Pulse Shape Recognition for CdZnTe Semiconductor Detector by using Multi-Shaping Amplifiers Method with Neural Network Algorithm

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Abstract

A new pulse shape recognition method with multi-shaping amplifiers, combined with a neural network algorithm, has been developed, where four pulse heights are sampled from one signal pulse through four linear amplifiers with different shaping time constants. The four pulse heights are used as characteristic parameters to recognize the pulse shape with a neural network. This method has been applied to signal processing for a CdZnTe semiconductor detector to improve the deteriorated energy spectra caused by pulse height deficits due to the different mobilities of electrons and holes in the detector. The neural network recognizes the pulse shape patterns and provides the corrective magnification factors of the pulse heights. After the corrective procedure, the energy spectrum for ^{137}Cs gamma-rays is improved from 9.3 keV to 7.4 keV in the energy resolution (FWHM) of the 662 keV gamma rays photopeak. The photopeak becomes a considerably symmetrical shape without a low-energy tail. It has been verified that this method is simple and useful for pulse shape analyses, which can be used for many other applications.

I. INTRODUCTION

In recent years, a neural network has been used in the field of radiation measurements [1-3] because of the simple structure and the good pattern recognition ability. Among many intelligent systems, a neural network is one of the simplest systems that can perform the good recognition process.

A CdZnTe semiconductor detector has good properties that are desirable for a radiation detector [4-6]. The high atomic numbers (48, 52) indicate a larger detection efficiency for X or gamma rays than other semiconductor detectors such as Si or Ge ones. The large forbidden band gap energy permits room temperature operation. Needlessness of a cooling system permits the CdZnTe detector to be applied to compact use such as a field work or a medical application. However, as is common with other compound semiconductor detectors, the pulse shapes from the CdZnTe detector differ from event to event depending on the positions of radiation interactions because of the different mobilities of the holes and the electrons, and the short lifetime of the holes for trapping in the bulk [7,8]. The typical pulse shapes from the CdZnTe semiconductor detector used in the present study are shown in Fig. 1. The different pulse shapes yield different degrees of ballistic deficits, *i.e.*, different pulse heights even for the same energy deposition in the effective detector volume. Consequently, the energy spectra of the CdZnTe detector become unusual shapes with low-energy tails below photopeaks.

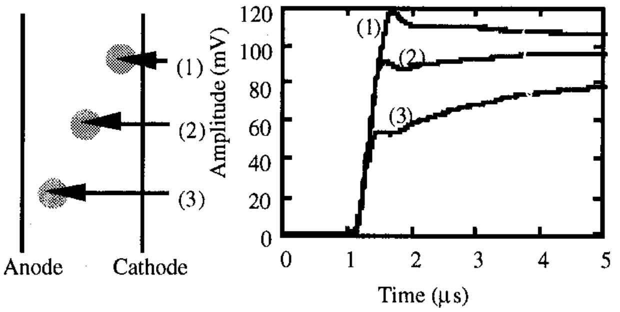

Figure 1: Output pulses of the preamplifier for gamma rays interacting (1) near the cathode, (2) at the intermediate position and (3) near the anode.

Recently digital pulse-shape-analysis methods became popular in the field of radiation measurements. In these digital-pulse-shape analysis methods, pulse shapes are analyzed by using many algorithms such as a neural network [3,9,10], template matching [11], fitting with an appropriate function [12], a Fast Fourier Transformation [13] and other methods [14-17]. Digital pulse-shape-analysis is potentially superior to an analog counterpart. However, it takes too much time to obtain and analyze the pulse shapes due to the huge data included in the digitized pulse shape and the poor vertical resolution of the digitizer.

In the present study, we have developed an alternative pulse-shape sampling technique named as 'multi-shaping amplifiers method'. We analyze pulse shape profiles by using a neural network algorithm. The multi-shaping amplifiers method is superior to the digital sampling method in the simplicity and the speed of data processing, although a detailed feature of the pulse shape could not be extracted.

II. MULTI-SHAPING AMPLIFIERS METHOD

In the present study, we tried to obtain the pulse shape profiles by using the multi-shaping amplifiers method instead of the digital one. Figure 2 shows the examples of the pulse pattern obtained with the two methods. By using the digital system, the pulse pattern is taken as $\mathbf{A}=(a_1, a_2, \cdots, a_n)$ where $a_1, a_2, \cdots, a_n$ are the pulse amplitudes at $t = t_1, t_2, \cdots, t_n$. By using the multi-shaping amplifiers method, the corresponding pulse pattern is taken as $\mathbf{A}'= (a_1', a_2', \cdots, a_n')$ where $a_1', a_2', \cdots, a_n'$ are the pulse amplitudes when the pulse is shaped by the linear amplifiers with the different shaping time constants of $t_1, t_2, \cdots, t_n$. The pulse height after shaping with a time constant t would have roughly the

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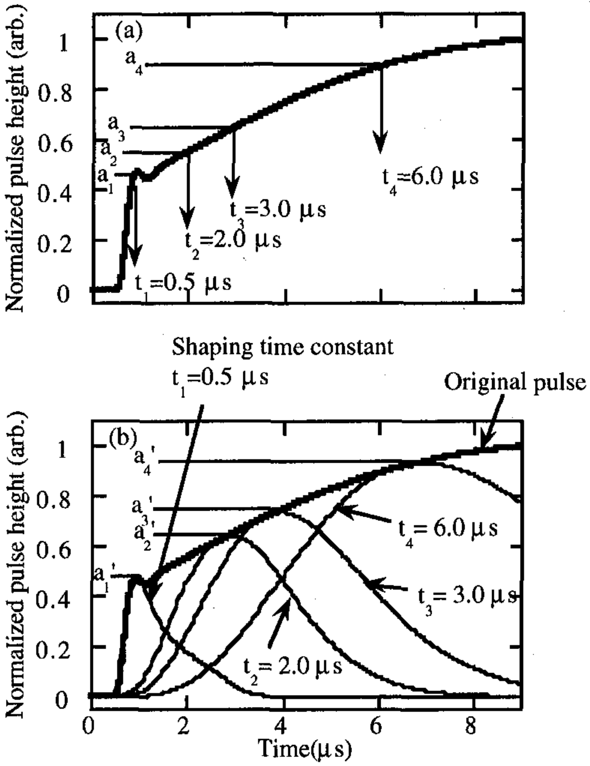

Figure 2: Examples of pulse pattern
(a) digital method and (b) analog method.

information on the pulse height of the original pulse at t, hence A and A' have nearly the same information about the pulse shape.

III. NEURAL NETWORK

As is described in the introduction, the pulse shapes of the CdZnTe detector differ from event to event depending on the interaction positions of incident radiations. The position dependency of the pulse heights of the CdZnTe detector can be corrected if the differences among the pulse shapes can be recognized. The neural network was used for the recognition of the pulse shapes.

A three-layered feedforward-type neural network was adopted as a recognition algorithm. The schematic diagram of the neural network is shown in Fig. 3. The first layer consisted of four neurons as input units and an another neuron as a bias unit. The four pulse heights shaped with the different shaping time constants were fed to the input units. The second layer consisted of four neurons as hidden units including a bias unit. The third layer consisted of one neuron as an output unit. The output of the last neuron was converted into the magnification factor of the pulse height. The response function of neurons used in this study was a sigmoid function as follows:

$$f(x) = \frac{1}{1+e^{-x}} \qquad (1).$$

The output of each neuron was transferred to the next neurons

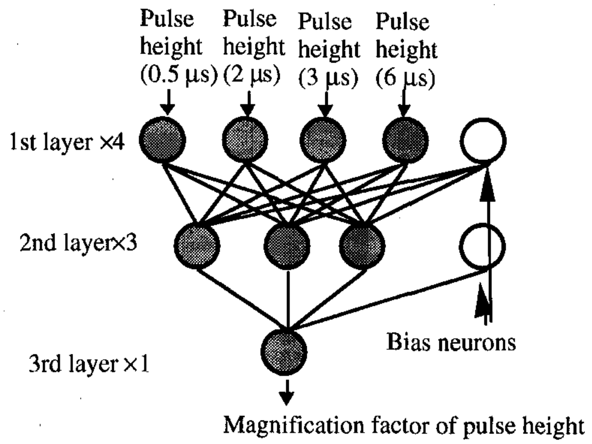

Figure 3: Schematic illustration of the neural network.

weighted by the weighting factor of the synapse that was the bridge between two neurons. An error back-propagation algorithm was adopted for a learning rule.

After the optimizing procedure, the neural network recognized the pulse shapes and provided the corrective magnification factors of the pulse heights. The corrected energy spectrum was obtained by summing up each pulse height signal multiplied by the corresponding corrective magnification factors.

IV. RESULTS AND DISCUSSION

A schematic diagram of the experimental system is shown in Fig. 4. Signals from a CdZnTe detector (eV Products 180.5.5.5s, 5×5×5 mm^3) are shaped with four linear amplifiers with time constants of 0.5, 2, 3 and 6 μs, hence the data obtained were four dimensional. The set of the shaping time constants is determined by the characteristics of the waveform from the detector. The pulse amplitudes of the output signals from the linear amplifiers were digitized by Wilkinson-type ADCs. The sets of four pulse amplitudes were stored in a personal computer. The signal

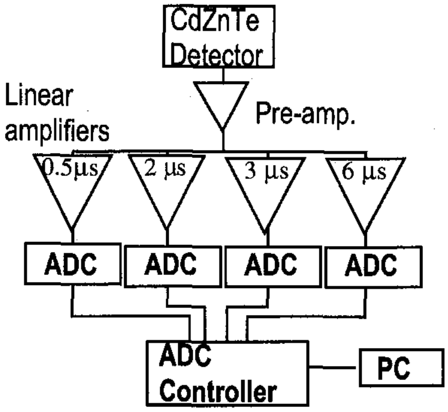

Figure 4: Schematic diagram of an experimental setup.

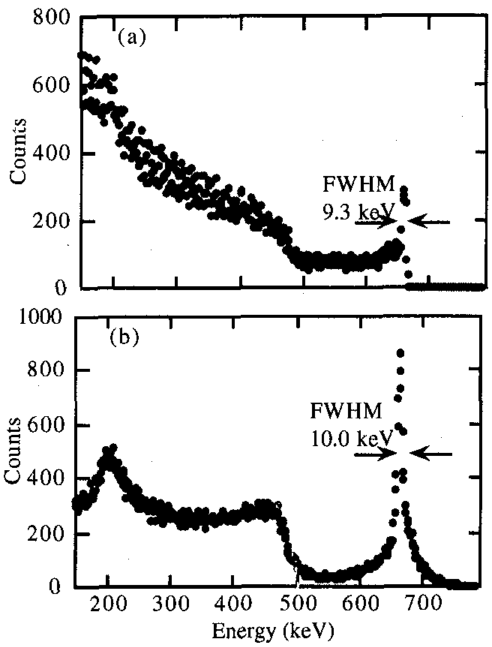

Figure 5: Energy spectrum for ^{137}Cs gamma rays (a) before and (b) after corrective procedure.

processing by using the neural network was done with the personal computer after the measurement.

We measured gamma rays from a ^{137}Cs gamma-ray source. The energy spectra before and after the corrective procedure are shown in Fig. 5. The photopeak area for the 662 keV gamma rays counts drastically increased from 838 to 9,233. Although the energy resolution (FWHM) for the photopeak of the 662 keV gamma rays counts deteriorated from 9.3 keV to 10.0 keV. The peak-to-valley ratio defined as a ratio of the counts at 662 keV to that at 550 keV increased from 4.0 to 23. The events with large magnification factor contained much fluctuations in pulse heights due to the trapping of holes. Hence the energy spectrum would further be improved if the threshold of the magnification factor is lowered. Figure 6 shows the energy spectrum, where the events with the magnification factors larger than 1.16 were discarded. The photopeak area for the 662 keV gamma rays decreased to 1,997 events from that of the spectrum in Fig. 5 (b). However the area increased from that of the original spectrum in Fig. 5 (a). The energy resolution of the photopeak improved to 7.4 keV and the peak-to-valley ratio increased to 1.6×10^2. The relation between the energy resolution after the correction procedure and the number of the events used is shown in Fig. 7. The threshold of the magnification factor must be determined by weighing the relative importance of the photopeak efficiency and the energy resolution.

This method is more effective for the measurement of multiple gamma-ray emitters, such as ^{133}Ba, or combination sources because the tailing effect can be corrected and the adjacent photopeaks can be separately identified. The energy spectra for ^{133}Ba gamma rays before and after the corrective procedure are shown in Fig. 8. The peak-to-valley ratio defined as a ratio of the count at 356 keV to that at 330 keV increased from 5.3 to 2.0×10^2. The photopeaks of the lower-energy gamma rays (303 keV, 276 keV) were faded due to the tail of the 356 keV gamma rays photopeak before the corrective procedure. The photopeak of the lower-energy gamma rays became easily recognizable after the corrective procedure.

It must be emphasized that this method can be used for a real-time processing of each pulse shape, only if some appropriate software is developed.

V. CONCLUSIONS

The novel pulse-shape-analysis method with the neural network algorithm was presented. The method was applied to the improvement of the energy spectrum characteristics of the CdZnTe semiconductor detector. The energy spectrum has been improved with the increased photopeak efficiency and the better peak-to-

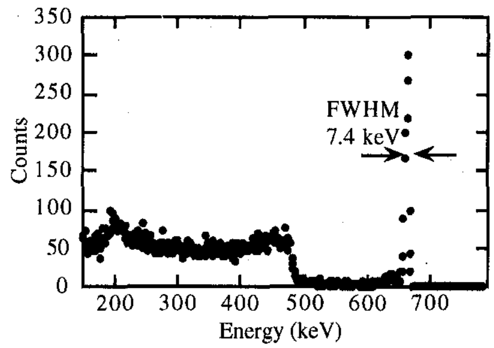

Figure 6: Energy spectrum for for ^{137}Cs gamma rays after the discarding procedure.

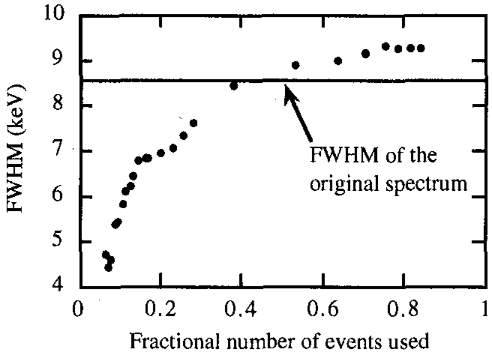

Figure 7: Relation between the energy resolution and the number of the events used.

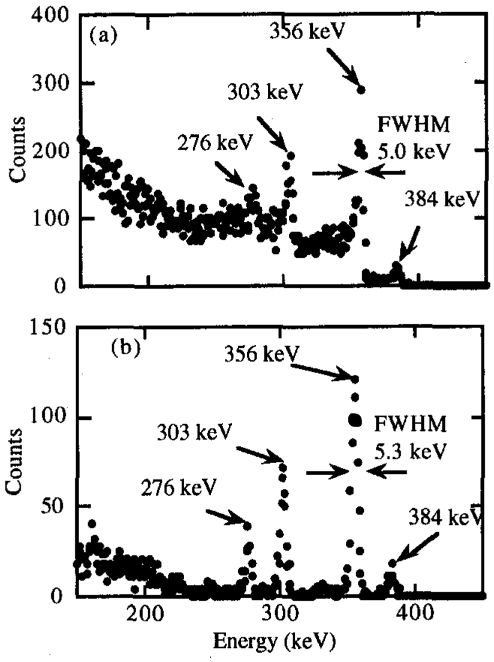

Figure 8: Energy spectrum for ^{133}Ba gamma rays
(a) before and (b) after corrective and discarding procedure.

valley ratio. The threshold of the magnification factor must be determined by weighing the relative importance of the photopeak efficiency and the energy resolution. This method is more effective in the measurement of multiple gamma-ray emitters, such as ^{133}Ba, or combination sources because the tailing effect can be removed and the adjacent photopeaks can be separately identified.

It has been verified that this method is simple and useful for real-time pulse shape analyses that can be used for many other applications.

VI. ACKNOWLEDGMENT

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