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 ~1 cm³, 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 cm³, 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.
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.

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.

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.
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.

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 \(\mu s\) to ~1.5 \(\mu s\).

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

McGregor “Characterization of charge carrier collection in a CdZnTe
Frisch collar detector with a highly collimated 137Cs source,” Nuclear
2010