Synchrotron Radiation Response Characterization of Coplanar Grid CZT Detectors

G. A. Carini, A. E. Bolotnikov, G. S. Camarda, G. W. Wright, G. De Geronimo, D. P. Siddons, and R. B. James

Abstract **– Commercial 15x15x7.5 mm^3 coplanar grid CdZnTe detectors were studied on the micron-scale using a collimated high-energy X-ray beam provided by Brookhaven's National Synchrotron Light Source. This powerful tool enables simultaneous studies of detector response uniformity, electronic properties of the material, and effects related to the device's contact pattern and electric field distribution. The availability of a front-end Application Specific Integrated Circuit, developed at Brookhaven's Instrumentation Division, providing low noise amplification of grids and cathode signals, corresponding timing signal and adjustable relative gain, allowed to correlate performance mapping and fluctuations in collected charge. We observed the effect of the strip contacts comprising the coplanar grids on the energy resolution of the coplanar-grid device.**

I. INTRODUCTION

THE coplanar grid sensing technique [1] has shown a considerable enhancement in the spectral performance of large volume CdZnTe detectors removing the limitations due to poor hole collection and providing an adequate correction for electron trapping. This technique, combined with recent advances in CdZnTe manufacturing, yields large-volume high-resolution room temperature gamma-ray sensors for a wide range of applications such as nuclear material monitoring, radioisotope identification, gamma-ray astronomy, and medical diagnostics [2,3,4,5]. Coplanar grid technique can potentially provide an energy resolution of less than 1% FWHM at 662 keV for a cubic cm device [6]. However, the actually measured resolution, typically more than 2%, is still far from the statistical limit calculated based on the Fano factor [7]. In general several factors can limit the energy resolution of these devices: material non-uniformity, device geometry, surface effects, electronic noise, electron trapping, edge effects, etc. Many of these deleterious effects are not fully understood. In this work, we performed a micron-scale characterization of several commercial coplanar-grid devices with a goal to investigate the effect of the electrodes configuration on the device response uniformity.

II. EXPERIMENTAL SETUP

A low-noise low-power application specific integrated circuit (ASIC) developed at Brookhaven's Instrumentation Division in collaboration with Los Alamos National Laboratory was employed to read out the signals from the coplanar grid devices [8]. The commercial detectors acquired from eV Products were first evaluated by using a ^{137}Cs (662 keV) source to determine the optimal operating biases required on the device electrodes (Fig. 1). Relative gain compensation method [9] has been employed to achieve the best energy resolution. Electronic noise contribution was evaluated yielding, with the detector connected, an equivalent noise charge (ENC) of 730 e$^-$ (7.9 keV). A typical inter-anode grid capacitance and an anode-cathode plus anode-ground capacitance on the order of 15pF and 4pF were measured respectively. Then, the detectors were studied at the X12A beam-line.

During the scan, we varied the bias applied on the cathode and use different grids/cathode voltage ratios. The lowest cathode bias was 600 V with a corresponding bias on the non-collecting grid of 30 V. The highest applied biases were 1000 and 75 V respectively.

A schematic of the experimental set up is shown in Fig. 2. The beam-line could be configured as a monochromatic beam with photon energies up to 50 keV or as a white beam with photon energies up to 100 keV. We used a pseudo-monochromatic beam produced by attenuating the white beam with a lead filter. The corresponding energies of the photons had a Gaussian-like distribution centered around 80 keV with ~7 keV FWHM. The data acquisition system included a multi-channel analyzer (MCA) to accumulate pulse-height spectra, a digital oscilloscope to store waveforms, and standard NIM electronics. To calibrate the spectroscopy electronics we used a standard ^{241}Am source. A SPEC [10] macro (a UNIX based software package for instrument control and data acquisition developed for X-ray diffraction) controls a X-Y stage and the data acquisition.

The detector, mounted inside a test-box, was placed on X-Y translation stage, with the cathode oriented perpen-

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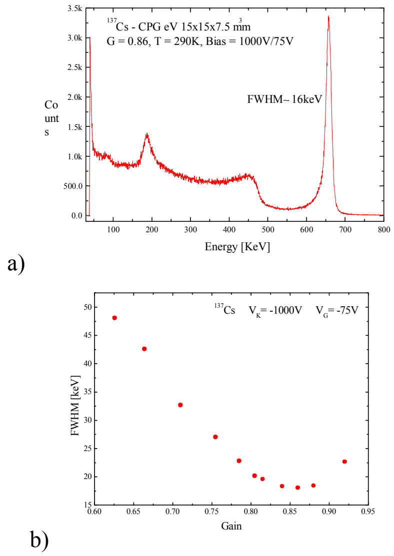
dicular to the incident beam, and was irradiated from the cathode side with a 25x25 μm^2 spot size beam.



a)

b)

Fig. 1. Spectral measurements using relative gain compensation method: a) spectrum from a ^{137}Cs source with G≈0.86 and b) FWHM vs G on the 662keV peak.

Several raster scans, with typically less than 100 μm step size in both directions, were performed. For each point, a pulse-height spectrum was collected during a 3 seconds time interval. Due to the high brightness of the beam it was possible to accumulate spectra with good statistics in such short period of time.

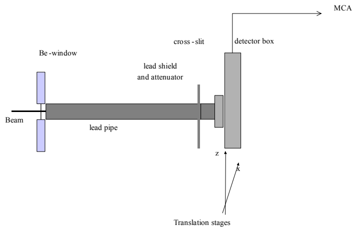


Fig. 2. Schematic of the setup at the X12A beam-line in white beam mode (1-100KeV) with attenuator. A cross-slit shaped the beam on 25x25 μm^2 spot size.

III. RESULTS AND DISCUSSION

Gaussian fitting was applied to evaluate the peak position, FWHM, and total number of counts for each pulse-height spectrum generated during the scan (Fig. 3). The peak position is directly related to the total collected charge produced by the incident photons. Usually the non-uniformity of the device response is attributed to the non-uniform distribution of the traps inside a CdZnTe crystal. In this work, we investigate other effects that may also contribute to the response non-uniformity of the device. Our primary goal was to understand the role of the strips comprising the coplanar grids.

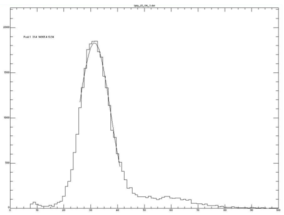
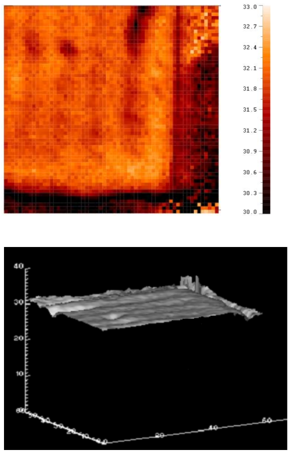


Fig. 3. Gaussian fitting of data collected by the MCA at a point xz of the scan. From this analysis peak position, FWHM, and peak amplitude were evaluated for each point of the raster scan.

Fig. 4 shows the variations in the collected charge which precisely correlate to the location of the coplanar-grid contacts. The signal is higher when the X-ray beam is pointed over the collecting electrodes and lower when the beam is over the non-collecting ones. Similar behavior was observed with all detectors used in these measurements. Fig. 5 shows one dimensional scans taken cross the device, the wave-like curves with peaks corresponding to the strips position in the contact pattern. We found that the typical peak-to-peak difference averaged over a 3x3 mm^2 area is



a)

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Fig. 4. Maps of a scanned corner. a) 2D and b) 3D peak position vs x-z position: a brighter point correspond to a higher peak position value and ultimately to higher pulse height.

around 1.6%. This value slightly changes when the cathode voltage was increased from 600 to 1000 V.

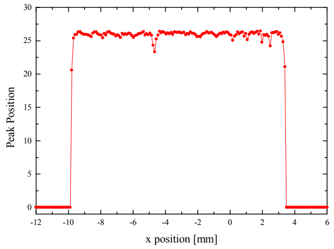

Fig. 5. Cross section along x at a z position. During this scan we applied cathode and grid biases of 600 V, 45 V respectively.

For example, the detector (for which we achieved with best resolution at the cathode and grid biases of 1000 V, 75 V respectively and relative gain G=0.86) a peak-to-peak difference was found to be 1.75%. When the biases were reduced to 800 and 60 V the peak-to-peak difference was found to be 1.78%. with the same relative gain value.

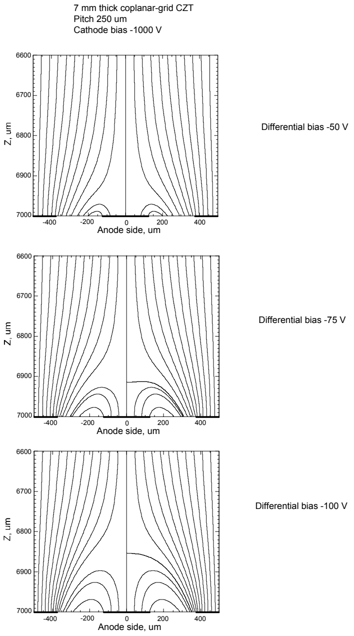

Fig. 6. Electric field fine distribution near the strips. We assume that potential changes as linear function in the gap between the strips.

It should be mentioned, that similar variations in the device response were also observed with pixel [11], drift-field [12], coplanar-grid [13], and other devices that employ steering electrodes.

Two effects can be responsible for the observed variations. The first is related to the different length of the passes traveled by the electron clouds from the points of interactions to the collecting grid. Indeed, most of the photons interact close to the cathode. However due to the charge steering effect by the non-collecting electrode (see Fig. 6), the electron clouds have different travel lengths. The longer travel length the greater fraction of the electrons is lost due to trapping. This results in non-uniformity of collected charge. Similar explanations were also considered in Ref. 13 to explain the response variations measured with 1 cm^3 coplanar-grid device.

It is clear, however, that the above explanation cannot entirely explain the observed variations especially in the case of thick detectors where the difference in the path length (for X-rays interacting close to the cathode) becomes very small. Indeed, for a 7 mm thick crystal and the contact pattern shown in Fig. 6, the calculations predict the charge loss less than 1% for the paths originating at the cathode above the middle of the collecting and non-collecting strips (1000 V is on the cathode and 75 V is on the non-collecting grid). Moreover, the electron diffusion and electron cloud broadening makes this difference even smaller. The second effect that can cause the observed non-uniformity response is the charge loss at the surface between the strips. As shown in Fig. 6, even at high differential bias between the grids the field lines originated at the cathode intersect the surface between the strips. Hence, the electrons can reach the surface which has different electronic properties than CdZnTe bulk. The electron mobility at the surface is less while the concentration of the traps is high. As a result, some fraction of the charge is lost in the gaps between the strips, which gives variations in the device response.

Other non-uniformities of the contacts itself are exhibited in Fig. 7 that shows a scan made along the two strips of a detector. Such a behavior is probably related to the properties (resistivity, trapping levels, etc.) of the surface areas separating the strip contacts. In fact CdZnTe is very sensitive to surface effects and surface properties strongly influence detector performances [14]. Similar effect was reported by F. Zhang et al. [15].

IV. CONCLUSIONS

We performed the X-ray scans of the commercial coplanar grid detectors with micro-scale resolution. We found strong variations of the detector responses that correlate directly with the contact patterns of the devices. The amplitudes of the output signals diminish when the X-ray beam is pointed above the areas of the non-collecting strips. These reductions in amplitudes, which fluctuate over the detector area, affect the energy resolution of the device. The magnitude of the fluctuation was evaluated to be ~1.6%, which might explain the energy resolution limit typically measured with the commercial coplanar-grid devices 2.3% FWHM at 662 keV.

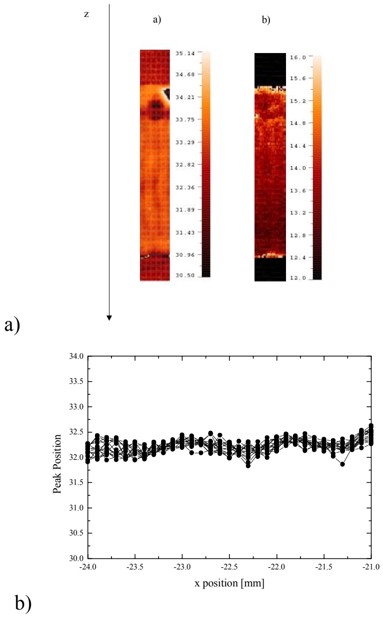

Fig.7. Maps of two collecting strips. a) Peak Position vs (x,z) position; b) FWHM vs (x,z) position.

New measurements with a smaller beam size (down to 10x10 μm^2), and waveform analysis of the collected signals are planned to better understand the cause of the variations of the collected charge and whether it may be an intrinsic effect that limits the energy resolution of coplanar-grid devices.

V. ACKNOWLEDGMENT

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VII. REFERENCES

[1] P. N. Luke, "Single-polarity charge sensing in ionization detectors using coplanar electrodes", *Appl. Phys. Lett.* **65** (22), pp. 2884-2886, 1994.

[2] R. Arlt, J. Brutscher, R. Gunnink, V. Ivanov, K. Parnham, S. A. Soldner, and J. Stein, "Use od CdZnTe detectors in hand-held and portable isotope identifiers to detect illicit trafficking of nuclear material and radioactive sources, *Proc. IEEE-NSS* **1** (4), pp. 18-23, 2000.

[3] T. H. Prettyman, K. D. Ianakiev, C. E. Moss, S. A. Soldner, M. R. Sweet, and M. C. Browne, "Developments of high efficiency, multi-element CdZnTe detectors for portable measurement applications", *Journal of Radioanalytical and Nuclear Chemistry* **248**, pp. 295-300, May 2001.

[4] P. N. Luke, M. Amman, J. S. Lee, B. A. Ludewigt, and H. Yaver, "C CdZnTe coplanar grid detector array for environmental remediation", *Nucl. Inst. Meth. Phys. Res. A* **458**, pp. 319-324, 2001.

[5] T. H. Prettyman, W. C. Feldman, K. R. Fuller, S. A. Storms, S. A. Soldner, C. Szeles, F. P. Ameduri, D. J. Lawrence, M. C. Browne, and C. E. Moss, "CdZnTe Gamma-ray spectrometer for orbital planetary missions", *IEEE Trans. Nucl. Sci.* **49**, pp. 1881-1886, 2002.

[6] Z. He, G. F. Knoll, D. K. Wehe, J. Miyamoto, "Position-sensitive single carrier CdZnTe detectors, *Nucl. Instr. Meth. Phys. Res. A*, **388**, pp. 180-185, 1997.

[7] G. F Knoll, *Radiation Detection and Measurements*, 3rd Ed. (Wiley, New York, 2000).

[8] http://www.certif.com

[9] G. De Geronimo, G. A. Carini, W. S. Murray, P. O' Connor, "Front-End ASIC for Co-Planar Grid Sensors", *IEEE-RTSD*, Rome, 2004.

[10] P. N. Luke, "Unipolar Charge Sensing with Coplanar Electrodes – Application to Semiconductor Detectors", *IEEE Trans. Nucl. Sci.*, **42** (4), pp. 207-213, 1995.

[11] A. E. Bolotnikov, C. M. Hubert Chen, W. R. Cook, F. A. Harrison, I. Kuvvetli, and S. M. Schindler, "Effects of Bulk and Surface Conductivity on the Performance of CdZnTe Pixel Detectors", *IEEE Trans. Nucl. Sci.,* NS 49, n.4, pp. 1941-1949, 2002.

[12] I. Kuvvetli and C. Budtz_Jorgensen, "A pixilated CZT drift detector", to be published in *IEEE Trans. Nucl. Sci.,* 2004.

[13] P. N. Luke, M. Amman, J. S. Lee, "Factors Affecting Energy Resolution of Coplanar-Grid CdZnTe Detectors", *IEEE Trans. Nucl. Sci.* **51** (3), pp. 1199-1203 , 2004.

[14] A. E. Bolotnikov, G. S. Camarda, G. A. Carini, G. W. Wright, D. S. McGregor, W. McNeil, R. B. James, "New results from performance studies of Frisch-grid CdZnTe detectors" *(Invited Paper)*, *SPIE* **5540**-04, Denver, 2004.

[15] F. Zhang, Z. He, D. Xu, G. F. Knoll, D. K. Wehe, J. Berry, "Latest results for the 3D position sensitive CdZnTe gamma-ray spectrometers**"**, *SPIE* **5540**-16, Denver, 2004.