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New results from testing of coplanar-grid CdZnTe detectors

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ABSTRACT

New results from studies of coplanar-grid CdZnTe (CZT) detectors are presented. The coplanar-grid detectors were investigated by using a highly collimated X-ray beam available at Brookhaven's National Synchrotron Light Source and by applying a pulse-shape analysis. The coplanar-grid detector operates as a single-carrier device. Despite the fact that its operational principle is well known and has been investigated by many groups in the past, we found some new details that may explain the performance limits of these types of devices. The experimental results have been confirmed by extensive computer modeling.

Keywords: CdZnTe, gamma-ray detectors, coplanar-grid devices, micron-scale characterization, synchrotron radiation, pulse-shape analysis

1. INTRODUCTION

CdZnTe (CZT) detectors with a coplanar-grid electrode configuration have demonstrated good energy resolution (~2%) and large effective volumes (1-2 cm^3), and they have been used for a variety of applications in gamma-ray detection [1,2]. These detectors have been investigated and optimized since many years to achieve better spectral resolution and greater active volumes. Despite a great number of works devoted to understanding the factors limiting the device performance, the potential of co-planar grid detectors (CPG) has not been fully realized, and the energy resolution has not improved significantly over the past years. Several factors limit the performance of coplanar-grid devices: contacts geometry, electron trapping, material non-uniformity, surface and edge effects, charge sharing, electronic noise, etc. [3,4,5,6,7]. This work addresses the intrinsic effects related to the coplanar-grid contact configuration and shows how electron trapping and electric field variations can magnify these effects. Devices were investigated by using standard gamma sources (^{137}Cs) and synchrotron radiation (at Brookhaven's National Synchrotron Light Source, NSLS). Waveform analysis techniques were applied to study the device responses [8].

The amplitude of the output signal of a coplanar-grid device, for the idealized case, does not depend on the location of the interaction points, and as long as the interaction doesn't occur too close to the grids, it is proportional to the total collected charge. In real devices, the collected charge and the charges induced by holes and trapped electrons on the collecting and non-collecting grids depend on the position of the point of interaction. This dependence is responsible for the degradation of CPG detectors performance.

It is possible to distinguish between *local* [9,10,11,12] and *global* [13] variations of the device response. The asymmetry of the strips pattern and the physical size of the detector cause a slow variation in the potential distribution depending on the *global* position in the device. The periodic function of the grids' weighting potentials and the difference of the electron cloud path length are primarily responsible for the

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local dependence of the CPG device response. In fact, the trajectories followed by the electron clouds depend on the positions of the interaction point with respect to the nearest collecting strip.

In this work, the *global* and *local* dependencies of the grid signals are addressed, and their effects on the spectroscopic performance of CPG detectors are determined.

2. EXPERIMENT SETUP

Commercial 15x15x7.5 mm^3 CPG devices with a 350-μm strip size located at 700-μm pitch were purchased from eV Products. The detectors were mounted with two Delrin brackets on polyimide substrates. The device electrodes (grids and cathode) were connected to the substrate's pins by using thin gold wires glued with silver paint (grids) and conductive epoxy (cathode). The detector holder was plugged inside two different text boxes.

The first has a printed circuit board (PCB) with the electronics layout and a low-noise low-power application specific integrated circuit (ASIC) developed at Brookhaven's Instrumentation Division [14]. The ASIC implements three front-end channels for the collecting grid, non-collecting grid and cathode signals. Each signal feeds a charge-preamplifier. A differential amplifier with a tunable gain for electron trapping compensation subtracts the grid signals. The outputs from the preamplifiers and from the differential amplifier are available through four buffers. Two shaping amplifiers carry out the difference and cathode signals. These two signals go into two comparators for timing measurements. A multi-channel analyzer (MCA) card was used to complete the data acquisition system.

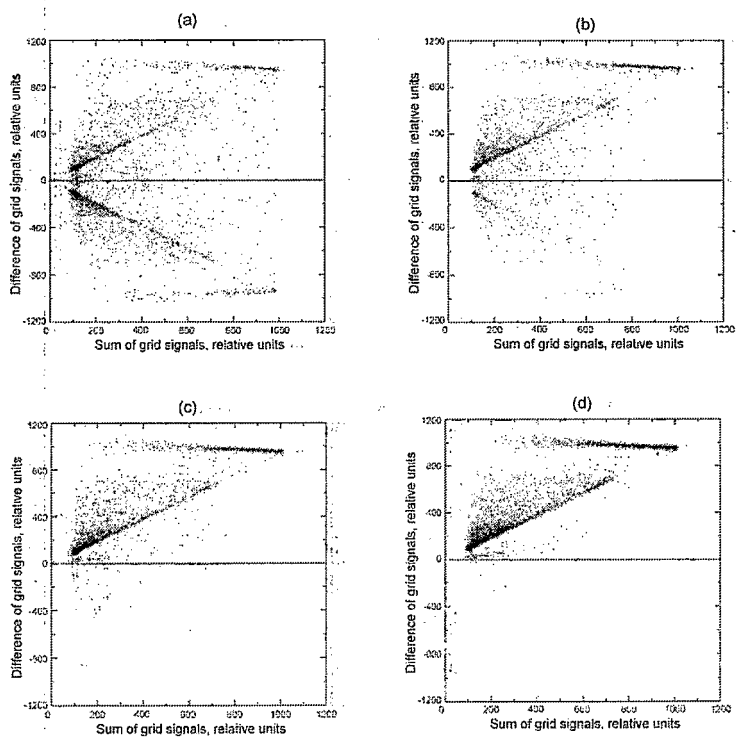

Fig.1. Correlations between the grids signals, *A1* vs. *A2*, measured at several differential bias voltages applied between the grids: (a) 0, (b) 15, (c) 30, and (d) 60 V.

When the second text box was used, the signals generated on the grids and the cathode were readout with standard eV Products preamplifiers and digitized with a LeCroy 6050 Waverunner for further analysis.

The detectors were first tested by using a ^{137}Cs (662 keV) source to determine the optimal operating values giving the best energy resolution. The typical bias voltage applied on the cathode was 1000 V, and the differential bias between the grids was varied between 0 and 80 V. Relative gain compensation method [15] was employed for this characterization.

To study the uniformity of the device response and the *local* dependencies of the grid signals, many runs at the X12A (NSLS) beam-line were performed [11,12]. A pseudo-monochromatic beam produced by attenuating the white beam with a lead window was used. The corresponding energies of the photons were between 75 and 85 keV. Depending on the type of measurements, either a 10 x 10 μm^2 or 25 x 25 μm^2 beam, shaped by using two different cross slits in tungsten, was used.

The CZT detector was mounted on an X-Y translation stage, perpendicular to the incident beam, and the device was irradiated from the cathode side.

Two different types of data were collected. First, for the 2-D and 1-D maps of the detector, a pulse-height spectrum was collected for each position of the beam during less than a 2-s time interval. Due to the high brightness of the source, it was possible to accumulate spectra with good statistics. The position and full-width-at-half-maximum (FWHM) of the primary photopeak were also evaluated. A standard ^{241}Am source was used to calibrate the spectroscopy electronics. A SPEC [16] macro (a UNIX based software package developed for x-ray diffraction) controlled the X-Y stages and the data acquisition.

Second, hundreds of waveforms were collected through the scope for each position of the beam all across the strips (1D-map like), and the waveforms were processed using an algorithm that is described elsewhere [8].

3. RESULTS AND DISCUSSION

Different correlation plots were evaluated to characterize the performance of the CPG device. In these plots every interaction event is represented by a point with the coordinates equal to the amplitudes of the signals measured from the grids, A_1 and A_2, or their linear combinations. For these measurements a ^{137}Cs source was used to irradiate the detector a few centimeters above the cathode and hundreds of waveforms were collected through the scope and processed. Fig.1 shows the correlations between the difference and the sum of the grids signals measured at four different bias voltages applied between the grids. It is possible to recognize in the figure the effects resulting from the electron trapping and from *global* and *local* variations of the device response.

The charge loss in CZT bulk due to electron trapping appears from the bending of the area around the line $|A_1-A_2|=Q_0$, corresponding to the total energy absorption events (photopeak area). The dots distribution in the figure follows the line $|A_1-aA_2|=Q_0$, where a is a numerical coefficient, independent of the photon energy.

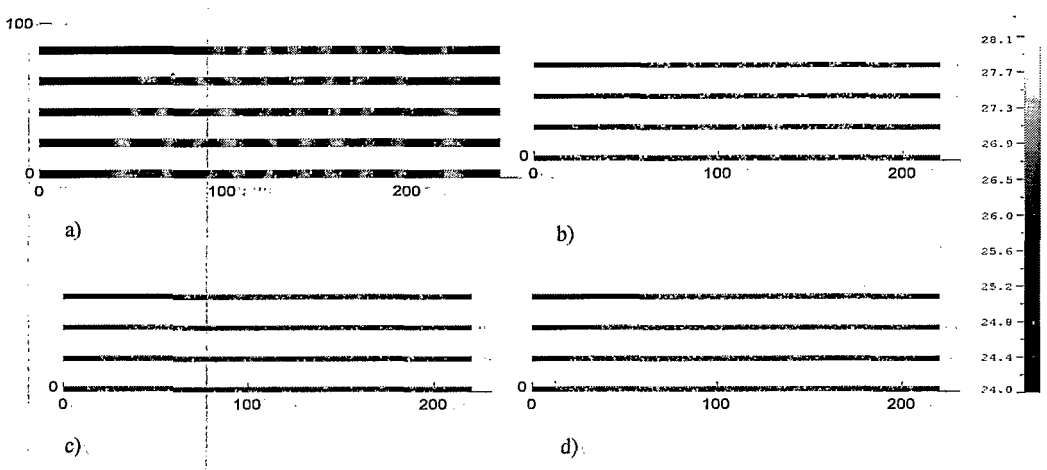

Fig.2: 2D-maps resulting from several scans across the grids at different position along the strips. a) 1000V-0V, b) 800V-24V, c) 1000V-30V, and d) 1200V-36V. The scans were performed with 100-um spatial resolution and with a 25 μm x 25 μm beam-size.

The dots distribution broadening, at the beginning of this area, indicates the *global* asymmetry between the grids weighting potentials, which are located near the device's edges. This corresponds to the long tails usually seen on the right and left sides of the peaks in the pulse-height spectra measured for CPG devices.

Finally, the width of the dots distribution, above the threshold where it starts broadening, can be explained by the anti-correlated electronic noise and by the *local* variations in the grids' signals. This is caused by the *local* dependences of the collected charge and the grids weighting potentials.

To study the uniformity of the device response and the *local* dependences of the grid signals, several experiments were performed at the X12A (NSLS) beam-line. Fig. 2 shows the uniformity of the device response (difference A_{col}-a_1A_{non}) measured over a large area of the CPG detector with a 100-um spatial resolution and with a 25 μm x 25 μm beam-size. We probed the detector in the direction across the strips at many positions all along the strips. First, we applied 0V between the grids. The resulting map exhibits a lot of non-uniformity all along the probed region. Then, we repeated the same scans at different biases. The non-uniform response of the detector is persistent even at high values of the differential bias voltage, and the pseudo-periodic trend of the pulse amplitude all across the strips is on the order of at least 1.5%, as clearly shown in Fig. 3. It seems, also, that maxima and minima positions do not always precisely coincide with the actual strip locations.

Two effects can be responsible for the observed variations. The first is related to the different length of the trajectories traveled by the electron clouds from the points of interactions to the collecting grid. The smaller amount of charge is lost when the interaction point is located above the collecting strip (the straight path), and the larger charge loss occurs when the path originates above the non-collecting strip (the curved path). Second, the *local* dependences of the grids weighting potentials are anti-correlated (i.e., the stronger signal is induced on the grid whose strip is closer to the interaction point). As a result, the *local* variations of the signals induced by the uncollected charges (both the holes and trapped electrons) add up when the grids' signals are subtracted.

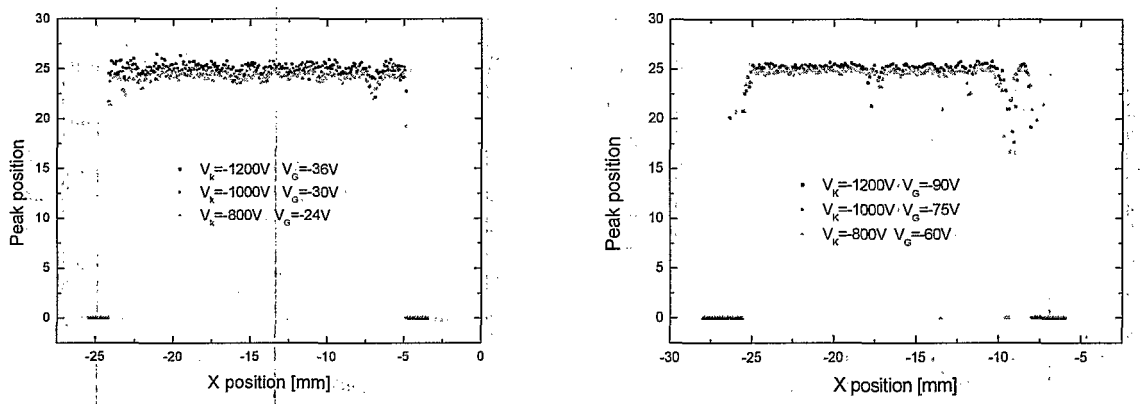

Fig.3. 1D-scans of two devices . The scans were performed across the grids at the same location for different applied differential biases. The scans were performed with 100-um spatial resolution and with a 25 μm x 25 μm beam-size.

More accurate data about the *local* variations of the device response result from the 1-D scans across the strips using a fine spatial resolution, <10-μm. The dependences of $(A_{col}-A_{non})/(A_{col}+A_{non})$ versus the beam position measured at several differential bias values between the grids are shown in Fig.4. The device response becomes almost flat at the differential grid bias of 40 V, which is about 2.5 times smaller than the value calculated for the same device geometry under the assumption of no space charge inside the crystal. This behavior is explainable assuming that the electric field inside the detector is not uniform in both the vertical and horizontal directions.The average electric-field strength decreases toward the anode (as if space charge existed inside the detector), resulting in a smaller differential grid bias required to steer all the electrons toward the collecting strips. At the same time, the lateral field variations cause random changes in the apparent strip locations in the x-ray map.

These *local* variations have not previously been considered as important. In fact, magnified by the non-uniformity of the electric field and charge loss [17] on the surface in the gaps between the contacts, they put an intrinsic limit of ~1-2% at 662 keV on the total energy resolution of current CPG detectors.

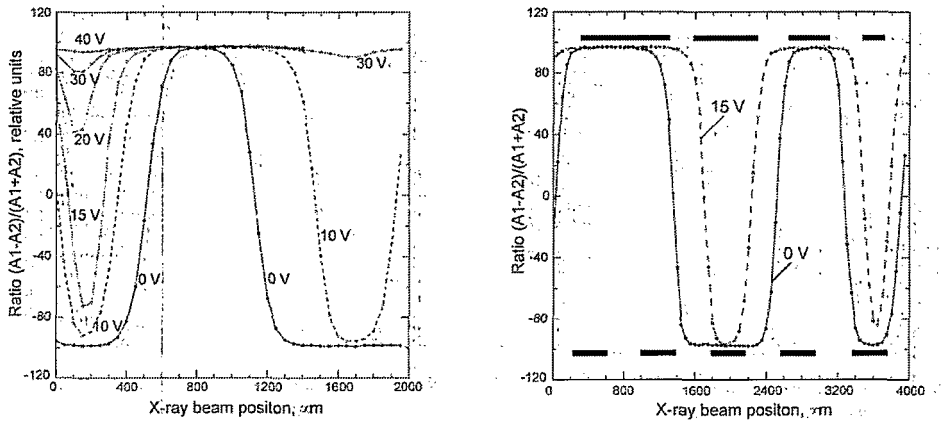

Fig.4 Dependences of $(A_{col}-A_{non})/(A_{col}+A_{non})$ vs. the beam position measured at several differential biases values between the grids.

4. CONCLUSIONS

In this work, we investigated different factors limiting the performance of the co-planar grid (CPG) detectors. Two approaches were used to characterize the devices responses: (1) Correlation plots, in which every interaction event is represented by a point with the coordinates equal to the amplitudes of the signals measured from the grids, A_1 and A_2, or their linear combinations were measured; and (2) Microscale scans were performed to finely investigate the *local* variations of the device response between the strips. These pseudo-periodic variations are caused by the *local* dependence of the grids' weighting potentials and the *local* dependences of the collected charge. They have not previously been considered as important. In fact, these variations, magnified by the non-uniformity of the electric field and charge loss on the surface in the gaps between the contacts, put an intrinsic limit of ~1-2% at 662 keV on the total energy resolution of current CPG detectors. The use of grids with a larger number of thin strips could reduce the local variations, but it may increase the grid capacitance and electronic noise beyond an acceptable limit.

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