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Biparametric correction methods using two shapers for In/CdTe/Pt radiation detector

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ABSTRACT

Biparametric correction methods have reportedly been used to improve the energy resolutions of CdTe or CdZnTe radiation detectors. There are two methods for the correction. One is a method that uses the rise time and pulse height, and the other is a method that uses two pulse heights acquired from a fast and a slow shaper. The latter one for a 2.3-mm-thick In/CdTe/Pt radiation detector was investigated for this paper. The polarization effect resulting in short-term instability in the energy spectrum should be resolved before an In/CdTe/Pt detector is used. A pulsed bias voltage shutdown technique was used with the two shaper biparametric correction method to overcome both the polarization effect and the incomplete carrier collection. An energy resolution of 4.6% for a 122 keV peak was observed for a 2.3-mm-thick In/CdTe/Pt detector at 35 °C for 2 h after applying a bias voltage of −800 V. Furthermore, the energy resolutions are improved for all the photo peaks when a constant correction factor is applied to the five photo peaks in the energy range 59.5–1333 keV.

1. Introduction

Cadmium telluride (CdTe) is a highly sensitive gamma-ray detector material that works at room temperature. The energy resolution deteriorates when a thicker CdTe detector is used because the carrier collection efficiency differs due to the carrier-generated position in the thickness direction [1]. Therefore, relatively thin CdTe detectors, such as those that are 0.5–1 mm thick, are preferred [2,3]. However, the volume of the detector must be increased to accommodate for the sensitivity of a high energy gamma ray. If only thin detectors are used, a lot of detector pieces are required and need to be assembled. This results in a low level of reliability and a high cost. The number of the detectors can be reduced if good spectral performances of the thick CdTe detectors are achieved.

The signal rise time strongly reflects the carrier generation position in the thickness direction. The number of carrier recombinations, i.e. the amount of decrease in pulse height, can be calculated and corrected if the carrier generation position information is acquired. Two methods called biparametric corrections have already been reported to overcome incomplete carrier collection. One is a method that uses the rise time and pulse height for each event [4]. The other is a method that uses two pulse heights consisting of the pulse height from a fast shaper and that from a slow shaper [5]. The latter method has the advantage of not requiring dedicated electronics, such as a rise time detection circuit. Auricchio et al. [6] reported that the latter method improved the energy resolution of the Pt/CdTe/Pt detectors. Although Pt/CdTe/Pt detectors do not have the polarization problem [7], the spectral performance is lower than that in In/CdTe/Pt detectors.

In/CdTe/Pt detectors exhibit good spectral performances due to their low leakage current, but suffer from the polarization problem. The charge accumulation of the crystalline defects causes the polarization effect, and this results in deterioration in the time dependency of the energy resolution and a time dependent peak shift [8]. Turning off the bias voltage can depolarize the CdTe detector, and thus, the required "off" duration is much shorter than the "on" duration [9]. Therefore, a pulsed bias voltage shutdown technique was reported for suppressing the polarization effect [10].

Both the two-shaper biparametric correction and the pulsed bias voltage shutdown technique were investigated in this paper to increase the spectral performance of the 2.3-mm-thick In/CdTe/Pt detector.

2. Experimental setups

2.1. CdTe detector

The CdTe detector has the dimensions $2.3 \times 9.9 \times 5.0\ mm^3$, as shown in Fig. 1. The detector has an In/CdTe/Pt electrode configuration and four pixels segmented by the indium face grooves. In this paper, the four pixels are electrically united to simplify the connection. All the gamma rays used in this paper (59.5–1333 keV) are irradiated from the $2.3 \times 9.9\ mm^2$ edge surface. Therefore, the absorption length is 5 mm and the absorption is almost uniform in the thickness direction.

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2.2. Measurement system

The measurement circuit and system configuration are shown in Fig. 2. A pulsed bias shutdown circuit for suppressing the polarization effect is installed in the same way as that reported in the previous work [11]. Both pulse heights of the fast and slow shapers are required to execute the biparametric correction. The biased side is connected to the fast shaper (τ=200 ns) and the grounded side is connected to the slow shaper (τ=1 μs), as shown in Fig. 2. The preamplifiers are resister feedback type charge sensitive amplifiers that have 50 μs decay constants and have 1.5 keV noises at 0 pF for CdTe detectors. The fast shaper is an ORTEC 579 and the slow shaper is an ORTEC 672. The pulse heights of the signals after the shapers are converted from analog to digital in an MPS-1600 pulse height analyzer (Laboratory Equipment Corporation). Two digital pulse heights and the time stamps for an event are generated in the MPS-1600, which then sends the data to a personal computer. The fast and slow pulse heights are paired using the time stamps, and then the corrected pulse height is calculated in the computer. The corrected data are accumulated and transformed into an energy spectrum.

The CdTe detector and preamplifiers are placed in a constant temperature chamber LHU-113, and the temperature is kept at 35 °C. The bias voltage is periodically shutdown for 30 ms every 30 s to suppress the polarization effect.

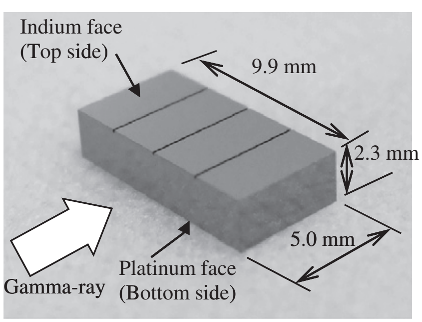

Fig. 1. In/CdTe/Pt detector. Indium face was divided into four pixels.

3. Results and discussion

3.1. Normal spectra (without correction)

The spectra for a ^{57}Co radiation source for various shaping times without the biparametric correction are shown in Fig. 3. An energy resolution of 10.3% was observed at a shaping time of 2 μs, but this is not an acceptable level compared to that of NaI scintillation detectors. The energy resolution was not improved for a long shaping time, because the carrier collections are incomplete and are different due to their carrier generation positions in the thickness direction. The $\mu\tau$ product must be sufficiently larger than the thickness/field for the complete carrier collections. The required (thickness/field) value is 0.23 cm/(800 V/0.23 cm)=6.6 × 10^{-5} cm^2/V. However, the $\mu\tau$ products of CdTe are estimated to be about 1.1 × 10^{-3} cm^2/V for electrons and 1 × 10^{-4} cm^2/V for holes [12]. Therefore, the electrons are considered completely collected, but the holes are not. Consequently, the energy resolution cannot be improved by stretching the shaping time.

3.2. Biparametric correction spectra

The relationship between the fast (τ=200 ns) pulse height H_f and the slow (τ=1 μs) pulse height H_s for a ^{137}Cs source is plotted in the upper half of Fig. 4(a), and the histogram of the slow pulse heights, i.e. the energy spectrum, is shown in the lower half of Fig. 4(a). A ^{137}Cs source was selected because it has a main 662 keV photo peak and does not have any other peaks around 662 keV. The k_N factor was used for normalizing the H_f values for the H_s values. There are around 1600–1800 H_s values for the 662 keV photo peak and this distribution was the cause of the deterioration in energy resolution. The corrected amount was calculated from the difference between H_s and H_f, and was added to H_s as shown below, to narrow the distribution

$$H_{c1} = H_s + k_{BP1}(H_s - k_N H_f) \tag{1}$$

where H_{c1} is the corrected pulse height and k_{BP1} is the correction strength factor. The relationship between H_f and H_{c1} is plotted in Fig. 4(b). As the values of H_{c1} are concentrated around H_f=1800, Eq. (1) improves the energy resolution. However, the values of H_{c1} around

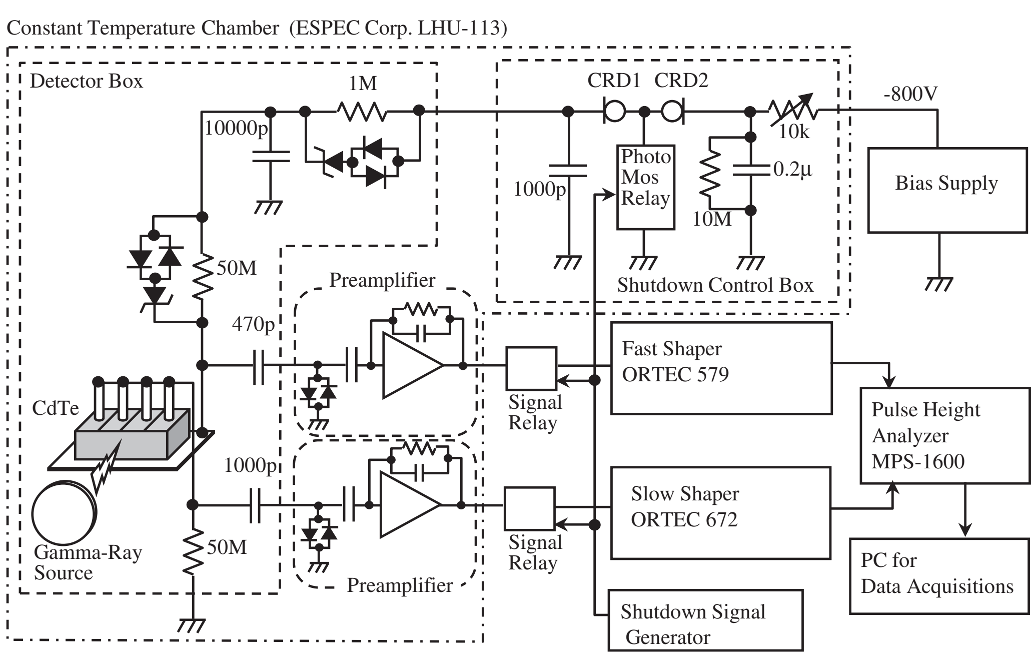

Fig. 2. Measurement system with pulsed bias voltage shutdown circuit.