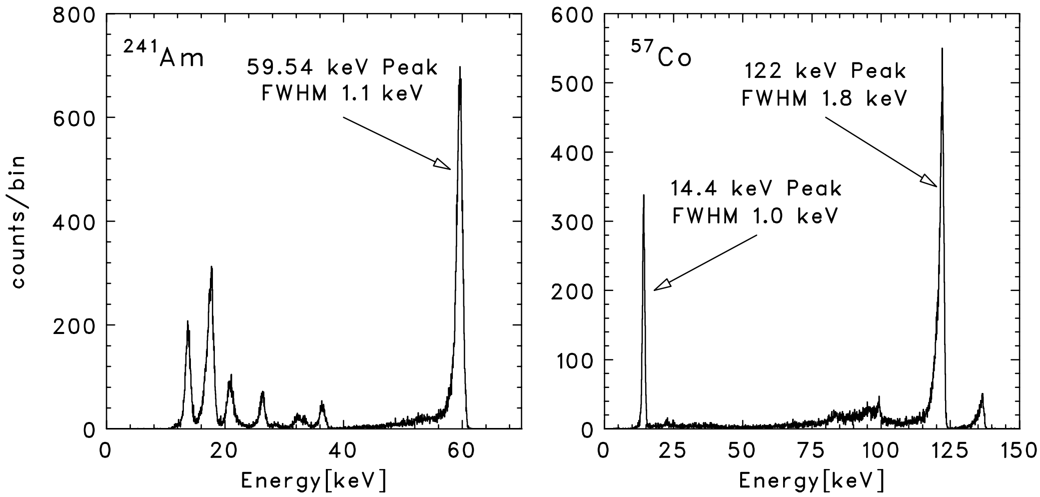

Fig. 2. ^{241}Am and ^{57}Co spectra obtained with one pixel of the Al/CdTe/Pt-pixel detector. The operating temperature was −20°C, and, the applied bias voltage was −400 V for the Pt common electrode. The achieved FWHM energy resolutions were 1.0, 1.1, and 1.8 keV at 14.4, 59.5, and 122 keV, respectively.

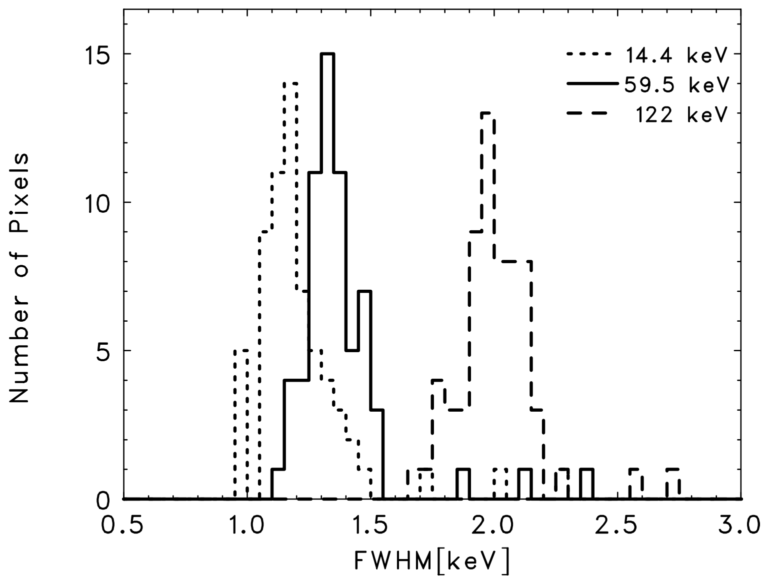

Fig. 3. Distribution of energy resolution from all 64 pixels of the Al-pixel/CdTe/Pt detector

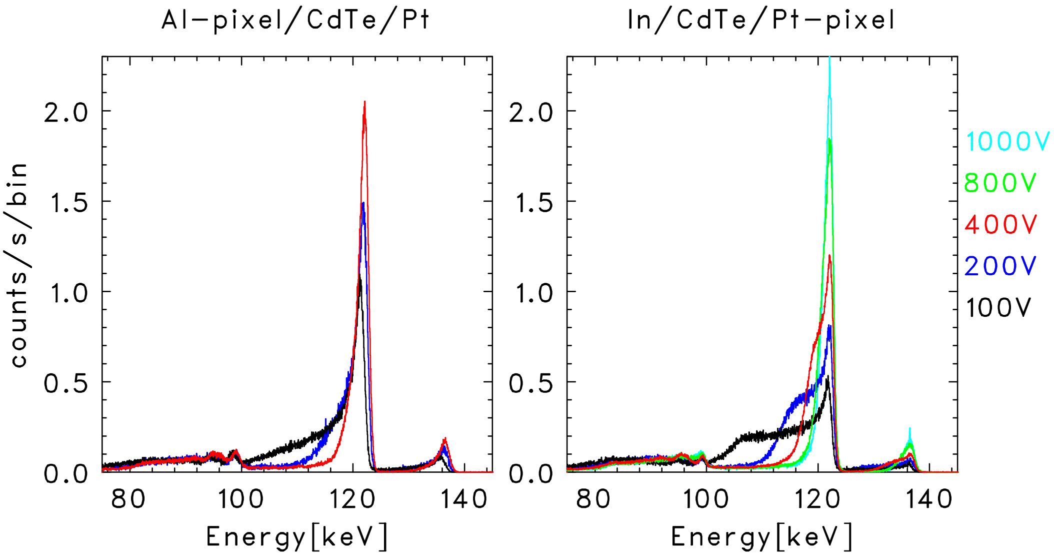

Fig. 4. Spectral changes of the 122 keV peak that are caused by the bias voltage [Left]: Spectra obtained with the Al-pixel/CdTe/Pt detector. Bias voltages of −100, −200, and −400 V were applied to the Pt common cathode. [Right]: Spectra obtained with the In/CdTe/Pt-pixel detector. Bias voltages of 100, 200, 400, 800, and 1000 V were applied to the In common anode. Both detectors were operated at −20°C. The thickness of the detectors was 0.75 mm. The spectra from all pixels were summed. The energy scales of Al-pixel/CdTe/Pt and In/CdTe/Pt-pixel were calibrated on the basis of the spectra of −400 and 1000 V bias, respectively.

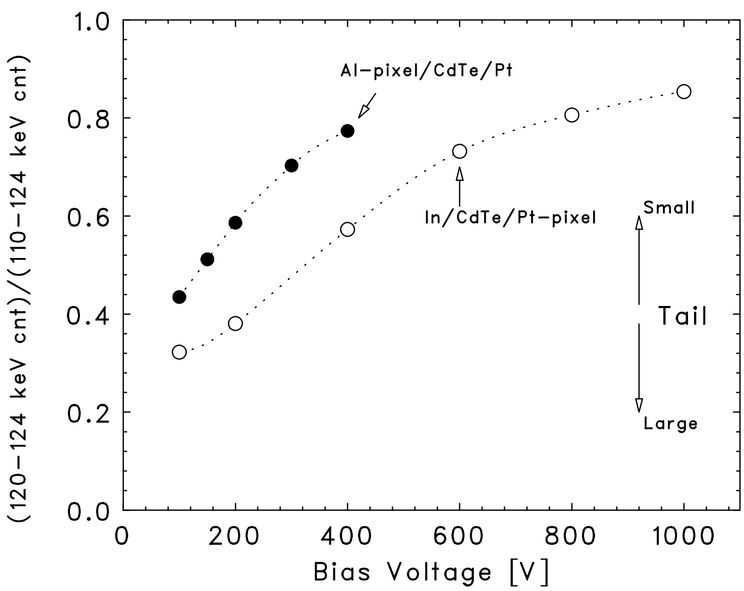

Fig. 5. Characteristics of 122 keV peak shapes. The ratios of 120–124 keV count rate to 110–124 keV count rate are plotted as a function of bias voltage. Filled circles show the data obtained using the Al-pixel/CdTe/Pt detector, and open circles show the data obtained using the In/CdTe/Pt-pixel detector.