Development of the Stacked CdTe Gamma-ray Detector Module with High Sensitivity and High Energy Resolution

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***Abstract*– A gamma-ray detector module with stacked CdTe detector has been developed to be applied to the homeland security where high sensitivity and high energy resolution are required. We introduced the stacked CdTe detector and multi-channel readout ASIC to achieve both high sensitivity and high energy resolution for high energy gamma-ray. Our measurement showed that stacked CdTe detector had the energy resolution of about 1.5 % for 662 keV gamma-ray and higher sensitivity as expected. These results show the flexibility and possibility of the stacked CdTe detector modules in reply to various requirements in gamma-ray detection.**

I. Introduction

THE gamma-ray detector module with stacked CdTe detector has been developed to be applied to the homeland security where both high sensitivity and high energy resolution are required. The Schottky-type detector was fabricated by applying *In* as anode and *Pt* as cathode on the CdTe wafer which was prepared from Cl-doped CdTe single crystal ingot grown by Traveling Heater Method (THM). The growth method and the characteristics were reported elsewhere [1].

The Schottky-type CdTe detector has high energy resolution without complicated spectrum correction, such as the discrimination with the drift time or anode to cathode ratio [2], [3], however its thickness is recommended to less than 1.2 mm to suppress the polarization effect, where the peak shift and the degradation of FWHM occur by supplying HV for several hours continuously. As a result, by using a single planar Schottky CdTe detector, it is difficult to accomplish high sensitivity for high energy radiation such as 662 keV gamma-ray from ^{137}Cs.

One possible solution to improve the sensitivity is to use plural planar detectors simultaneously. It is one of the methods for this concept to stack some detectors and increase the total detector volume, and we call this kind of detector the *stacked detector* [4]. However, when all signal electrodes are connected to 1 readout circuit, the input capacitance and leakage current become larger in proportional to the number of the detectors connected, and these increase the noise which deteriorates the energy resolution shown in Fig. 1. Therefore, it is effective to process the signal from each layer of stacked detector independently to avoid the increase of the noise. By combining the energy spectrum obtained from each channel, it is expected to achieve both high energy resolution and high sensitivity for high energy gamma-ray.

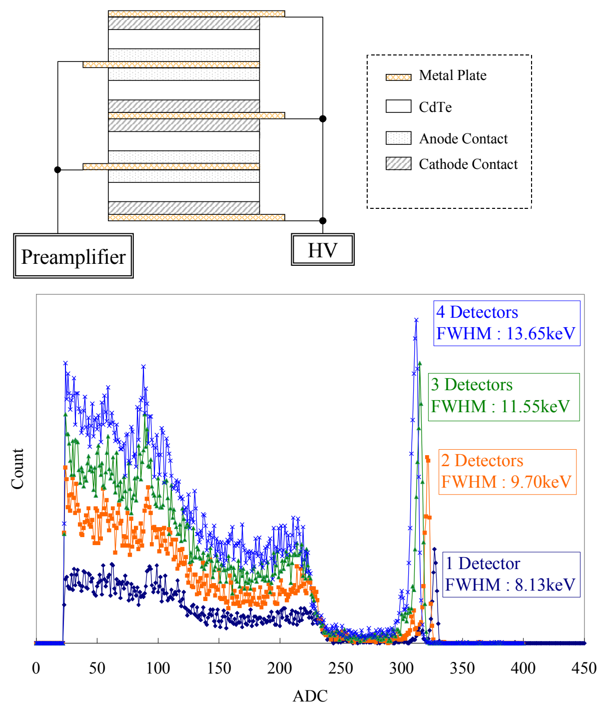

Fig. 1. Energy spectra of ^{137}Cs with 1 readout circuit. 1 to 4 pieces of 10 mm × 10 mm × 0.5 mm CdTe detector were measured simultaneously. FWHM became worse as the number of detectors were increased. The following devices were used.
Preamplifier : 580H (Clear Pulse), Shaping Amplifier : 571 (ORTEC)
HV Supply : 6637 (Clear Pulse), MCA : 7800 (SEIKO EG&G)

II. Experimental

The stacked CdTe detector module was fabricated from stacked CdTe detectors, multi-channel readout ASIC, and data acquisition system. When the energy spectrum obtained from each input channel is combined, the gain correction is necessary because the output voltage for specific energy is different among input channels of ASIC due to the gain variation of each amplifier circuit.

A. Structure of Stacked CdTe Detector

1 layer of 5 mm×5 mm×0.5 mm CdTe detector and 7 layers of the 10 mm×10 mm×0.5 mm ones were stacked, as shown in Fig. 2. The small top layer was used for the low

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energy gamma-ray detection and the rest 7 layers were for the high energy gamma-ray.

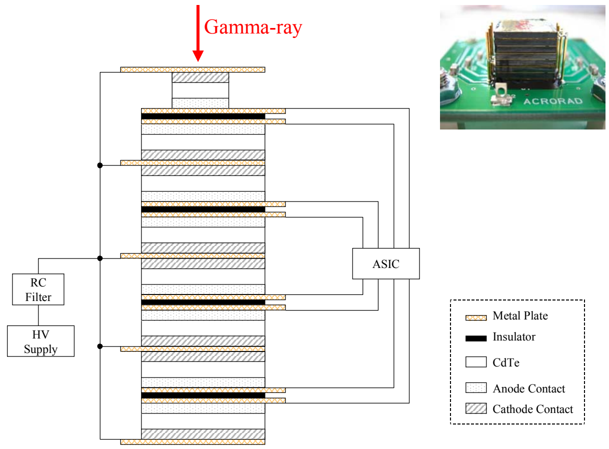

Fig. 2. Structure of the stacked detector

The signal electrode of each layer was insulated by the thin polyimide film and alumina plate for each other, connected to the input channel of the ASIC independently. On the other hand, high voltage (HV) electrodes of all layers were common and connected to the HV supply via the RC filter. Owing to this structure, it is not necessary to increase the HV with the increase of the total thickness and volume of the stacked detector.

For the best energy resolution in relatively lower energy range, that is less than 150 keV, the smaller top layer of 5 mm ×5 mm was adopted to decrease the detector capacitance to around 5 pF. In spite of the smaller volume, the sensitivity of the top layer is still expected to be high enough for the 150 keV compared with 662 keV gamma-ray detected by the bottom 7 layers altogether. The total volume of the stacked detector was 0.36 cm^3.

B. Stacked CdTe detector module and the data acquisition sytem

Fig. 3 shows the detector board. To obtain the higher sensitivity for the high energy gamma-ray, 4 pieces of the 8-layers stacked CdTe detector were mounted on the glass-epoxy detector board. The total detector volume was 1.45 cm^3.

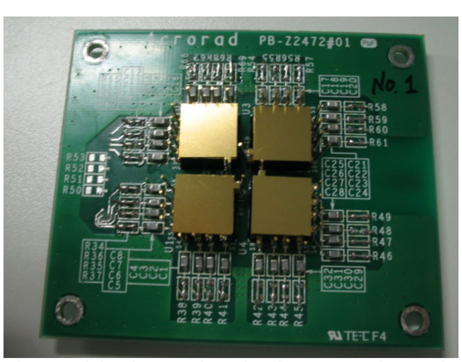

Fig. 3. Picture of the detector board. There are 4 pieces of 8-layers stacked detector, and each layer is connected to the connector with AC coupling. The connector is on the backside from this view.

Fig. 4 shows the block diagram of the data acquisition system, supplied by NOVA R&D Inc., containing the daughter board, where the 2 RENA-3^{TM} ASICs were mounted, FPGA, HV supply, test pulse generator, optic interface, and so on. The specification and the operation principle of the RENA-3^{TM} ASIC were reported elsewhere [5]. The flexible gain configuration of this ASIC can realize the very wide dynamic range. The detector board was connected to the daughter board and HV supply. The top layer channel was configured to be high gain amplification, and the lower layer channels were configured to be low gain amplification. The signal from the stacked detector was processed by the RENA-3^{TM} chips, which were controlled by FPGA. The analog output signal from the ASIC was converted to 16 bits digital value by analog to digital converter, and it was sent to the Personal Computer via the optical interface.

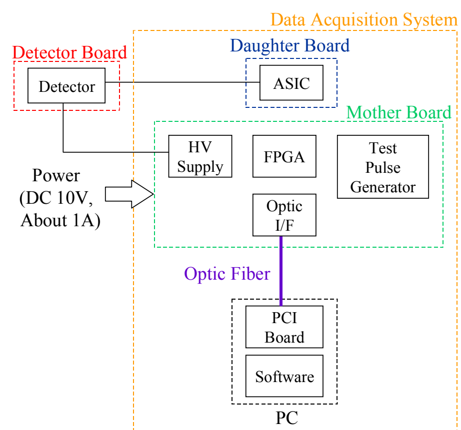

Fig. 4. Data acquisition system

C. Gain Correction

Due to the output voltage difference among the input channels, the correction for the gain and offset of signal amplification was necessary to combine the spectrum from each channel. This correction was carried out after the analog to digital conversion of output voltage from the ASIC.

We applied the simple linear fitting based on the energy calibration for the correction of ADC value. For each channel, there is a correlation between ADC value and the energy as follows:

$$E = a_k x + b_k \quad (1)$$

where E is the energy, x is ADC value, and a_k and b_k are the fitting parameters for channel k. The value of a_k and b_k should be determined channel by channel. In order to combine the energy spectra, the ADC values for specific energy should be identical among different channels because the energy spectrum is the discrete histogram. Therefore, we introduce following linear transform function from x to x':

$$x' = (a_k / a)x + (b_k - b)/a \quad (2)$$

where a and b are the arbitrary numbers, and x' is the corrected ADC value. Then the energy for each channel can be written in the common form for all channels as follows.

$$E = ax' + b \tag{3}$$

a_k and b_k can be determined from (1), and then x can be transformed to x' with given parameter a and b by (2). In consequence, the all spectra from different channels can be summed up directly to form the combined spectrum.

The gamma-ray point source can be used for the energy calibration. ^{57}Co and ^{241}Am were used for calibration of the top layer channel, and ^{60}Co, ^{137}Cs and ^{57}Co were used for the lower layer channels. The fluctuation of ADC value for 662 keV gamma-ray, which was calculated from the average and standard deviation of the peak channel for all input channels, was 0.2 % after gain correction, while it was 2.8 % before gain correction, when a = 0.085 and b = 0 were adopted. The difference of ADC value for photoelectric peak was mainly caused by the offset difference of signal amplification.

III. Result and Discussion

The energy resolution and sensitivity for ^{57}Co, ^{137}Cs, and ^{60}Co were measured with the system described in section II. For the measurement of ^{57}Co, the only top layer of each stacked detector was used, and the active detector volume was 0.05cm^3 (4 pieces of 5 mm$\times$ 5 mm$\times$ 0.5 mm detector). On the other hand, 7 layers were used for ^{137}Cs and ^{60}Co, and the detector volume was 1.4 cm^3 (28 pieces of 10 mm $\times$ 10 mm$\times$ 0.5 mm detector). All measurements were performed at 25 °C and 35 % RH. HV of -300 V was applied to the cathode of each layer. The key configuration of ASIC is listed in Table I.

Table I
Key Configuration of ASIC

Item	^{57}Co	^{137}Cs	^{60}Co
Feedback Capacitor	15 fF	60 fF	60 fF
Feedback Resistor	1200 MΩ	1200 MΩ	1200 MΩ
Gain	5.0	5.0	1.8
Shaping Time	1.9 µs	1.9 µs	1.9 µs
FET size	1000 µm	1000 µm	1000 µm

A. Energy Resolution

Fig. 5, 6, and 7 show the energy spectra of ^{57}Co, ^{137}Cs, and ^{60}Co, respectively. In these figures, blue dashed line represents the spectrum for 1 layer, and red solid line represents the combined spectrum with gain correction.

The measured energy resolution from FWHM is shown in Table II. It was found that energy resolution from combined spectrum was almost the same as that from 1 layer energy spectrum. The high energy resolution was obtained without spectrum correction: 4.0 % for 122 keV, 1.5 % for 662 keV, and 1.4 % for 1332 keV from combined spectrum.

B. Sensitivity

Fig. 8 shows the geometry for the sensitivity measurement. The activity of point sources was 0.24 MBq for ^{57}Co, 2.3 MBq for ^{137}Cs, and 86 kBq for ^{60}Co, respectively. Solid angle was 1.1$\times$ 10^{-3} sr for top layer, and 4.4$\times$ 10^{-3} sr for other 7 layers.

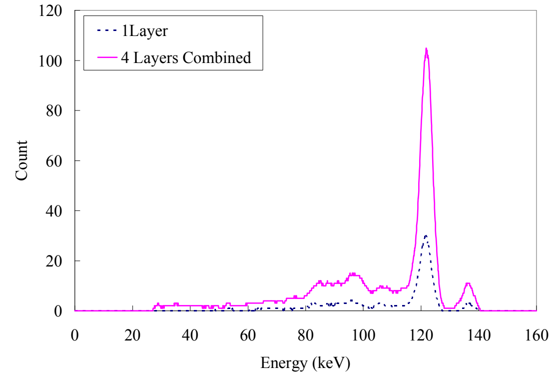

Fig. 5. Energy spectrum of ^{57}Co

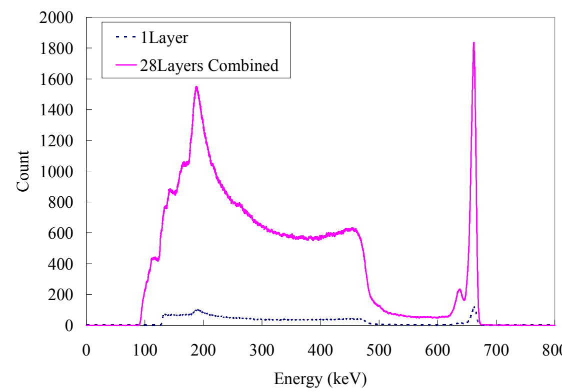

Fig. 6. Energy spectrum of ^{137}Cs

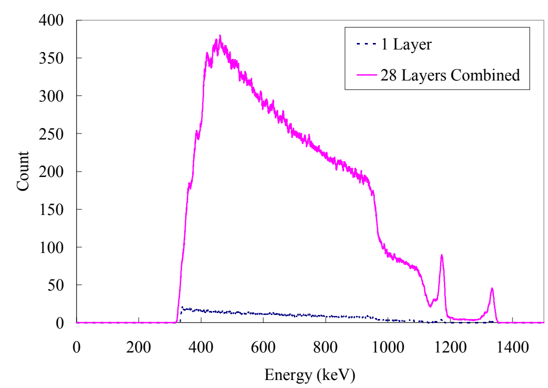

Fig. 7. Energy spectrum of ^{60}Co

Table II
Result of Energy Resolution

	^{57}Co (122 keV)	^{137}Cs (662 keV)	^{60}Co (1332 keV)
1 Layer	3.7 % to 4.1 %	1.2 % to 1.8 %	0.8 % to 2.0 %
Combined	4.0 %	1.5 %	1.4 %

The measured sensitivity is listed in Table III. The dose equivalent rate was measured with ICS-321 (ALOKA) for

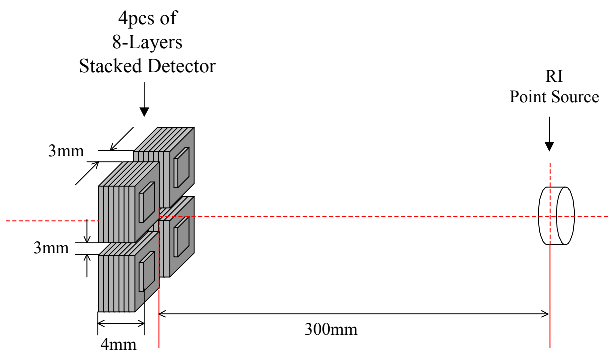

Fig. 8. Geometry of sensitivity measurement

^{137}Cs, while it was calculated from dose rate constant for ^{57}Co and ^{60}Co: 0.021 μSv·m^2/h/MBq for ^{57}Co, and 0.35 μSv·m^2/h/MBq for ^{60}Co, respectively. The sensitivity from combined spectrum was higher than that from 1 layer spectrum as expected. Although it was measured with the fewer detector of smaller area, the sensitivity for ^{57}Co was much higher than that for ^{137}Cs and ^{60}Co. These results, including the result of energy resolution, show that high sensitivity was accomplished with keeping high energy resolution by using stacked structure CdTe detector and multi-channel readout ASIC. Furthermore, it was found that this method had flexibility about the energy range by adjustment for the gain configuration of ASIC and the detector area. This result clearly demonstrated that the sensitivity could be increased by using more number of the stacked detectors. We expect that this method can satisfy various requirements in gamma-ray detection, including homeland security application.

TABLE III
RESULT OF SENSITIVITY MEASUREMENT

	Unit : cps/(μSv/h)		Unit : cps/MBq	
	1 layer	Combined	1 layer	Combined
^{57}Co [116 keV to 128 keV]	12 to 13	50	2.7 to 3.1	11
^{137}Cs [649 keV to 672 keV]	6.6×10^{-2} to 9.8×10^{-2}	2.2	7.1×10^{-2} to 1.0×10^{-1}	2.4
^{60}Co [1306 keV to 1389 keV]	1.8×10^{-3} to 8.8×10^{-3}	8.1×10^{-2}	6.8×10^{-3} to 3.4×10^{-2}	0.31

IV. CONCLUSIONS

The stacked CdTe detector module with multi-channel readout ASIC has been developed. 1 piece of 5 mm×5 mm ×0.5 mm detector and 7 pieces of 10 mm×10 mm×0.5 mm detectors were stacked to form a block of the stacked detector. 4 blocks of the stacked detector (total volume of 1.45 cm^3) were connected to the ASIC. The gain difference among the input channels was successfully corrected by the simple linear equation. The combined spectrum showed the high energy resolution, that is, 4% for 122 keV, 1.5% for 662 keV, and 1.4% for 1332 keV, with higher sensitivity of 50 cps/(μSv/h) for 122 keV, 2.2 cps/(μSv/h) for 662 keV, 0.081 cps/(μSv/h) for 1332 keV. This result well demonstrated that this structure enabled us to increase the sensitivity without the degradation of the energy resolution by increasing the stack layer of CdTe. These characteristics of the stacked CdTe detector are preferable for the various practical application, including the homeland security. Furthermore, we are now developing improved data acquisition system, which can carry out the gain correction with the FPGA and CPU so that the data with gain correction can be obtained directly from the data acquisition system with USB interface.

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