Evaluation of a CdZnTe pixel array for X- and γ-ray spectroscopic imaging

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Abstract

X-ray imaging is an essential tool for a wide range of disciplines. Whilst the majority of applications rely on analog integrating or on photon counting formats, the future development of this field lies in the exploitation of spatially resolved spectroscopy and in particular, using materials which can operate with near Fano limited energy resolution at room temperature. This communication focuses on a new prototype 16 × 16 cadmium zinc telluride (CdZnTe) pixel array fabricated by eV Products [1], which, assembled with an ASIC made by Ideas ASA [2], provides both imaging and spectroscopic capabilities at the individual pixel level. We report detailed results of hard X-ray measurements carried out at the X1 beam line of the HASYLAB synchrotron radiation facility in Hamburg, Germany [3].

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1. Introduction

Spatially resolved spectroscopy can be considered a natural evolution of conventional digital imaging techniques in which, not only the photons hitting a detector pixel are recorded, but also the energy deposited in that pixel. In essence, this is an evolution equivalent to that of colour photography over black and white photography. Spatially resolved spectroscopic imaging has been an essential tool in X-ray astronomy for some time and has more recently gained the interest of medical radiologists. For these applications, the overall performance of the system is critically dependent on the quality and stoichiometry of the sensor material.

The Science Payload and Advanced Concepts Office of ESA is involved in a number of programs to develop X- and γ-ray spectroscopic devices for future space missions based on compound semiconductors. The ultimate research goal has been to

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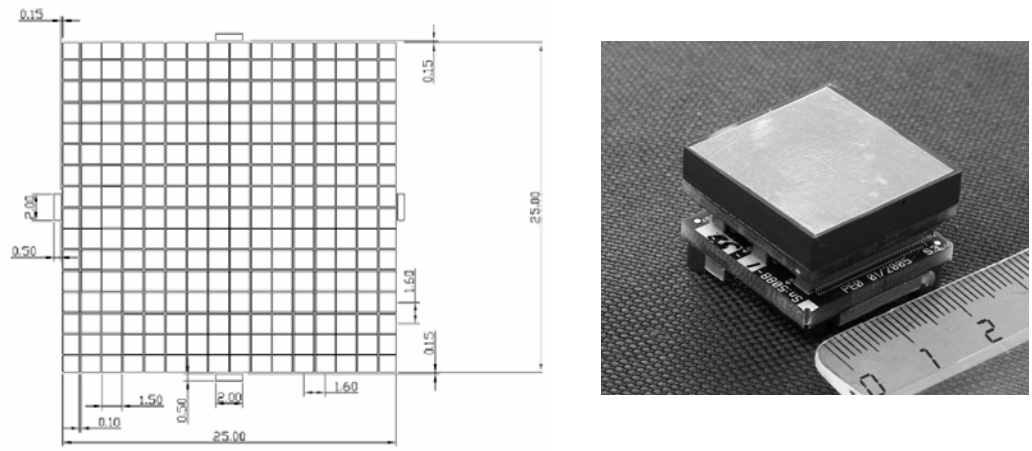
develop sensitive and viable alternatives to Si and Ge, which operate at, or near, room temperature and with superior stopping power. Towards this end we have, in the past, successfully developed near Fano limited compound semiconductor arrays based on GaAs [4]. Here, we report the first results for a new prototype CdZnTe pixel array with stochiometric composition of $Cd_{0.9}Zn_{0.1}Te$, which results in a band-gap energy of 1.572 eV, an electron-hole pair creation energy of 4.64 eV and a Fano-limited energy resolution of ~130 eV at 5.9 keV and 420 eV at 59.54 keV [5,6].

2. Imaging assembly description

The imager is fabricated on a single crystal of CdZnTe (CZT) of size of 25.3 × 25.3 × 5 mm^3 grown by eV Products, Pennsylvania, USA [1]. A 16 × 16 pixel array was pattered on one side of the crystal using standard photolithographic techniques by eV Products as well. The array has a unit pixel size of 1.5 × 1.5 mm^2 and a pitch of 1.6 mm. A schematic view is shown in Fig. 1a, and a picture of the detector is shown in Fig. 1b. The details on the metal composition of the contacts are a trade secret and unknown to us.



(a) (b)

Fig. 1. Left: The schematic view of the detector pixel layout. The overall dimensions are 25.3 × 25.3 × 5 mm^3, the pixel size is 1.5 × 1.5 mm^2 and the gap between pixels is 0.1 mm. Right: picture of a CZT detector mounted on a socket which then forms the interface to the ASICs.

The detector was bonded using conductive glue to a substrate and then connected to the front-end electronics, which consist of two IDEAS Xa1.6 ASIC produced by Ideas ASA, Fornebu, Norway [2]. Each ASIC has 128 channels and each channel has preamplifier, shaper and peak hold circuitry. The read-out is configured to collect electrons. An external 10 MHz 12-bit ADC digitalizes the output of the ASICs. Each channel has also leakage current compensation with 50 nA maximum value and the ASIC can disable noisy pixels. The assembly is irradiated on the cathode side.

The equivalent noise charge of the front-end electronics is typically ~380 e^- rms for a 0.5 μs peaking time, which corresponds to an expected limiting energy resolution of ~4.1 keV FWHM. The detector operates at room temperature and with a bias of 600 V. The rest of the detection system consists of the XA-Controller, the detector bias, digital and analog power supplies. The system is PC controlled using a National Instruments card and dedicated software.

When an event in a pixel exceeds a preset threshold, its peak value and address are sent to the XA-controller for record processing. This allows both imaging and spectroscopic capabilities at the individual pixel level. Preliminary tests have shown that the system is stable in terms of gain and energy resolution over time periods of several hours at counts rates up to ~100 kHz. Its response to higher count rates is yet to be tested. No improvement in energy resolution was observed by cooling the detector and front-end electronics to 12°C. However, the gain shows some sensitivity to temperature, increasing by 1.5% from room temperature to 12°C. The same effect has been reported and successfully fixed by other authors for similar device and application contexts [7].

3. Experiments and results

Preliminary tests were carried out as full-area illumination measurements using an uncollimated ^{241}Am radioactive source. In Fig. 2 are shown spectra collected for both single pixel and the whole 256 pixels array, the latter including 3 noisy pixels usually turn off during imaging recording. The spectra refer to the same record obtained with the ^{241}Am source placed at 2.5 cm from the detector and with the trigger threshold set at 8 mV. After calibration and gaussian-fit we evaluated a resolution of 5.9 keV, FWHM, for the summed spectra and 5.6 keV for the single pixel. The difference in noise floor is because only one common trigger threshold can be set for the whole array, leaving a 7% fraction of pixels untuned for DC offset.

Hard X-ray measurements were carried out on the beam line X1 at the HASYLAB synchrotron research facility in Hamburg, Germany. This beamline utilizes a double Si crystal monochromator to produce tunable, highly monochromatic X-ray beams across the energy range 10 keV to 100 keV [3]. A [511] reflection was used, yielding an intrinsic energy resolution of ~10 eV at 60 keV. The beam spot size used in the measurements was $20 \times 20\ \mu m^2$. The detector was mounted on an X-Y table capable of positioning the array to a precision of <1 μm in each axis.

Because of time constraints, we only investigated a selected area of 3 × 3 pixels near the centre of the detector matrix. Preliminary tests have shown the data are representative of the entire array. Measurements were carried out at discrete energies of 20, 25, 30 keV and then in steps of 10 keV up to 100 keV. At each energy, spectra have been recorded for all the 9 selected pixels by raster scanning the beam across the pixels. The results for the central pixel and for the whole selected area, *i.e.* the summed signals from 9 pixels, are shown, respectively, in the left and right hand of Fig. 3. The noise floor, or triggering threshold, occurs at ~ 5 keV.

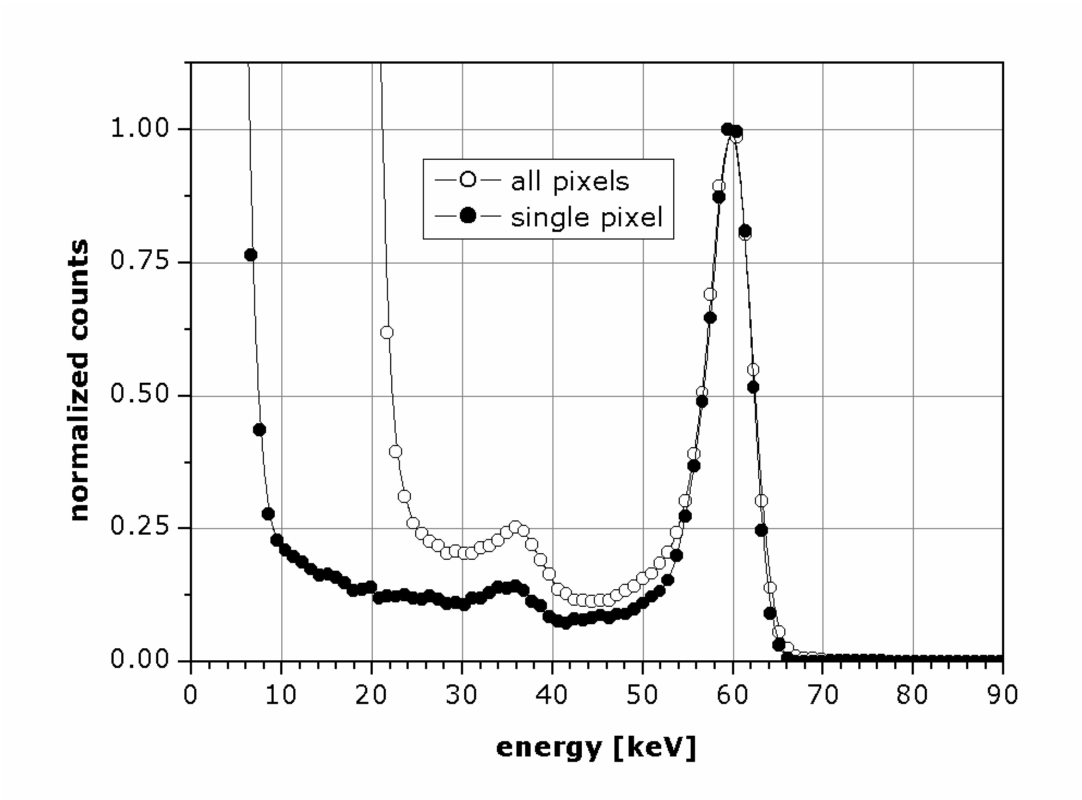


Fig. 2. Spectra of an uncollimated ^{241}Am source placed at 2.5 cm normal to the detector. The spectra refer to single pixel and to all pixels events. There is an evident difference on the noise floor in the two spectra. As the trigger threshold is common for the whole array, it is impossible to have a tuned setting for each channel. However, above this noise floor, the resolutions of the two spectra are comparable. For single pixel we measured 5.6 keV FWHM and a value of 5.9 keV for the sum of all 256 pixels.

From Fig. 3, we see that the ratios FW0.1M[*]/FWHM and FWFM[°]/FWHM increase from low to higher energies. For example, at 20 keV for the summed signal, we found 1.872 and 2.383, respectively, while at 100 keV the FW0.1M/FWHM becomes 1.887 and the FWFM/FWHM 3.113. This variation is ascribed to the poor hole mobility in CZT, typically 10 times lower than electrons at least [5,8]. For absorbed photons of higher energies, the greater carrier concentration generated and the poor hole mobility combine to create significant trapping and recombination with subsequent loss of signal.

The system response is found linear as seen in Fig. 4. The channel to energy calibration gives regression-coefficients ranging from 0.9992 to 0.9995 for the 9 pixels.

[*] FW0.1M: Full Width at 1/10 of the Maximum.
[°] FWFM: Full Width at 1/50 of the Maximum.

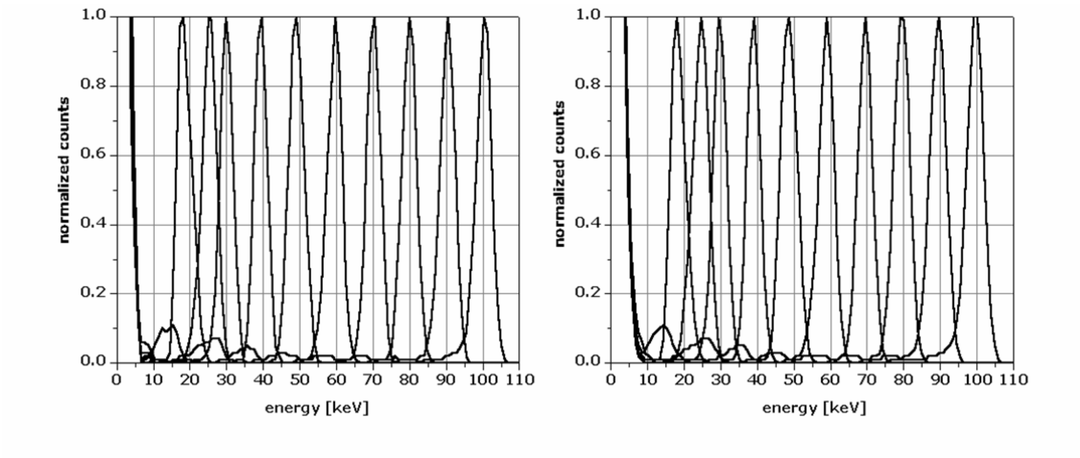


Fig. 3. Spectra collected irradiating the selected 3 x 3 pixel matrix with monochromatic (~10 eV at 60 keV) synchrotron radiation at the nominal settings of 20, 25, 30 keV and up to 100 keV in steps of 10 keV. On the left hand is the plot corresponding to the central pixel. On the right hand are the summed spectra for the 9 pixels. There are no appreciable differences on the responses of the 9 pixels. The noise floor is found at about 5 keV.

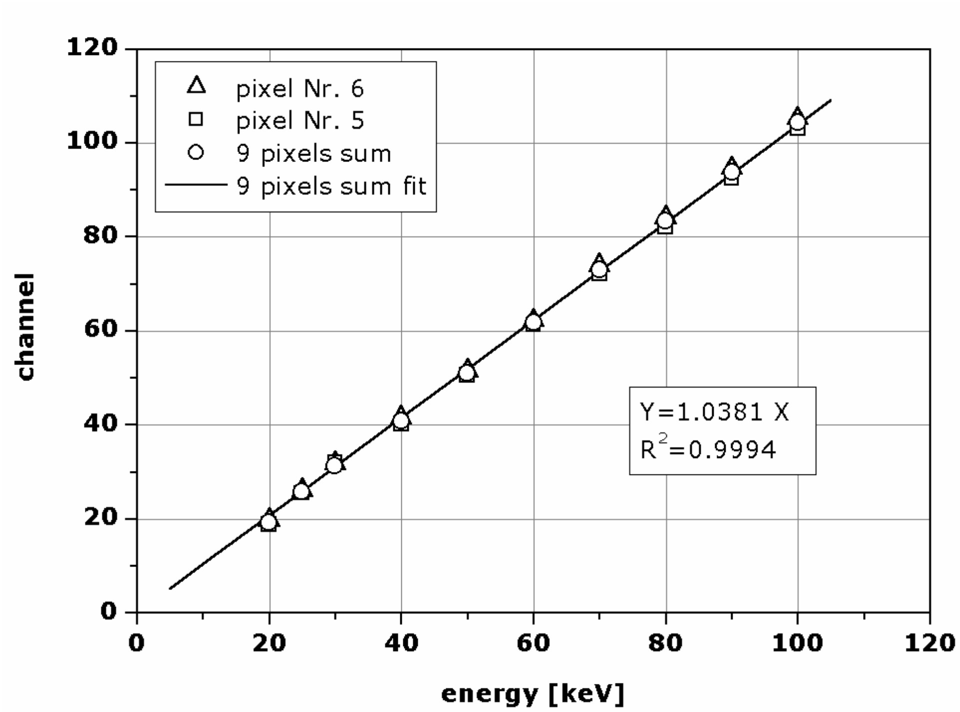


Fig. 4. On the chart are plotted three channel-to-energy calibrations. The one with the lower linear coefficient, y=1.0256x corresponding to the pixel Nr 5; the one with the higher y=1.0484x, pixel Nr 6, and the calibration for the 9 pixels summed signal. The linear coefficients show differences of about 2%.

The FWHM energy resolution is plotted in Fig. 5 in terms of both the percentage and actual energy resolution as a function of energy. The resolution is found to be nearly independent of all over the inspected energy range, suggesting that the performance of the system is dominated by electronic noise.

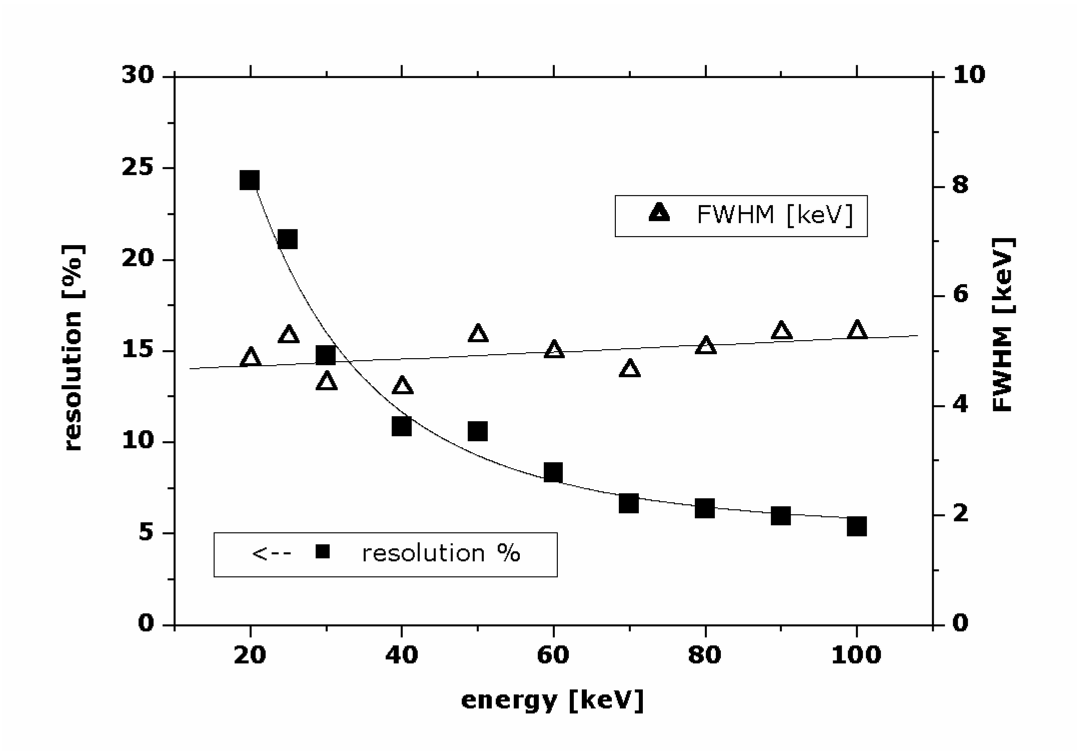
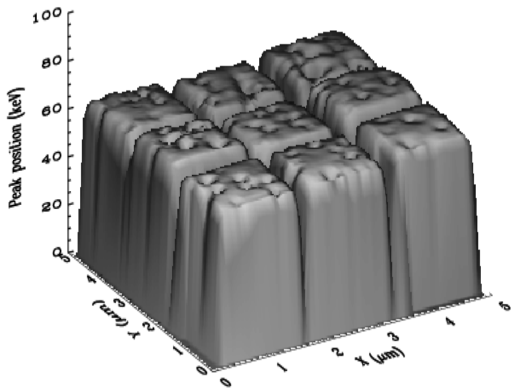
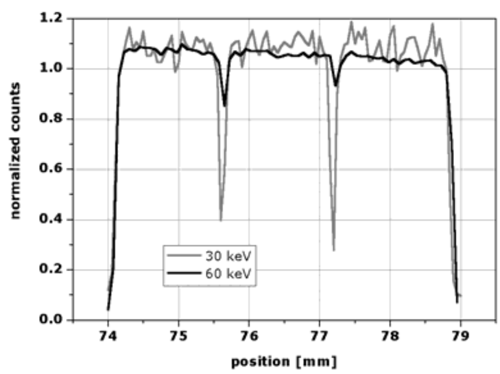


Fig. 5. With respect to the left scale, in the chart is plotted the percentage resolution together with the energy resolution [keV], which is refers to the right scale. Considering the electronic noise of the system, possible resolution is ~4.1 keV, although the best value we measured is with 4.3 keV at 40 keV slightly higher.

During the campaign we performed an experiment on the cross talk, or charge sharing, effect: *i.e.* charges due to photons absorbed in one pixel volume are collected by the neighbour pixels [9]. The spectroscopic response of the whole 3 × 3 area was scanned in steps of about 65 × 65 μm^2 and at two energies, 30 and 60 keV. The 60 keV scan is shown in Fig. 6a, where the Z-axis refers to the peak position. Counts versus position, for the central cross section and for both 30 and 60 keV of beam energy, are compared in Fig. 6b.





(a) (b)

Fig. 6. The scans result. (a) The signal in terms of peak channel is plotted as function of the X-Y position for a 60 keV irradiation. (b) Comparison of the signals for the 60 and 30 keV for the central section of the explored area. The 30 keV data are noisier because of the lower statistics: 400 average counts as opposed to 6000 for the 60 keV record.

From the last plot it is observed, that the decrease in count rate in the inter-pixel region is smaller for 60 keV than it is for 30 keV beam energy. A further investigation of the spectra we used for the peak position plots (Fig. 6a) should point out whether the difference between 30 and 60 keV, not only depends on the greater amount of charges generated by the 60 keV, but also on its deeper penetration and larger electron cloud, which could allows to non-linearity on the energy dependence of the charge sharing.

4. Discussion

We have investigated the development of a CZT pixel array and tested its suitability for spectroscopic imaging applications. Although the energy resolution of the system is well above the Fano-limit, its uniform 5 keV resolution in the energy range from 20 to 100 keV can be considered to be sufficient for most imaging spectroscopy applications in astrophysics, where, presently, CdTe based systems with high spatial resolution but lower energy resolution are often proposed [see these proceedings]. Also, results obtained so far on CZT with coplanar grid detectors are equivalent to ours in the hard X-rays range [7,10].

The evaluation of the results obtained so far encourages the fabrication of a larger 32 × 32 pixels CZT array. In a first step we intend to achieve this larger active area by creating a mosaic of 2 × 2 detectors of the type presented in this work. At the same time we are implementing the system with extra read-out channels (signal and pixel addresses) that can be used with an external DAC-MCA. This will make it possible to test larger detector's areas spectroscopically in an automated fashion and with the possibility to extend the system dynamic range, presently limited at about 400 keV, without the need of a completely re-designed ASIC.

We intend to investigate the matching of the detector leakage current with a front-end electronic input. Moreover, the performance of the system when exposed to high count rates of the order of the MHz will be evaluated. The scan technique we used to explore charge sharing effect will be further applied. We intend to point out, through a quantitative evaluation of this effect, its possible relation with the carrier transport properties of our array.

References

[1] http://www.evproducts.com/

[2] http://www.ideas.no/products/ASICs/pdf/XA1.6.pdf

[3] http://www-hasylab.desy.de/facility/

[4] C. Erd et al., Hard X-ray test and evaluation of a prototype 32 × 32 pixel gallium-arsenide array, Nucl. Instrum Meth. **A 487** (2002) 78.

[5] http://www.evproducts.com/material_prop.pdf

[6] Alan Owens et al., The X-rays response of CdZnTe, Nucl. Instrum. Meth. **A 484** (2002) 242.
[7] F. Zhang and Z. He, 3D position sensitive CdZnTe gamma-ray spectrometer – improved performance with new ASICs, SPIE proc. **5540** (2004) 135.
[8] Z. Burshtein et al., Charge-carrier mobilities in Cd0.8Zn0.2Te single crystals used as nuclear radiation detectors, Appl. Phys. Lett. **63** (1993) 102.
[9] E. Kalemci and J.L. Matteson, Investigation of charge sharing among electrode strips for a CdZnTe detector, Nucl. Instrum. Meth. **A 478** (2002) 527.
[10] Z. He et al., 3-D position sensitive CdZnTe gamma-ray spectrometers, Nucl. Instrum. Meth. **A 422** (1999) 173.