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Preliminary Results of KSU Frisch-Collar CZT Array

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***Abstract*–Cadmium zinc telluride (CdZnTe or CZT) is a well-known problematic material once dimensions exceed ~1cm^3, due to material imperfections that cause severe charge carrier (hole) trapping, compromising the energy resolution for basic planar detector designs. Advances in CZT detector design at Kansas State University (KSU) have demonstrated that room-temperature energy resolution less than 0.9% for 662 keV gamma rays can be consistently achieved. The Frisch-collar detector, developed at KSU, is a design based on the Frisch grid effect, which changes a basic planar detector from a low-resolution device into a high-resolution device by suppressing deleterious effects from charge carrier (hole) losses. We studied the application of Frisch-collar CZT detectors to hand-held or remotely-deployable rapid spectroscopic devices, designed to operate in signal-summation and Compton-suppression modes, employed for greater counting efficiency and improved energy resolution, respectively. The array is made from small volumes of Frisch-collar CZT, lowering cost and easing purity requirements for ingot growth. Timing resolution for signals arising from Compton-scattered gamma rays as a function of detector bias voltage will be discussed.**

I. INTRODUCTION

Applications presently requiring high-resolution gamma spectroscopy could be improved and simplified if satisfactory performance were available in a compact, less expensive, room-temperature version. High resistivity and excellent electron mobility are unique properties of CZT, but the CZT devices suffer from poor hole mobility. This causes the Frisch-collar CZT detector to act as a new material. While CZT itself is not a new material, the development of Frisch-collar technology at KSU changes the electric field within the crystal, mitigating the effect of hole trapping, and effectively changing the material from a two-carrier device to a single-carrier device, thus changing a basic planar detector from a low-resolution device into a high-resolution device [1]. Hence, long-drift CZT Frisch-collar device performance can be limited to only the electron transport properties.

The KSU CZT array [2] uses 16 individual Frisch-collar detectors for a total volume of ~3.4 cm^3, but there is no fundamental limit to how many detectors can be combined or the maximum size of such a high-resolution array. The signal-to-noise ratio of the array is not affected by the addition of more CZT detectors. Summation of Compton-scattered incoming gamma photons improves counting efficiency and allows an array of small CZT detectors to function as a single larger detector, but with added directional sensitivity. The array will also be capable of operating in Compton-suppression mode, for improved spectral resolution and imaging capability. The array can be made from small volumes of CZT, greatly lowering cost and easing purity requirements for ingot growth. Recent advances in cadmium zinc telluride (CZT) detector design at the Kansas State University SMART Laboratory have demonstrated that room-temperature ***energy resolution less than 0.9% for 662 keV gamma rays*** can be achieved (see Figure 1) [3], along with improvement in the linearity of charge collection efficiency.

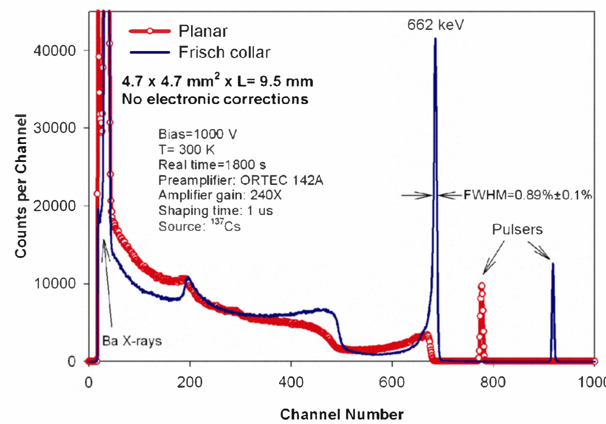

Fig. 1. Pulse height spectra taken with a 4.7 mm x 4.7 mm x 9.5 mm CdZnTe Frisch-collar device being fully irradiated with a Cs-137 gamma ray source positioned directly underneath the device. A 0.89 % FWHM energy resolution is achieved at 662 keV.

Combining the Frisch-collar technology with some relatively simple electronic signal correction is expected to improve the energy resolution even further. In each of the devices, gated current integration instead of current pulse height is available to make a first-order correction for depth-of-interaction effects.

II. CZT ARRAY DESIGN

Individual Frisch-collar CZT detectors are shown in Fig. 2, below. Sixteen Frisch-collar detectors were fabricated from varying grades of starting material, and ranged in energy resolution from <1% to 2.2%, with most being ~1.3%. The 4 x 4 array of detectors in shown in Fig. 3, mounted on the 16-channel array motherboard.

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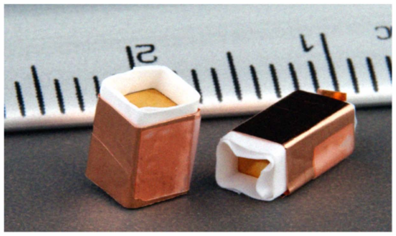

Fig. 2: Individual Frisch-collar CZT detectors

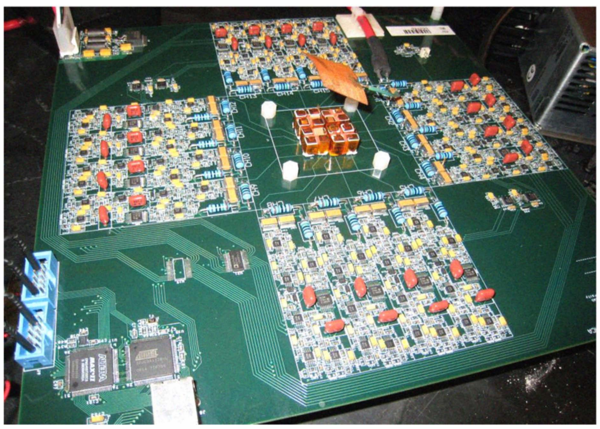

Fig. 3: CZT array mounted on 16-channel motherboard. The detectors are grouped in the center, below the moveable cathode screen.

Each detector has a dedicated amplifier, and the lower-level discriminator levels are set in groups of eight. If the amplified signal from an individual detector exceeds the lower-level discriminator threshold, a digital timing signal is generated for that channel. Analog data collection can be in either pulse-height or integrated-current mode. Analog values for each active channel are held and sent in turn to a single Analog-to-Digital converter. The timing signals are shown in Fig. 4, below.

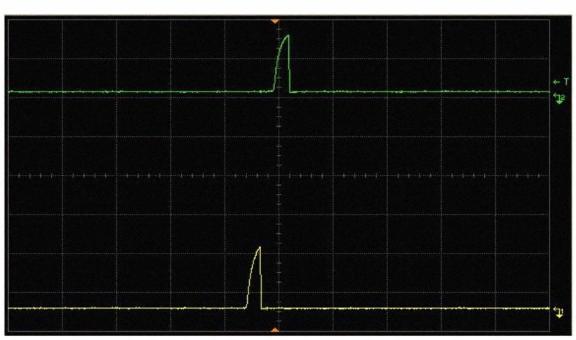

Fig. 4: Preamplifier timing signals from adjacent detectors during a possible Compton-scattering event. The vertical scale is 2 V/div, and the horizontal scale is 5 µs/div.

Once the preamplifier timing signals reach approximately 330 mV, they generate logic signals with 3.5 V amplitude, and are synchronized to the system clock. The digital timing signal is synchronized to a 10 MHz clock for use in coincidence/anti-coincidence operation. Thereafter, their time separation will be a multiple of 100 ns, as shown in Fig. 5.

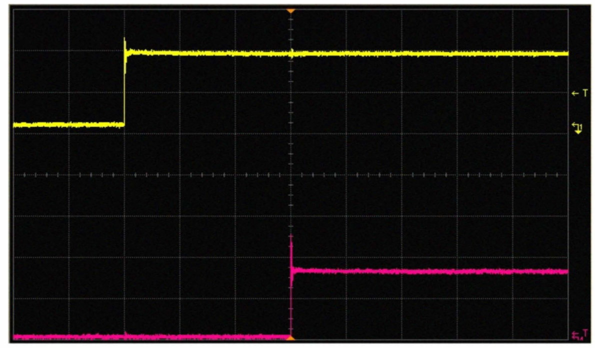

Fig. 5: Synchronized timing signals from adjacent detectors during a possible Compton-scattering event. The vertical scale if 2 V/div, and the horizontal scale is 500 ns/div.

III. Experimental Procedure

To test the timing resolution of the system, the time distribution of synchronized timing signals from adjacent detectors were compared under irradiation with 662 keV gamma rays from ^{137}Cs under different bias voltages. The maximum observed time difference between synchronized signals resulting from a single Compton-scattered gamma photon is expected to occur when the absorption of photon energy is near the anode end of one detector and near the grounded cathode end of the adjacent detector, as shown in Fig. 6, below.

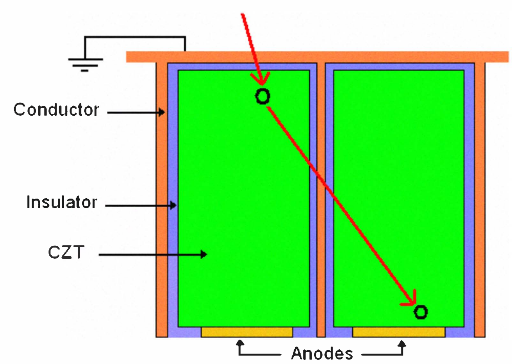

Fig. 6: Gamma absorption events in adjacent Frisch-collar detectors during a Compton-scattering event, resulting in the maximum time difference between the correlated signals.

This maximum time difference should reflect the maximum time for collected charge to travel the length of the detector at the given bias voltage for any of the detectors, whether or not Compton-scattering occurred. This allows for a measurement of maximum charge collection time versus bias voltage that is not possible when a single detector absorbs the full photon energy.

IV. Results

Timing histograms were obtained, showing the total variation in processing time for synchronized digital timing signals from adjacent detector elements. A Compton-scattered photon causing signals in two adjacent detector CZT crystals allows for a measurement of relative signal arrival times in the system arising from near-simultaneous events in the adjacent detectors. Obtaining timing histograms from adjacent detectors also enabled the determination of the relative frequency of random coincident counts versus coincident counts resulting from Compton-scattering events between the two detectors. To date, two different bias voltages were used, one at 180 V and the other at 300 V, as shown in figures 7 and 8, respectively.

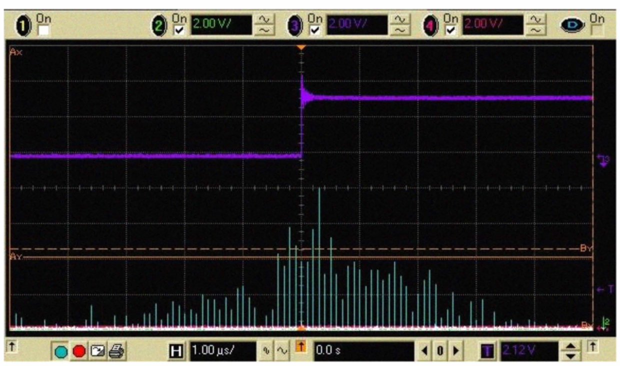

Fig. 7: Relative time histogram of synchronized timing signals from two adjacent Frisch-collar detectors at 180 V bias, taken for one hour. The upper trace is triggered on the rising edge of the timing signal from one detector, and the vertical bars at the bottom represent the arrival times of the leading edge of the timing signals from the adjacent detector, normalized to the highest histogramming bin. The horizontal scale is 1 µs/division.

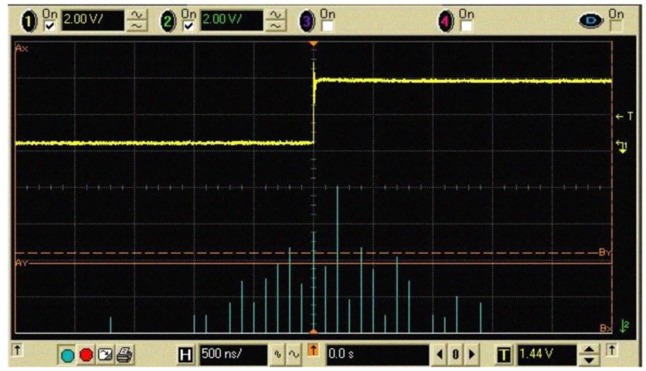

Fig. 8: Relative time histogram of synchronized timing signals from two adjacent Frisch-collar detectors at 300 V bias, taken for 10 minutes. The horizontal scale is 500ns/div.

In Figs. 7 and 8 it is not known which detector generated the timing signal first, therefore the peak width represents twice the maximum time difference of synchronized timing signals between detectors. Counts outside the peak represent random coincidences. Note that the histogram counts occur only at 100 ns intervals, synchronized to the 10 Mhz system clock. Increasing the bias voltage from 180 V to 300 V cut the current collection time from ~3 µs to ~1.5 µs.

V. Conclusion

Each detector has an identical timing signal processing time (within one clock cycle), therefore the remaining variation in maximum time difference of synchronized timing signals between adjacent detectors should reflect the actual variation in maximum charge collection time as a function of detector bias. The maximum planned bias for the array is 1000 V, and the expected variation in charge collection time is needed to optimize parameters for summation or suppression of Compton-scattered incoming gamma rays. The number of coincident signals arising randomly appears to be relatively low.

References

[1] United States Patent Office, Patent # 6175120

[2] United States Patent Office, Patent # 6781132

[3] Alireza Kargar, Mark J. Harrison, Adam C. Brooks, Douglas S. McGregor "Characterization of charge carrier collection in a CdZnTe Frisch collar detector with a highly collimated 137Cs source," *Nuclear Instruments and Methods in Physics Research A,* vol. 620, pp.270–278, 2010