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Investigation of charge collection in a CdTe-Timepix detector

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ABSTRACT: Energy calibration of CdTe detectors is usually done using known reference sources disregarding the exact amount of charge that is collected in the pixels. However, to compare detector and detector model the quantity of charge collected is needed. We characterize the charge collection in a CdTe detector comparing test pulses, measured data and an improved TCAD simulation model [1]. The 1 mm thick detector is bump-bonded to a TIMEPIX chip and operating in Time-over-Threshold (ToT) mode. The resistivity in the simulation was adjusted to match the detector properties setting a deep intrinsic donor level [2]. This way it is possible to adjust properties like trap concentration, electron/hole lifetime and mobility in the simulation characterizing the detector close to measured data cite [3].

KEYWORDS: Solid state detectors; X-ray detectors; Models and simulations; Charge induction

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1 Introduction

It is common practice to do an energy calibration of CdTe detectors using known radioactive reference sources and secondary (fluorescence) x-rays from metals. Disregarding the exact amount of charge that is collected in the pixels a calibration curve can be plotted. However, to compare detector and simulation model and characterisation of the sensor material, the quantity of charge collected is needed. We propose a method to characterize the charge collection in a CdTe detector comparing test pulses, measured data and an improved TCAD simulation model [1,7].

A 1 mm thick CdTe sensor is bump-bonded to a TIMEPIX chip and operated in Time-over-Threshold (ToT) mode and used throughout all measurements. The resistivity of the simulation model was adjusted to match the detector properties setting a deep intrinsic donor level [2]. This way it is possible to adjust properties like trap concentration, electron/hole lifetime and mobility in the simulation characterizing the detector close to measured data [3]. Furthermore, the simulation allows to visualize effects that otherwise would not be recognized directly.

2 Methods

The fluorescence x-ray as well as test pulse measurements were divided into two sets per energy setting with I_{Krum} set to 5 and 10. I_{Krum} influences how much leakage current a pixel can adjust to and the shaping time of the charge shaping amplifier (CSA).

The CdTe detector was biased with -300 V with a measured leakage current of around $5\ \mu\text{A}$ to $6\ \mu\text{A}$ during all measurements. All measurements were taken with the Fitpix readout system and the device was kept in a dark environment at room temperature. [8, 9] A finite element simulation implemented with TCAD Sentaurus (Synopsys) matching the parameters was fed with the charge that corresponded to the chosen energies is described in detail in 2.3. The data analysis was done with scientific python, specifically NumPy and Scipy as well as PyROOT.

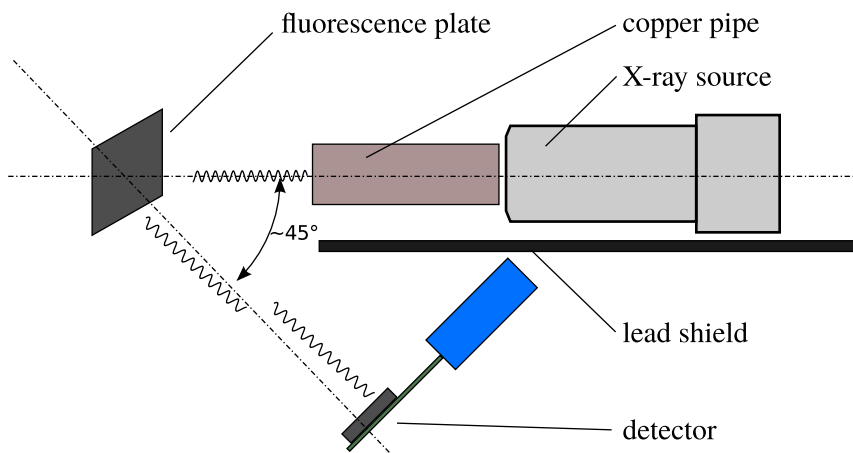


Figure 1. The figure shows the experimental assembly of the x-ray tube, fluorescence metal and detector.

Table 1. The table shows the used materials with their K_{α} lines, the corresponding test pulse for the TIMEPIX chip and the charge that the X-ray photon would generate in CdTe with a conversion factor of 4.43 [5].

Material	K_{α} (keV)	Test Pulse (mV)	Charge (pC)
Indium	24.209	116	0.000876
Praseodymium	36.026	173.5	0.0013
Erbium	49.128	237	0.001778
Tungsten	59.318	286	0.002145

2.1 Test pulses

Every pixel of the TIMEPIX chip is equipped with an 8 fF capacitor that can be used to inject a defined charge into the analogue pre-amplifier. A multiplexer that is mounted on the chip board can be controlled to generate square shaped pulses with a defined amplitude. The typical rise time of a test pulse is about 7 ns. The magnitude of the amplitude corresponds to the injected charge. The gain corresponds to $46875 e/mV$ [4]. We used a THL (low threshold) setting of 400 and RefClk (external reference clock) was set to 48 MHz, which corresponds to 20.8 ns per ToT value. The test pulses were injected with a matrix spacing of 8. Ten test pulses per recorded frame were injected into the CSA and stored in binary format. In order to validate the stability of the threshold, the threshold was scanned with test pulses. This measurement was repeated 700 times see figure 3.

2.2 Fluorescence measurements

The fluorescence measurements were done with the laboratory setup shown in figure 1. We used a Y.FXE micro-focus x-ray tube with a transmissive head in high power mode to irradiate the target metal. The target metal was placed approximately 25 cm away in a 45° angle. The detector was also placed in 25 cm distance from the metal sheet, shielded from the source head with a plate of lead. The peak energy of the tube was chose to be approximately twice as high as the K_{α} -edge of the

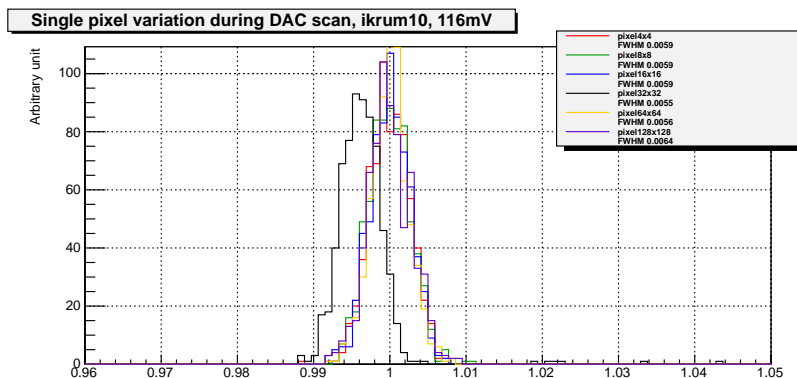


Figure 2. Variation of single pixels in counting mode over 700 DAC scan measurements.

metal. The CdTe TIMEPIX detector was kept at room temperature with a passive cooling system. For the comparison of fluorescence and test pulses only single pixel hits were selected by looking for hits without neighbours.

2.3 Simulation model

The finite element model consists of 3 pixels with a pixel pitch of $110\mu\text{m}$. The simulated CdTe volume measures $440\mu\text{m} \times 1000\mu\text{m}$ with a thickness of 1 mm. Resistivity is modelled by introducing traps into the material based on a simplified trap model [2]. The mesh is refined around the contacts and the position of the inserted charge to prevent numerical errors. Using this method, it is possible to visualize the charge cloud through the sensor material and the charge collection at the electrodes. In the simulation only fully deposited charge was simulated. Effects of fluorescence in the sensor material were not take into account. Initially the bias voltage was ramped up from 0V to -300V . The propagation of the charges were simulated in a second step and the charge plotted over at time of $1\mu\text{s}$.

3 Results and discussion

The graphs in figures 3 and 4 seem to show contradicting results. Ideally test pulses and measurements should appear as two parallel lines. The curves from X-ray were expected to be lower than the test pulses due to incomplete charge collection. A setting of $I_{Krum} = 5$ shows lower charge collection in single hit clusters of x-ray photons than the corresponding test pulses.

Increasing I_{Krum} to 10 shows nearly identical ToT values for 24.2keV and larger values for x-ray photons than test pulses at higher energies. This last effect could be explained with the fact that high energy photons have a longer attenuation length. When a photon is absorbed close to the metallisation, its charge cloud travels to the weighting potential of the pixels and induces a charge at the pre-amplifier. If the amplitude has the opposite polarity on the neighbouring pixel, it will not be counted but compensated by the next pixel. As stated before the I_{Krum} setting has an effect on the shaped pulse as well as the leakage current compensation [6]. A lower setting means longer shaping time. The test pulses do not have that effect since the voltage at the test capacitance is stable. In the simulation results in figure 5 it can be see how holes and electrons travelling through

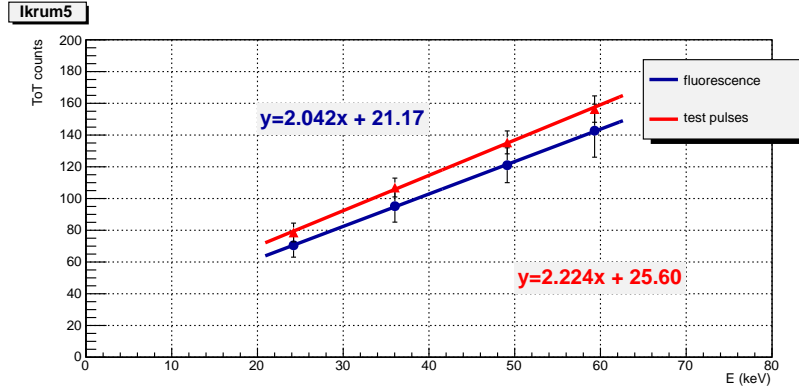


Figure 3. The graph shows the ToT values versus energy of the source of fluorescence spectra for four different materials and their corresponding test pulses.

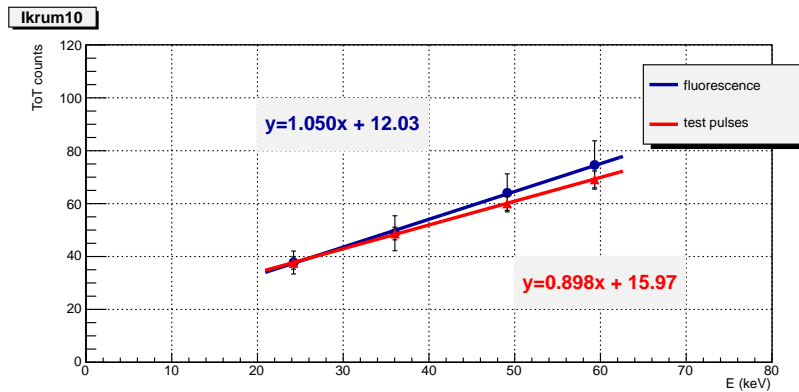


Figure 4. The graph shows the ToT values versus energy of the source of fluorescence spectra for four different materials and their corresponding test pulses.

the weighting potential influence the shape of the charge that is induced at the pixel side. For a charge deposited close to the pixel an undershoot of the neighbouring pixels is visible. A charge in the centre of the sensor shows a fast electron component first and a slower hole component. The case where a photon is absorbed close to the surface of the sensor material shows no contribution from holes. The charge collection efficiency (CCE) can be defined as

$$\text{CCE} = \frac{Q}{Q_0} \tag{3.1}$$

the ratio between induced charge Q at the electrode and the deposited charge Q_0 .

Simulation results suggest that without charge summing more than 100 percent charge collection efficiency could be achieved when the charge is deposited close to the metallisation of the pixel. This effect would become stronger with increasing photon energies due to the greater attenuation length and does not become apparent with test pulses. Gain and capacitances do not change during the different measurements with the same I_{Krum} settings. Both lines would be affected by the variation and shift to higher or lower ToT values.

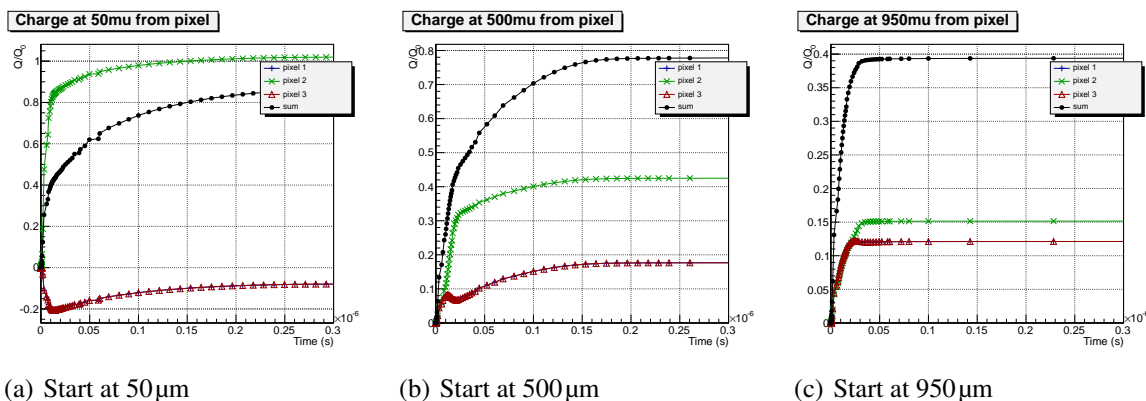


Figure 5. Charge collection in simulation. The green line corresponds to the centre pixel, the blue and red line correspond to the adjacent pixels.

4 Conclusion

In this paper we showed a comparison between simulation, test pulses and x-ray measurements on a TIMEPIX detector with a cadmiumtelluride sensor in ToT mode. The proposed method can be a tool to study CdTe material mounted on a pixel detector. Further investigation of the influence of absorption depth on the collected charge is currently in progress and can be provided by a synchrotron beam with a tilted beam. Furthermore, the undershoot of neighbouring pixels could provide more information about the charge collection in the sensor material.

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