A Study of Charge Sharing in Pixellated Cadmium-Zinc-Telluride Detectors

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Abstract: In this paper we present the status and preliminary results from a CZT development program of fine pixel detectors. These are to be used at the focus of high-energy grazing-incidence optics (20-75 keV) of the HERO-Experiment under construction at the Marshal Space Flight Center.

1.INTRODUCTION

Our understanding of the universe and various types of objects has been revolutionized by recent extra-ordinary experiments such as the Chandra Observatory. These accomplishments were made by a combination of due very high angular resolution (0.5 arc-sec) and very high sensitivity $4x10^{-15}$ ergs/cm^2/s in 0.4 to 6 keV range with an exposure time of 10^4sec, but are limited in energy to below 10 keV. Although many X-ray experiments have been launched on board various satellites to study celestial objects above 20 keV, the low sensitivity of these experiments has not been able to provide matching data above 20 keV for any of the celestial objects and thus this energy region is not fully explored. There are many issues in X-ray astronomy requiring high sensitivity and high spatial resolution at energies above 20 keV. These include the complex phenomena such as, for example, fine structure of galactic center above 20 keV, the study of cyclotron lines and the study of spectral changes at higher energies such as high-energy tails.

The X-ray-astronomy group at NASA's Marshall Space Flight Center (MSFC) is developing a high-energy grazing-incidence telescope which will have a resolution of 15 arc-sec and an effective area of 200 cm^2, giving a altitudes sensitivity of few millicrab for an observation of one day at balloon [1]. To compare this sensitivity with the other experiments one can note that that the high energy experiment, HEXE, on board the Compton Observatory had a sensitivity of 50 millicrab for one day of continuous observation but with a spatial resolution of a fraction of degree. The MSFC experiment, called HERO for High Energy Replicated Optics, is initially scheduled to be launched on a balloon-borne platform towards the end of 2003.

A proving balloon flight was conducted successfully in May 2001, during which the Crab Nebula was observed at a signal to noise ratio of 7-sigma with an effective area 4 cm^2

Launch of the fully developed HERO experiment, together with other hard-x-ray telescopes under development, will initiate a
revolution in high energy X-ray astronomy similar to those of the Einstein and Chandra Observatory at low energy energies.

2. TESTING AND QUALIFICATION OF DETECTORS

HERO requires a detector that matches the angular resolution of the optics, has lowest possible noise and has high photon absorption efficiency. This is achievable with a 64x64x2mm pixellated CZT detector with a pixel size of 250 microns.
We have built a test facility to study (see figure 1 and figure 2) the performance of these detectors as they are developed. The test facility is equipped with computer controlled data acquisition and motion control, and a fine X-ray beam system with beam sizes of 25 and 50 micron

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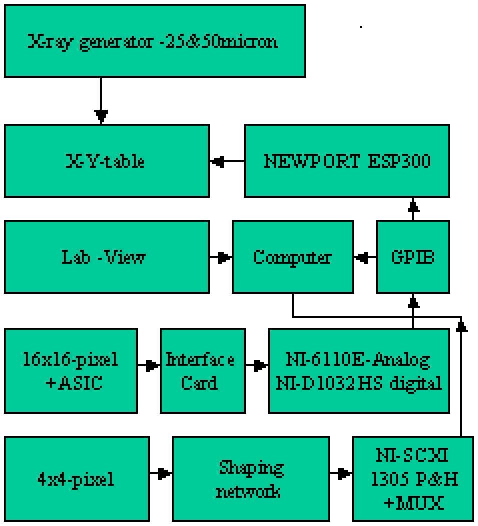

Figure 1. Main elements of the test facility

The data acquisition and control of an X-Y table for scanning the detector with a fine X-ray beam is facilitated by Lab-View software. The primary aims of the initial evaluation are:

1. Detailed study of charge sharing between pixels and its effect on the energy & spatial resolution.
2. Energy resolution, its variation with energy, and its relation with the point of interaction on the detector.

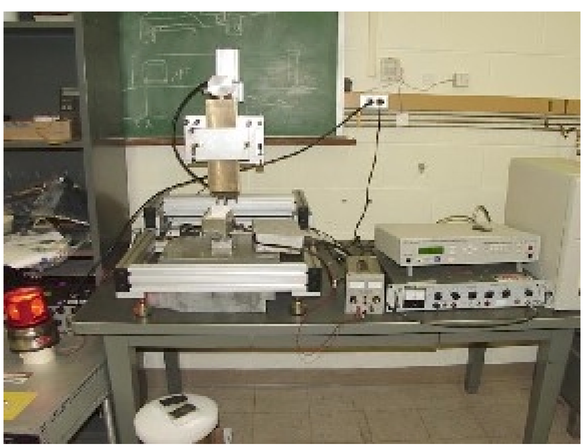

Figure 2. A photograph of test the set-up.

3. Charge loss due to sharing and its effect on energy resolution, spatial resolution and the overall performance of detectors.
4. Generation of a response matrix to indicate possible performance of flight detectors.
5. Performance of the detectors at the focus of the telescope.

At present, the detectors required by HERO are not available off the shelf; various aspects are still under development and evaluation. To help us in the selection process of the best possible detector schemes, we have initiated test and evaluation of three types of detectors as described below:

Detector-1

- Is 1-mm thick and has a 4x4 pixel array.
- Pixel size is 650 micron.
- Inter-pixel distance (or gap) is 100 micron.
- Detector signal is processed by discrete charge sensitive preamplifiers.
- Detector supplied by Metorex, Finland.

Detectors-2

- These sets of detectors have 16x16 pixel arrays and are 1-mm and 2-mm thick .
- Pixel size is 250 microns.
- Inter-pixel distance is 50 microns.
- Detector signal is processed initially by a *Pixel Array Chip* (PAC5) and then by two Shaper-And Multiplexer- Read-Out-Chips (SHAMROC) developed by *Rutherford Appleton* Laboratory (RAL), Oxford, UK. For details see reference [2].
- Metorex, Finland has supplied these detectors.

Detector-3

Figure 3 shows the photograph of the main detector and ASIC mounted on the ceramic carrier

- Is 2-mm thick with a 16x16 pixel array.
- Pixel size is 250 microns.
- Inter-pixel distance is 50 microns.
- Detector signal is processed by the ASIC chip, AXGAM, developed by University of California, Riverside.
- The ASIC is equipped not only with charge sensitive preamplifiers but also with shaping and peak detection.
- This detector has been provided by the University of California, Riverside [3].

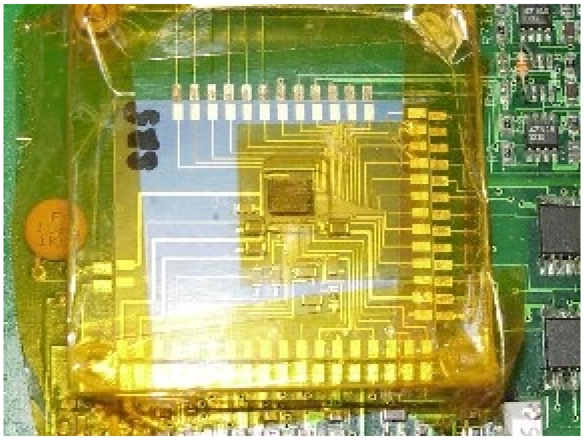

Figure 3: Photograph of 16x16 detector mounted on ASIC and its ceramic chip carrier (AXGAM).

3. PRELIMINARY RESULTS

We are in the process of conducting detailed studies of the detectors acquired by us. Figure 4 and table-1 shows the energy resolution measured for these detectors for unshared events. Detailed tests of detector-3 are not yet complete.

Table-1: Measured resolutions

Energy	4x4-D1	16x16 -D2	16x16-D3
17.5 keV	5.6%		
22 keV	4.3%	7.4%-9-pixels	
32 keV	2.4%		Tests
44 keV	2.5%		Not
60 keV	1.8%	3%-9 pixels	Complete

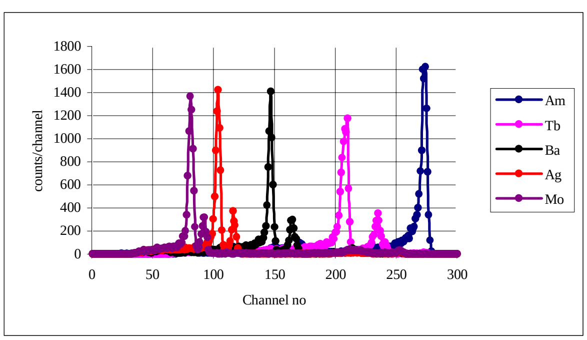

Figure 4: Pulse height spectrum of 4x4 pixel detector-D1 when irradiated at various energies from 17.5 to 60 keV. Smaller peaks are K-beta lines.

The pulse height spectrum for 60 keV events that are not shared with those in neighboring pixels are shown in figure-5, giving an energy resolution of 3% when output from 9 pixels is combined. The data depicted is from the 16x16 detector that is equipped with PAC5 ASIC

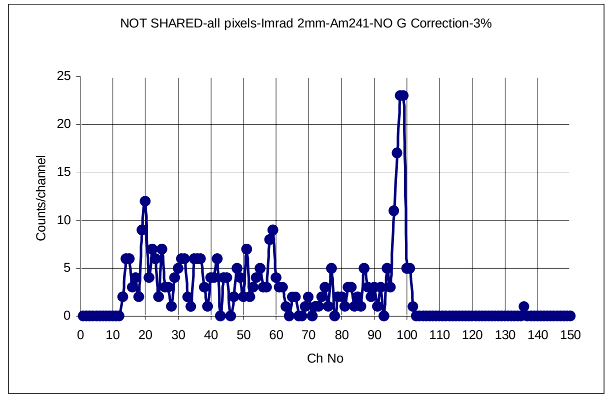

Figure 5: The pulse height spectrum for Am-241 source (60 keV) from 16x16 pixel, detector-D-2. It gives a 3% resolution when output from 9 pixels is combined.

Preliminary tests show, as expected, that maximum charge loss occurs when the events interact in the middle of the inter-pixel gap and the events are shared between two or four neighboring pixels. In the case of detector-1, which has a pixel gap of 100 microns, the loss (see figure 6) when events are shared only between two pixels is found to be about 16%. In case of the 16x16 pixel detector our initial tests indicate that loss is minimal. This indicates, as expected that detectors with smaller pixel-to-pixel gap will show less loss in recovered signal.

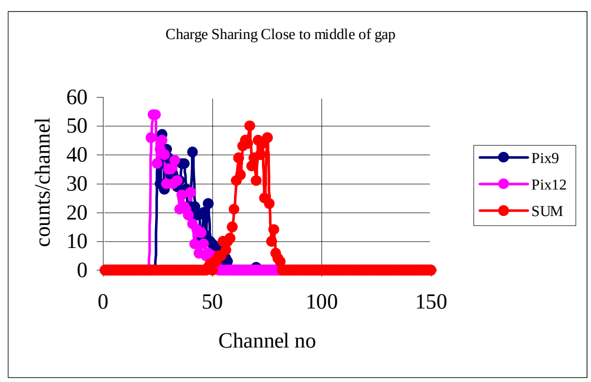

Figure 6: Pulse height spectrum of shared and recovered signal when the events interact in the middle of the gap of 4x4 detector. Two curves at the left are shared signals from individual pixels and the graph on the right hand side is summed output from the shared events, showing a loss of 16%.

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There is also a loss in the resolution when charge is shared, which essentially depends on the noise of the combined pixels. The noise threshold (in our case noise is estimated to be 1 keV and 2 keV for detector-1 and detector-2 respectively) also decides the extent of the signal recoverable. If the threshold is low, then much smaller amounts of shared charge can be recovered resulting in lesser loss.

As the pixel size and gap are reduced, we will expect many more shared events. Initial measurements with the 700-micron-pitch detectors show that near the middle of the gap the percentage of the events shared is more than 85%.

As mentioned earlier, the shared events data from 16x16 pixel (detector 2), which has a gap size of only 50 microns, shows loss to be much smaller (see figure 7) thus confirming that the loss in the recovered signal is dependent on the gap size.

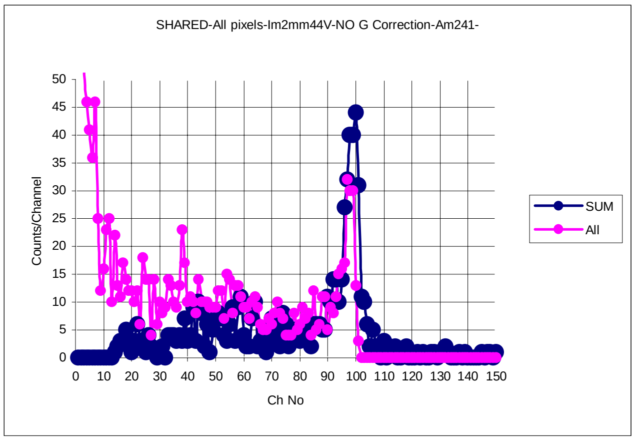

Figure 7: The pulse height spectrum of Shared and recovered signal. Detector used is 16x16 pixel detector–2. It is noticed that the 60 keV peak from recovered signal (dark) has almost same position as obtained from the individual events (light) indicating a smaller loss when the gap is smaller.

4. CONCLUSIONS

In this paper we have described a test set up for fine pixel detectors and have presented preliminary results. This is a collaborating program amongst many institutions with an aim to develop pixellated CZT detectors for astronomical use. Probing of these detectors should lead to a successful development of good quality detectors for our balloon flight.

5. REFERENCES

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