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Readout System for Arrays of Frisch-ring CdZnTe Detectors

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Abstract **– Frisch-ring CdZnTe detectors have demonstrated good energy resolution for identifying isotopes, <1% FWHM at 662 keV, and good efficiency for detecting gamma rays. We will fabricate and test at Brookhaven National Laboratory an integrated module of a 64-element array of 6x6x12 mm^3 Frisch-ring detectors, coupled with a readout electronics system. It supports 64 readout channels, and includes front-end electronics, signal processing circuit, USB interface and high-voltage power supply. The data-acquisition software is used to process the data stream, which includes amplitude and timing information for each detected event. This paper describes the design and assembly of the detector modules, readout electronics, and a conceptual prototype system. Some test results are also reported.**

Keyword – CdZnTe, Data Acquisition System, Frisch-ring detector

I. Introduction

CdZnTe (CZT) is very attractive material for room-temperature semiconductor detectors due to its wide bandgap and high atomic number [1]. However, CZT detectors are typically single-charge-carrier devices because holes have poor mobility. Thus, to achieve high-energy resolution, techniques for designing special detectors are required, such as pixilated, co-planar grid, and virtual Frisch-grid devices [2]. Since the introduction of the first Frisch-ring CZT detector [3], a variety of similar devices were designed and tested. Our group in Brookhaven National Laboratory has expended efforts in improving the performance of the Frisch-ring CZT detectors; our most recent work focused on the non-contacting Frisch-ring detector [5]-[7]. The unique features of this configuration are its simplicity, yet outstanding spectral performance [5]. Its form allows us to build an inexpensive large-volume detector array, which has high energy resolution and a large effective area.

On the other hand, compact efficient radiation spectrometers are needed in non-destructive detection, radiation imaging, and homeland security (for example, non-proliferation safeguards, custom inspection, and radiation field survey). Most of these applications desire an instrument with compact size, room-temperature operation, high gamma-ray energy resolution and absorption efficiency, and low cost. The devices presently used for portable gamma ray spectroscopy include NaI(Tl)-based detectors and portable high-purity germanium (HPGe) detectors, yet neither of them fulfill the requirements. Gamma-ray spectrometers based on CZT detectors have been developed in the past; they either are very expensive or have low gamma-ray absorption efficiency. Our improvements on the Frisch-ring technique makes it possible to assemble a detector array that meets the above requirements.

Recently, our group at Brookhaven National Laboratory designed a 64-channel gamma-ray spectrometer utilizing the non-contacting Frisch-ring detectors. Our goal is to demonstrate the feasibility of employing such a detector in a hand-held or portal systems. A detector module of Frisch-ring detector array has been designed and assembled in our laboratory. The readout electronics design is done. By using the Multiple Input/Output System (MIOS) developed by BNL's Instrumentation Division, a conceptual prototype system has been built. In this paper, we describe the system design and detail the assembly of the detector module. The results from testing several detectors are reported, which help us to characterize the performance and determine the structure of our final compact spectrometer system.

II. Detector Module

To install the system more easily, we divided 64 CZT crystals into a series of detector modules, each consisting of a 4x4 array.

A small printed circuit board (PCB board) served as the substrate of the detector module. To reduce the parasitic capacitance of the traces on this PCB board, the substrate was made out of Rogers 4003 material. On one side of the substrate, there is a 4x4 array of gold-plated square pads (3 mm x 3 mm) with a pitch between them of 5.5 mm. On the other side, there are two mini connectors to the preamplifier board. As shown in Fig. 1, manually wrapped Frisch-ring CZT crystals were glued onto the pad using conductive epoxy resin. To ensure a good connection between the crystal and the pad, the pad side of the substrate was grooved so there were slots, 1.5 mm wide and 0.7 mm deep, between pads. On the top of the crystal, high voltage is applied to the cathode through a copper tap, which also is glued to the crystal using epoxy. All the detector cathodes in the array share the same high voltage supply, and all the copper shields are connected to the signal ground of the system.

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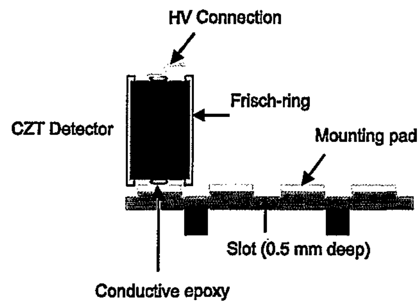

Fig. 1. Detector module assembly.

With this approach, we assembled a detector module with four crystals installed, three good ones and one that was revealed to be faulty during the subsequent test. The good ones are 4x4x12 mm long (small), 5x5x14 mm long (mid-sized), and 6x6x14 mm long (large). The bad one is 5x5x14 mm long.

III. DATA ACQUISITION SYSTEM

The design of the data-acquisition system (DAQ) considered the possible portal hand-held application and used two Application Specific Integrated Circutis (ASICs) developed at BNL: a 16-channel low noise preamplifier ASIC for CZT detector readout [8] and a peak detector/derandomizer (PDD) ASIC [9]-[11]. The preamplifier ASIC has a continuous reset system that enables it to self-adapt up to 150 nA leakage current from the CZT detectors. Its input transistor and the shaping circuit are optimized for the CZT detector application so that the Equivalent Noise Charge (ENC) is only 93 e^- with 2 pF input capacitor, 1 nA leakage current, and 1 fC input charge. The PDD ASIC is a 32:1 multiplexer that uses analog techniques (precision peak detectors and time-to-amplitude converters) with arbitration logic to concentrate the data before digitization. For signals arriving at any of its 32 channel inputs, the ASIC provides amplitude and timing (occurrence time, rise time, or time-over-threshold) signals in analog format and the channel number in digital format. Fig. 2 shows our system's structure based on these two ASICs.

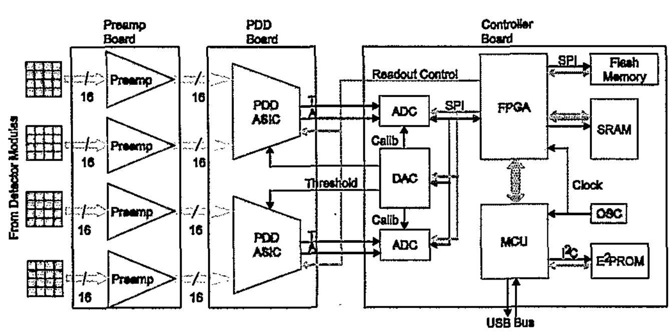

Fig. 2. The structure of the data-acquisition system for the Frisch-ring CZT detector array.

There are three PCB boards in this stacking system: preamplifier board, PDD board, and controller board. The detector modules reside on the top of the system.

Signals from each 16-channel detector module are amplified by a preamplifier ASIC that has a programmable gain (33 mV/fC to 200 mV/fC) and peaking time (0.6 μs to 4.0 μs). Output signals from two preamplifier ASICs are processed and buffered in a PDD ASIC. Then, the amplitude and timing are digitized by a 12-bit analog-to-digital converter (ADC). Thereafter, all the digitized information is collected by a FPGA and sent to a computer through a universal serial bus (USB) controlled by a microcontroller [12]. The computer has DAQ software to control the system and process the data stream.

Recently we designed and fabricated the detector module and the preamplifier PCB board. To test these two boards, we built a prototype system using the PDD test box [13] and the MIOS system developed by BNL's Instrumentation Division. This is a safe and satisfactory way to design the final compact system, because the prototype system can help us to evaluate our designs for the detector substrate and preamplifier, so ensuring that they do not introduce extra electronic noise into the system. Fig. 3 shows a photo of the whole system. Our preamplifier boards are plugged into the PDD test box directly (shown on the right in Fig. 3). The MIOS system (shown on the left in Fig. 3), with a similar structure to our controller board, digitizes the signals from PDD ASICs and sends the data to computer.

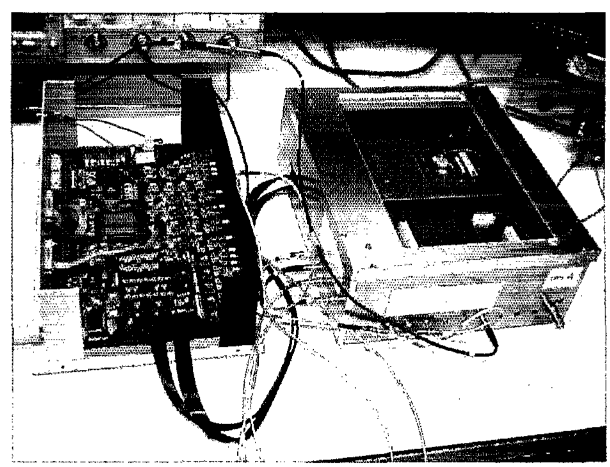
Fig. 3. The DAQ system for the CZT detector array

IV. TEST RESULTS

We tested the system in the laboratory using both the pulse generator and ^{137}Cs gamma ray source. In this section, some results from these four crystals are discussed.

A. Noise

The electronics noise was studied first when the prototype system was built. To identify and understand the contributions from different sources to the total noise, we measured the ENC of the prototype system at different steps during system integration steps: 1) with the preamplifier ASIC's input pins lifted up; 2) with the preamplifier ASIC input pins soldered onto the preamplifier board; 3) with the detector module plugged onto the preamplifier board; and, 4) with the detector biased at different high voltages. Fig. 4 shows the test results.

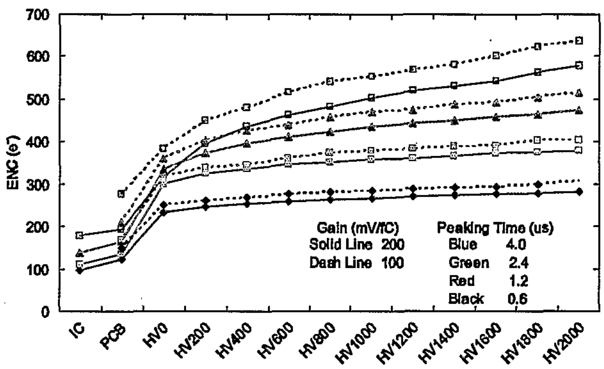

Fig. 4. Equivalent noise charge of the prototype system. IC: The input pin of the preamplifier ASIC is lifted up from the PCB board. PCB: The input pin of the preamplifier ASIC is soldered onto the PCB board. HV0 to HV2000: Detector module is plugged into the system, and biased at certain high voltage, e.g. HV 2000 means 2000 V.

The figure shows that the detector's noise dominates the total noise level. In particular, due to the detector's leakage current, the total noise gets higher as the bias voltage goes up. From these values, we determined the intrinsic system noise. For example, with a 2000 V bias, 2.4 μs peaking time, and gain of 100 mV/fC, the ENC is about 500 e^-, equivalent to 0.8% FWHM resolution for energy of 662 keV.

B. Spectra from CZT Detectors

Fig. 5 shows the spectra obtained from these four crystals with ^{137}Cs source, 2000 V bias voltage, 2.4 μs peaking time, and 100mV/fC gain. The small crystal gives best resolution of 1.38% (FWHM) for the ^{137}Cs 662 keV peak. The mid-sized one and large one also have good results, 1.78% and 2.68% resolutions (FWHM), respectively. However, the large faulty one is noisy and there is no significant peak. We note that the performance of CZT crystals varies greatly due to the growing process and other factors, although the same Frisch-ring fabrication process was used.

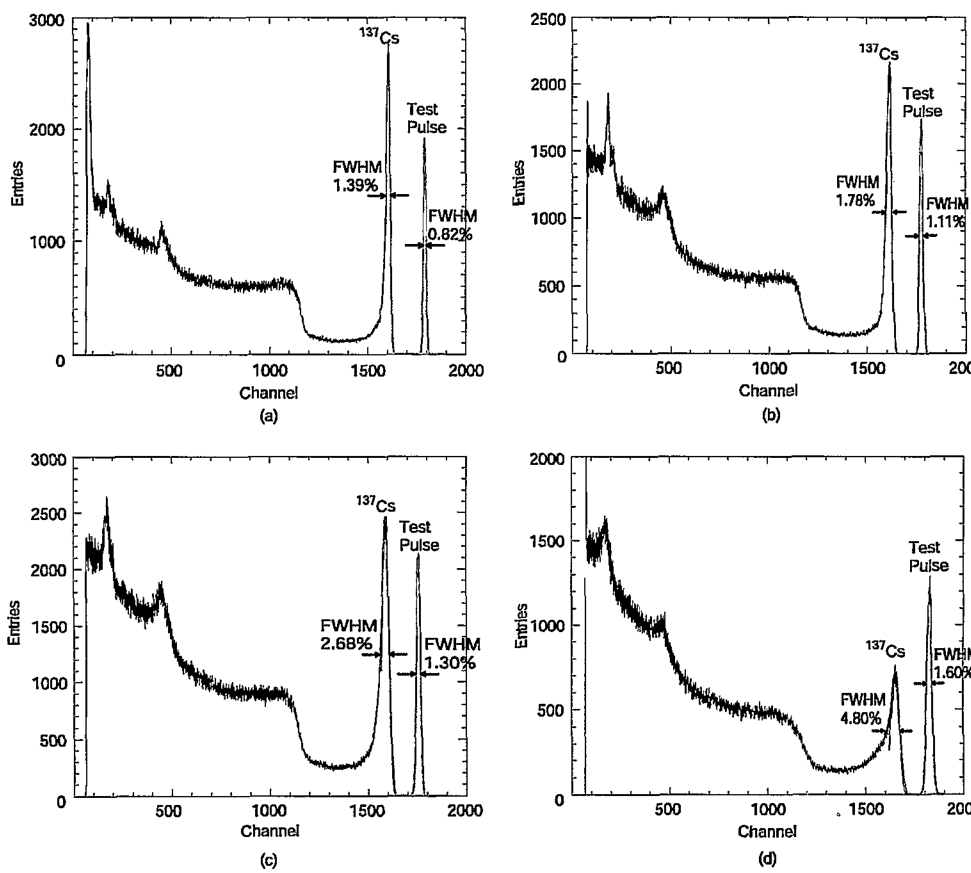

Fig. 5. Spectra from different CZT detectors with 2000 V bias, 2.4 μs peaking time, and 100mV/fC gain. (a) the small detector; (b) the mid detector; (c) the large detector; and, (d) the bad detector. Blue curves are the Gaussian fitting of the ^{137}Cs source. Red curves are the Gaussian fitting for the test pulse.

A. Energy resolution vs. Peaking Time

To see how the peaking time affects the energy resolution, we took spectra using the small detector with (a) 1.2 μs, (b) 2.4 μs, and, (c) 4.0 μs peaking time (Fig. 6). From the test pulse spectra, we see that the total noise worsens as the peaking time increases, a result in agreement with our test in section IV(A). However, the ^{137}Cs spectrum is best resolved with 2.4 μs peaking time.

To find the reason for this, we compared the peaks' shapes in different peaking times by normalizing the ^{137}Cs peaks with 1.2 μs and 2.4 μs peaking times, and comparing them in Fig. 6 (d) after aligning their centroid position. We did the same for 2.4 μs and 4.0 μs peaking times in Fig. 6 (e). As Fig. 6 (d) shows, the marked difference between two peaks is in the left slope of the peak with 1.2 μs peaking time; this can be explained by incomplete electron collection in the crystal. In Fig. 6 (e), the two peaks have the same shape. The peak taken with 4.0 μs peaking time is just slightly wider than that with 2.4 μs peaking time, because the parallel noise (detector's leakage current) dominates the total noise level in the system.

Thus, the energy resolution is related to the peaking time. Selection of the peaking time is determined by electron mobility in the CZT material, high voltage bias applied to the detector, the detector's leakage current, and the detector's dimensions.

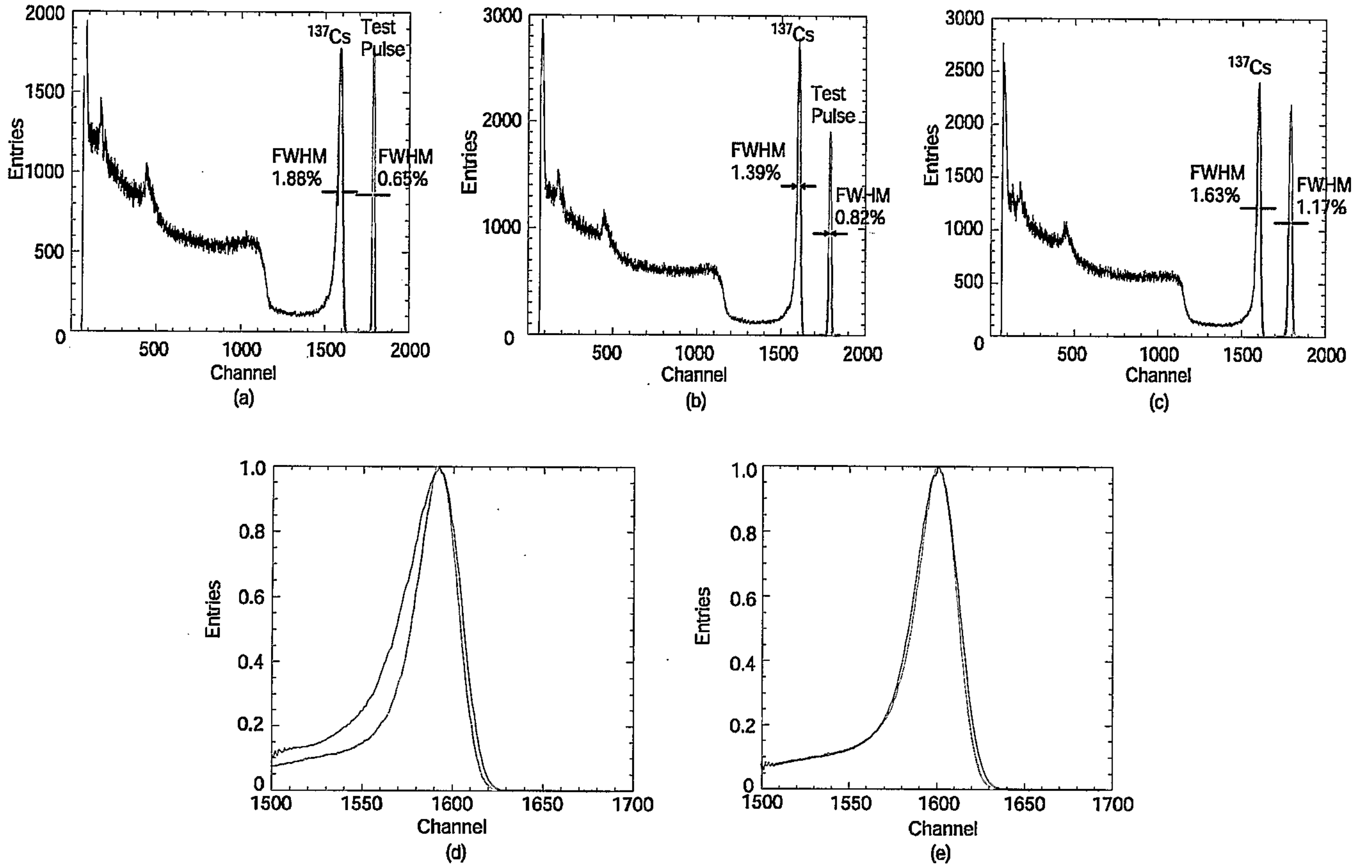

Fig. 6. Spectra with different peaking time. (a) 1.2 μs peaking time; (b) 2.4 μs peaking time; (c) 4.0 μs peaking time; (d) normalized peaks of 1.2 μs and 2.4 μs peaking times; and (e) normalized peaks of 2.4 μs and 4.0 μs peaking times. In (d) and (e), the red curve is the spectrum with 2.4 μs peaking time.

I. Conclusions

We completed a prototype system for the compact spectroscopic device based on CZT Frisch-ring detectors. Test results show that the system's performance meets the design requirements for the compact Frisch-ring CZT array spectrometer system. Our analysis of these findings helps us to determine the specifications of the final portal system design. Based on the work so far, we already started designing the portal system that will be published later.

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