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Depth of interaction and bias voltage depenence of the spectral response in a pixellated CdTe detector operating in time-over-threshold mode subjected to monochromatic X-rays

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ABSTRACT: High stopping power is one of the most important figures of merit for X-ray detectors. CdTe is a promising material but suffers from: material defects, non-ideal charge transport and long range X-ray fluorescence. Those factors reduce the image quality and deteriorate spectral information. In this project we used a monochromatic pencil beam collimated through a 20μm pinhole to measure the detector spectral response in dependance on the depth of interaction. The sensor was a 1mm thick CdTe detector with a pixel pitch of 110μm, bump bonded to a Timepix readout chip operating in Time-Over-Threshold mode. The measurements were carried out at the Extreme Conditions beamline I15 of the Diamond Light Source. The beam was entering the sensor at an angle of ~20 degrees to the surface and then passed through ~25 pixels before leaving through the bottom of the sensor. The photon energy was tuned to 77keV giving a variation in the beam intensity of about three orders of magnitude along the beam path. Spectra in Time-over-Threshold (ToT) mode were recorded showing each individual interaction. The bias voltage was varied between -30V and -300V to investigate how the electric field affected the spectral information. For this setup it is worth noticing the large impact of fluorescence. At -300V the photo peak and escape peak are of

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similar height. For high bias voltages the spectra remains clear throughout the whole depth but for lower voltages as -50V, only the bottom part of the sensor carries spectral information. This is an effect of the low hole mobility and the longer range the electrons have to travel in a low field.

KEYWORDS: X-ray detectors; Detector design and construction technologies and materials

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1 Introduction

1.1 Background

High Z-materials are needed to achieve high stopping power in X-ray detectors. CdTe is a promising material but suffers from: material defects, non-ideal charge transport and long range X-ray fluorescence [1–4]. Those factors reduce the image quality and deteriorate spectral information. In order to better understand the charge transport we have illuminated the sensor with a monochromatic pencil beam at a small angle. This enables us to extract spectral information from different depths in the sensor and examine how the charge transport affects the signal.

1.2 Measurement setup

The sensor was a 1mm thick CdTe detector from ACRORAD, with a pixel pitch of 110μm. It was bump bonded to a TIMEPIX [5] readout chip by FMF in Freiburg. The TIMEPIX chip has a pixel pitch of 55μm, so in order to match the larger pixel pitch of the sensor only one in four pixels was connected. Bias was applied with an ohmic contact and the chip was operated in electron capture mode. The read out was done using a FITPIX [6] USB read out system and PIXELMAN [7] software. The ToT reference clock was set at 48 MHz.

Our measurements were carried out at the Extreme Conditions Beamline I15 of the Diamond Light Source. Photon energy was tuned to 77 keV. The beam was entering the sensor at an angle of 20 degrees to the surface and then passed through 25 pixels before exiting. Spectra in Time-Over-Threshold mode were recorded showing each individual interaction along the beam path. Figure 1 shows the measurement setup and a schematic representation of fluorescence and charge diffusion. Details can be found in [3] and [8].

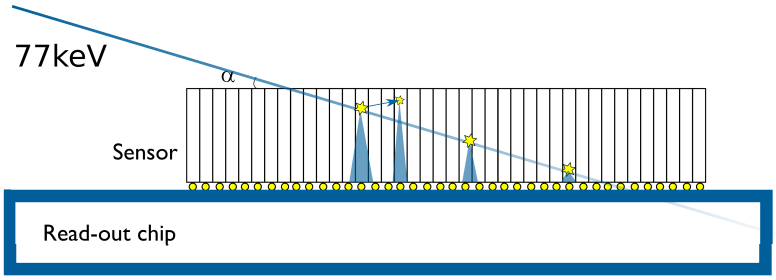

Figure 1. Measurement setup and schematical representation of fluorescence and charge sharing.

2 Measurements

2.1 Calibration

Timepix operated in Time-over-Threshold mode can measure the energy deposited in a pixel from a single photon interaction. However we need to perform an energy calibration to match Time-over-Threshold to energy. This is complicated by the fact that the ToT - Energy dependence is not linear for low energies.

We have used a similar method to that described by J. Jakubek et.al in papers [9] and [10]. The low threshold was first equalized with the Pixelman Threshold Equalization plugin using "Noise center". This sets the adjustment bits of each pixel to compensate for low threshold offset. Then we made measurements with fluorescence from Mn, Cu, Mo and Ag metal sheets as well as radioactive decay of ^{241}Am and fitted a surrogate function to the mean value of the peak positions. Measurements and the fitted function is presented in figure 2 Individual pixel thresholds were also shifted offline to compensate for any remaining threshold offset.

2.2 Beam profile verification

Before starting with the Time-over-Threshold measurements we did an initial characterization of the beam and the sensor in Photon Counting mode. Figure 3 shows the absorption through out the sensor. Even with the intensity varying with three orders of magnitude the response is still uniform through the sensor following the linear attenuation coefficient.

We did two measurements one at 20°and one at 25°from those we could estimate an initial offset of 1.3°. By extracting the linear attenuation coefficient we could also verify the photon energy.

2.3 Depth of interaction dependence

As mentioned the detector was operated in electron collection mode. The objective of this measurement was to investigate if the low hole mobility could cause a depth of interaction dependence in the response. ToT spectra were recorded in each pixel along the beam path. Bias voltage was kept at -300V. Clusters from a single interaction were summed and allocated to the pixel with highest signal. To identify clusters from a single interaction we used a short acquisition time in order to keep occupancy low, and threated connected pixels as occurring form one interaction. Events when the fluorescent photon travels more than one pixel or escapes the sensor altogether is not detected

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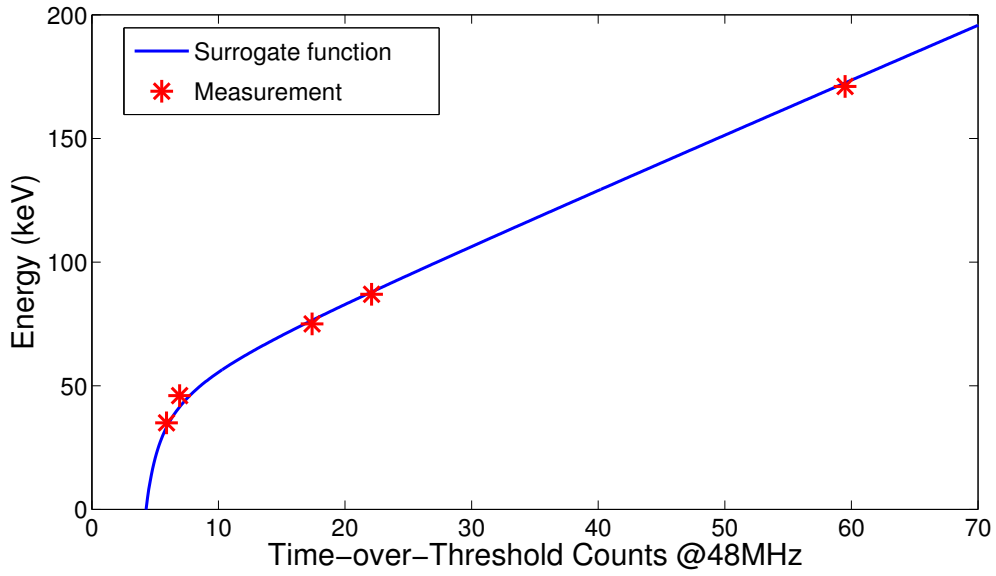

Figure 2. Fitted surrogate function and measurement data from fluorescence and radioactive decay.

correctly. This summing removes most of the effects of fluorescence and charge diffusion from the pulse height spectrum.

2.4 Bias voltage dependence of the spectral response

The detector was also operated at different bias voltages from -30V to -300V to investigate charge transport and lateral diffusion. Time-over-Threshold spectra were recorded for the different settings. During the transport towards the readout electrodes the generated charge cloud will be widened due to diffusion. This is essentially a function of the charge collection time. ([8, 11, 12]) By increasing the electric field the drift time and thus the effect of diffusion will be reduced. This will show up in the spectra before summing. In addition higher electric field could also lead to higher charge collection efficiency due to reduced trapping.

3 Results

3.1 Depth of interaction dependence of the spectral response

Figure 4 shows the spectra at three different depths in the sensor. Time-over-Threshold signals are summed over a depth region to produce better statistics. We see that with the different interaction depths the photo peak still remains at the same place. This is also consistent with the "Small Pixel Effect" [1] for a device with a ratio between the width (W) and length (L) of W/L=0.11.

The only depth effect observed is that the escape peak is higher relative to the photo peak for the top layer of the sensor. This is because fluorescent X-rays escaping from the sensor surface do not contribute to the ToT signal sum. Also there is no fluorescent peak showing in the figure since we are looking at pixels in the beam path. Only very few photons escapes more than one pixel in the beam direction. Those photons who travel more than one pixel in other directions leave the

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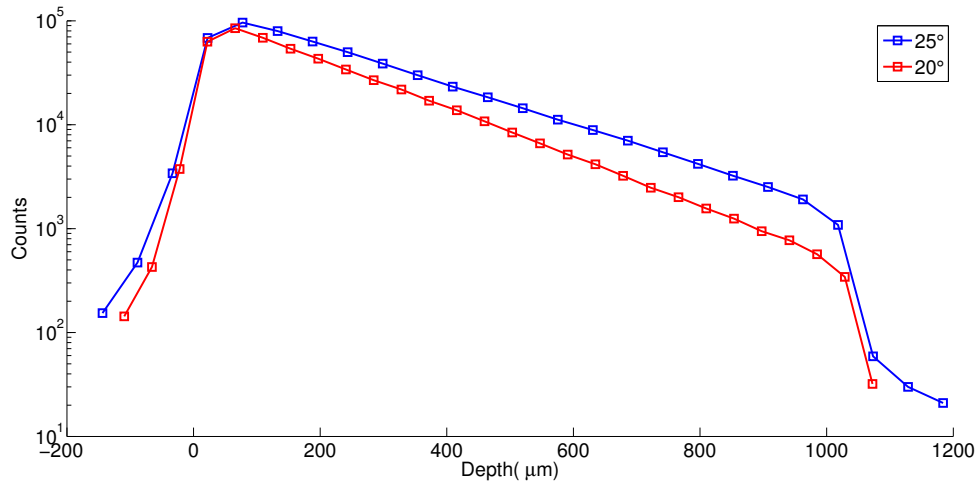

Figure 3. X-ray intensity measured by each pixel along the beam path, plotted as a function of interaction depth in the sensor.

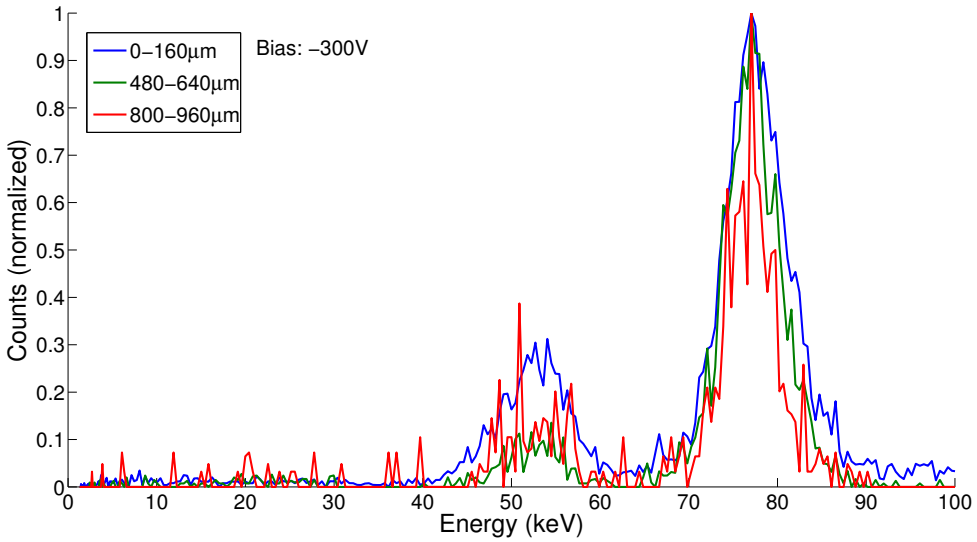

Figure 4. Pulse height spectra at different interaction depths obtained after ToT signal summing.

escape peak (~55keV). If we study all pixels in the sensor the fluorescent peak is clear. (Figure 6, -300V)

3.2 Bias voltage dependence

Charge diffusion in the sensor layer as well as X-ray fluorescence causes distorted spectra. The effect of charge diffusion is reduced by applying higher bias as shown by the red line in figure 6. However charge sharing effects are canceled by charge summing individual clusters of pixels from each X-ray interaction. The peak around 55keV is caused by escape of fluorescent photons. The

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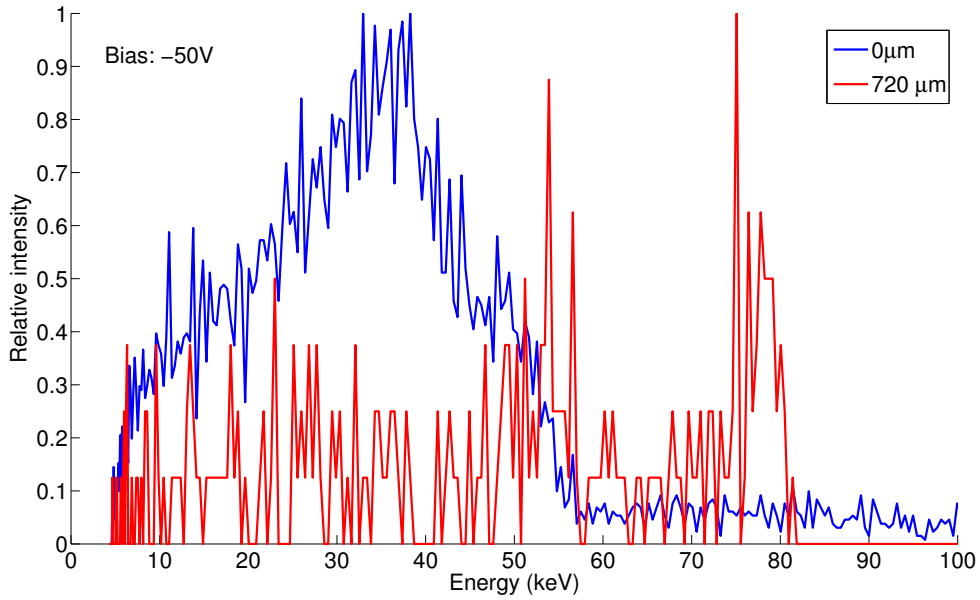

Figure 5. Single-pixel TOT spectra at two different interaction depths: near the sensor surface ($0\mu m$) and deep inside the sensor ($720\mu m$).

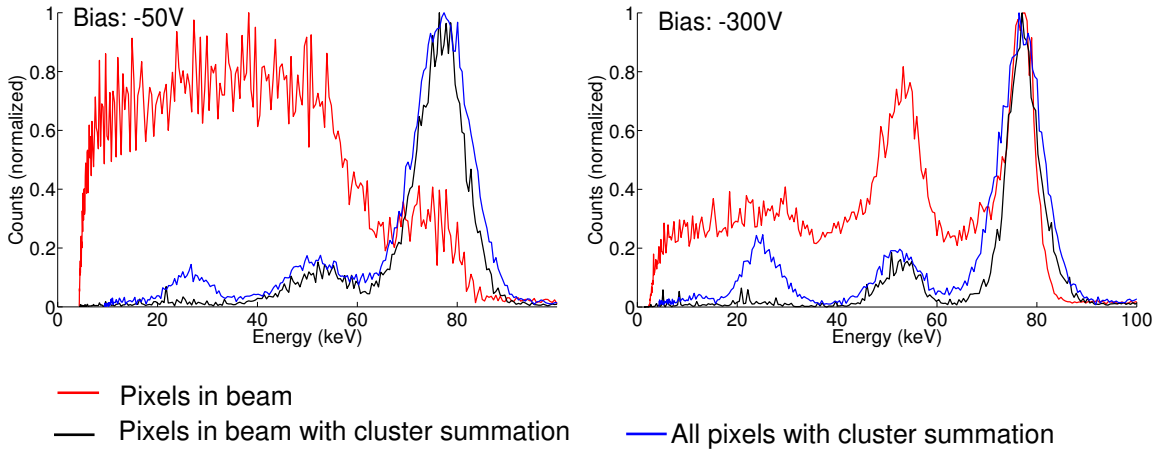

Figure 6. Bias voltage dependence of the spectral response.

peak around 22keV is caused by long range fluorescent photons in the sensor which are outside the summing range. The peaks from Cd and Te fluorescence could not be separated in this experiment.

If we do not use charge summing we see a better spectral performance close to the bottom of the sensor (figure 5). This is because the charge has less time to diffuse before entering the region close to the pixel contact where most of the signal is generated. This behavior is consistent with the signal being dominated by the more mobile electrons.

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4 Conclusions

We have characterized a pixellated CdTe detector with a thickness of 1mm and a pixel size of 110 x 110μm^2 using a narrow monoenergetic X-ray beam. The count rate varies according to the expected X-ray attenuation over the full thickness of the sensor. The spectral response is uniform over sensor thickness when charge summing is applied.

The results are promising for the development of high-resolution detectors for spectral imaging. They emphasise however the need for charge-summing mode as MEDIPIX3 [13] for operation with small-pixel CdTe devices.

Acknowledgments

This work has been carried out in the framework of the MEDIPIX collaboration. Pixelman software and FITPIX [6] read out from CTU in Prague has been used to control the chip. The TIMEPIX chip is bumb bonded by Freiburger Materialforschungzentrum on ACRORAD CdTe material.

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