Single-Sided Charge-Sharing CZT Strip Detectors

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Abstract—We describe a new type of CZT strip detector module designed to perform gamma-ray spectroscopy and 3-d imaging. We report preliminary performance measurements with the first of five 7.5 mm thick prototype devices. The CZT single-sided charge-sharing strip detector features an anode pattern with contacts whose dimensions and spacing are smaller than the size of the charge cloud created by ionization near the gamma interaction site. The tiny anode contact feature size and the use of emerging high-density interconnection technologies permit multi-dimension imaging using the charge-sharing principle. Unlike double-sided strip detectors, this device features both row and column contacts on the anode surface. This electron-only approach circumvents problems associated with poor hole transport in CZT that normally limit the thickness and energy range of double-sided strip detectors. These devices can achieve similar performance to pixel detectors for both 3-d imaging and spectroscopy. The work includes laboratory and simulation studies aimed at developing compact, efficient, detector modules for 0.05 to 1 MeV gamma radiation measurements. The low channel count strip detector approach significantly reduces the complexity and power requirements of the readout electronics. This is particularly important in applications requiring large area detector arrays.

I. DETECTOR CONCEPT

Fig. 1. Single-sided charge-sharing strip detector (left). Unit cells (right) show interconnections.

Fig. 1 shows the anode pattern and two 1 mm square unit cells or ‘pixels’ (expanded, right) to illustrate the detector concept and to show pad interconnections. Unit cells contain an array of closely packed anode contact pads in two interlaced groups (gray and black in this illustration). The two groups are identically biased for charge collection but, within and between pixels, are interconnected in columns or rows in the layers of the carrier substrate. A non-collecting grid electrode surrounding each pixel, biased between pixel pad and cathode potentials, provides a signal that can be used for measuring the depth of interaction, the Z-coordinate. A single cathode contact on the opposite side is not shown.

The principle of operation requires sharing of charge between row and column anodes for each event. This is feasible when the lateral extent of the electron cloud exceeds the pitch of the anode contact pads (Fig.2). This approach takes advantage of the increasing capability of manufacturers to interconnect fine features with the carrier substrate. Interconnections, shown schematically in the figure, reside on the layers of the carrier substrate.

This new device concept was presented earlier [1, 2]. A similar approach exists for silicon detectors [3].

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Advantages: The single-sided charge-sharing strip detector design addresses some of the limitations encountered with an earlier single-sided strip detector design [4]. The front-end electronics are simpler. Unlike the previous design, charge collecting is used for both the x and y-coordinate measurements. Polarities and shaping times (and ASICs) can now be the same for both. Column and row signals will be reduced on average to half the total collected charge, but the size of the non-collecting strip column signal in the previous design was much smaller (25% the size) and required faster (noisier and higher power) front-end circuitry. Surface leakage between row and column electrodes, now identically biased, is eliminated. In addition, the large area covered by the grid electrode results in improved depth resolution than was available from the individual strip column electrodes in the earlier design.

Disadvantages: In this new design, column and row signals are summed to measure energy, degrading the achievable energy resolution by a factor related to the electronic noise. Capacitance effects due the compact pad and interconnect structure will also increase the noise. We anticipate, however, that selecting the proper ASIC will minimize this effect. We also anticipate that limited charge sharing due to the small size of the electron cloud at low energies will, for some events, result in a 1-d measurement and will, at least for the first prototype detectors, set the effective lower energy threshold. This effect was observed in the initial tests with the first prototype detector.

II. SIZE OF THE CHARGE CLOUD

To better understand the charge cloud size as a function of the photon energy, we have embarked on a series of comprehensive Monte-Carlo simulations using GEANT (v.4.6). The preliminary result, illustrated in Fig. 3, shows the radial energy-deposit distribution from the primary photon impact point. Compton scattered events were excluded. We find that the electron cloud size increases abruptly from 20 keV to 30 keV due to the production of the K-shell X-rays in CZT, and that ~10% of the deposited energy lies outside the 100 µm radius up to 150 keV. Diffusion of the charge cloud as it moves toward the anode surface will further increase the size of the charge cloud. We calculate a point charge will spread to a radius of 10 µm for each mm of drift to the anode. Lower energy photons interact nearer the cathode surface. The larger drift lengths for these events will partially compensate for the small initial size of the charge cloud.

The effective threshold for having sufficient shared signal to measure x and y will depend on the electronic noise and the anode pad size. A 250 µm diameter charge cloud is shown projected on two expanded unit cell anode patterns of detectors with different pad and gap sizes to illustrate how small feature size improves the charge sharing (Fig. 4). With present manufacturing capabilities, 100 µm pads and gaps, the effective energy threshold is greater than what will be possible when manufacturers can fabricate and bond detectors with 20 µm pads and gaps, the goal of eV Products' Z-bond technology.

![Fig. 3. GEANT simulated charge cloud extent for photoelectric interactions as a function of the photon energy.](image)

![Fig. 4. Unit cells of two charge-sharing strip detectors with a 250 µm diameter charge cloud. Currently reasonable feature size (left); manufacturing goal (right).](image)

III. PROTOTYPE DETECTOR MODULE CONSTRUCTION

Photographs of the components of an 11 row x 11 column (121 “pixel”) prototype detector module are shown in Fig. 5. Pixel pitch is 1.225 mm for both rows and columns. The patterned CZT anode surface is shown at the top (a). The anode-mating or top surface of the ceramic substrate is shown in Fig. 5b. The bottom surface of the ceramic substrate is shown in Fig. 5c. The ceramic substrate, designed for us by MillPack, Inc., is formed using Dupont Fodel layers on an alumina substrate. Multiple Fodel layers provide the mating surface contacts, the interconnection of the row contacts, the interconnection of the column contacts, a shield layer to reduce signal coupling between rows and columns, vias to interconnect the layers and routing of row and column signals and biases to and from the passive components and the connector (integrated on the underside).

Fig. 6 is a photograph of an assembled detector module. The eV Products Z-bond process was used to bond the 7.5 mm thick patterned CZT substrate to the ceramic substrate. A photograph through glass of a Z-bond sample layer on a unit cell of the ceramic substrates is shown in Fig. 7. The black dots are the metal filaments that electrically connect the contact pads on the mating surfaces. The pad size on our substrate is 115µm. The reader can see the interconnect pattern for columns on the first layer below the contact pads. The reader can also discern the "shield" layer below that. Row interconnections are below the shield and cannot be seen here. The shield layer is present to reduce row-column crosstalk.
IV. ARRAY CONCEPT

The compact module design lends itself to assembly of closely-packed imaging arrays. A side view of an image plane segment (Fig. 8) helps illustrate the approach to image plane array design. The image plane is essentially a board assembly on which is the mechanical, electrical and thermal support necessary for detector module operation. This includes module mating connectors, module alignment pins and supports, the FEE ASICs, bias routing and filtering, thermal shunts and a microprocessor with an integrated ADC. This all fits within the footprint of the modules. Note that the guide rails with pins on the logic board serve to align and support the modules. They also serve to dissipate heat. This design was developed using the VA32-TA32CG combination of front-end electronics ASICs from Integrated Detector Electronics (IDE).
Platform logic for each ASIC pair

Microprocessor

(1 per 4 modules)

support rail, thermal path

logic for each ASIC pair

ceramic substrate

Fig. 8. Image plane design. Modules plug in to an image plane assembly forming a compact array.

V. PROTOTYPE PERFORMANCE

For our initial laboratory evaluations we used the cathode signal to trigger simultaneous acquisition of pulse height data for all row, column, grid and cathode signals. We illuminated the detector with a collimated beam (1 mm diameter) of gamma photons of various energies for these studies. Measurements were performed at room temperature.

Fig. 9. shows a scatter plot of row (x) vs. column (y) pulse heights for beam spot illumination of the detector with a $^{57}$Co source at the unit cell x8, y6.

Events are distributed along two lines corresponding to $x+y=122$ and 136 keV, the $^{57}$Co photopeak energies. The top two panels in Fig. 10 show the raw x and y spectra as well as the spectra for 'shared' events where both x and y pulse heights are above a threshold of 8 keV. The third and bottom panels show the spectra of the $x+y$ sum for all events and for just the shared events. At 122 keV we find that 75% of the events are shared. Similar measurements at 60 keV (Fig. 11) and 662 keV (Fig. 12) show the percentage of events shared to be 61% and 85% respectively. Good energy spectra are obtained by summing the row and column pulse heights of shared events. The measured energy resolution (FWHM) at 60, 122 and 662 keV is 12.5%, 7.5% and 3.4% respectively. The low energy tail of the 662 keV photopeak is due to small angle Compton scattering from the collimator. The upper HWHM is 1.2%. Similarly, the x, y location can be determined to first order from the row and column channel registering the largest signal for shared events (Fig. 13). The spatial resolution is at least as good as the pixel pitch.
Fig. 11. Response to collimated $^{241}$Am beam spot.

Fig. 12. Response to collimated $^{137}$Cs beam spot.
VI. CONCLUSIONS AND FUTURE WORK

We have designed a new type of CZT strip detector and fabricated the first prototypes for evaluation in the laboratory. Initial tests of first prototype device demonstrate good spectroscopic response as well as the effectiveness of the charge-sharing approach for 2-d imaging using row and column contacts on a single detector surface. We will continue the laboratory study extending it to 3-d imaging and the evaluation of the remaining prototype devices. We will then pursue an improved design with smaller anode contact features. We feel this will improve the row-column charge sharing efficiency thus increasing the efficiency of these devices as imagers.

Our goal is to develop and demonstrate mature designs for compact, efficient, high performance CZT strip detectors for imaging and spectroscopy in the 0.05 to 1 MeV energy range and and be ready to employ them in large area detector arrays when large volumes of suitable CZT materials become available and affordable.

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REFERENCES


