Influence of silicon sensor thickness to spectral properties of Timepix detector operated in counting mode

Jan Jakubek

Introduction

The Timepix read-out chip (ROC) can be combined with various sensors. The most typical sensor material is Silicon. The Silicon sensors can be manufactured in various thicknesses (from 50 µm up to 1.5 mm). The proper thickness is always selected according to application.

In imaging applications with X-rays the device is usually operated in counting mode. The possibility of setting of certain energy threshold is often very advantageous since it allows to optimize imaging performance of the detector or to perform a multi-channel imaging for visualization of material composition of inspected sample.

The obvious question is whether the thickness of silicon sensor affect the energy sensitivity of the detector. In this paper we show several examples of X-ray or gamma spectra measured with Timepix detector equipped with Silicon sensors of several different thicknesses in counting mode.

In this paper we also explain how the spectroscopic measurement in counting mode is performed in the Pixelman software.

Spectroscopic measurement in counting mode

In counting mode each pixel of Timepix detector counts the number of particles (e.g. X-ray photons) depositing within such pixel energy larger than threshold (THL value). The energy spectrum of certain radiation source can be measured performing scan over certain range of THL values. For each THL value we record number of events depositing larger energy than this threshold. This means that such integral spectrum is in ideal case a decreasing function of energy. In real case there can be influence of poissonian noise making the integral spectrum locally non-monotonic. The differential spectrum is obtained calculating differences of subsequent energy channels in integral spectrum.

The tool for THL scan and calculation of the differential spectrum is included in the Pixelman software (Menu: Tools/DACs scan). The example of spectrum measured using this tool is shown in Fig. 1. In the displayed spectrum of ^{241}Am source and Indium X-ray fluorescence (XRF) we see several interesting features: The gamma peak of Am with energy of 59.54 keV is not fully separated from the XRF peak of In. The reason is charge sharing effect. Some gamma photons deposit their energy close to the border between two (or more) pixels. The ionization charge is then shared by all such pixels, each of them receiving signal smaller than which would correspond to the original particle. This effect results in presence of continuum or plateau stretched from the spectral peak towards lower energies. The number of all the events in such continuum compared to the total number of all particles gives the probability that the charge sharing effect occurs.

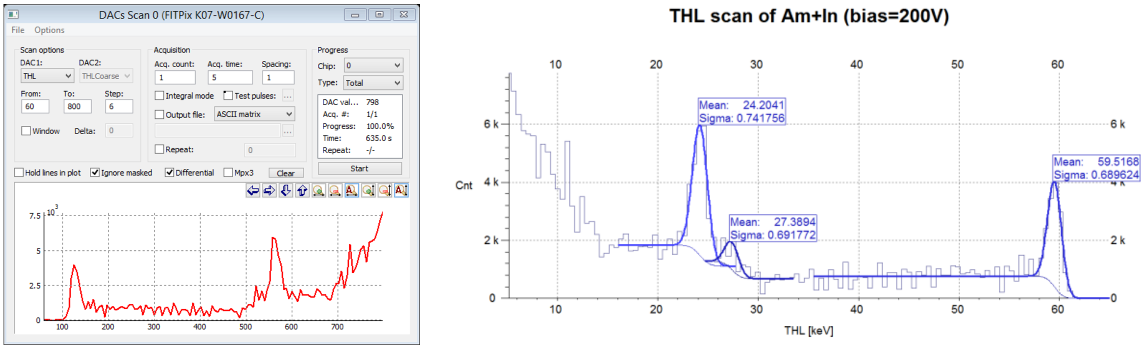

Fig. 1. The window of tool for threshold scan (left) in the Pixelman software with the sample differential spectrum of ^{241}Am gamma source (59.54 keV) covered with Indium foil emitting X-ray fluorescence (K_α peak at 24.14 keV and K_β at 27.27 keV). Since the THL value is inverted, the spectrum shown in the window is mirrored (left side corresponds to higher energies). The same spectrum after proper calibration of THL value to energy is shown right. The peaks are fitted with combination of Gaussian and error functions. The measurement was performed with row of 3 Timepix detectors with edgeless 300 µm thick silicon sensors.

Influence of detector bias voltage to charge sharing

The amount of charge sharing effect strongly depends on the detector thickness (thinner is better) and the bias voltage used (higher is better). Both parameters affect the speed of charge collection process within the sensor. Faster charge collection limits excessive enlargement of the charge clouds being collected which decreases the probability that such charge cloud would be detected by multiple adjacent pixels resulting in charge sharing effect. This phenomenon is demonstrated in following picture.

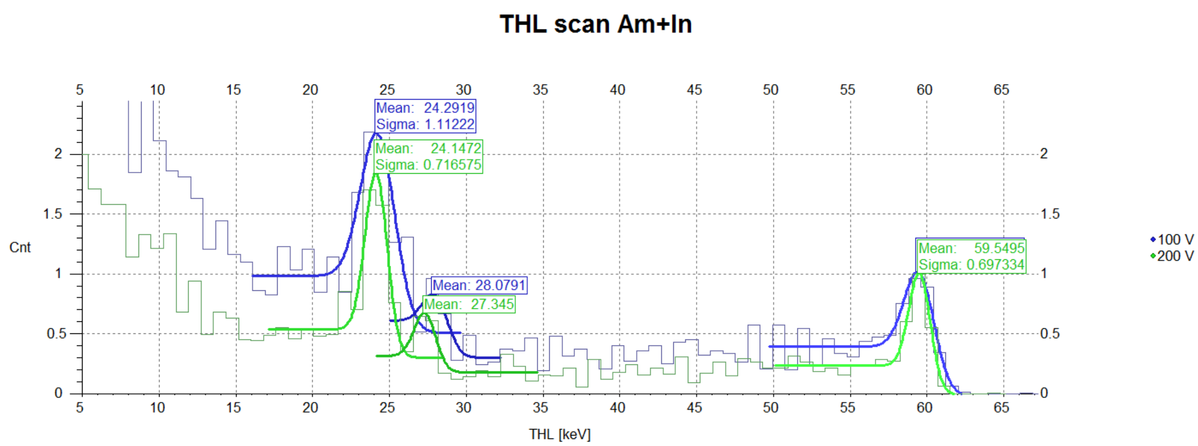

Fig. 2. Comparison of two spectra of the same source (^{241}Am + In XRF) measured with two different settings of bias voltage. The sensor was 300 µm thick P-on-N silicon. Both spectra were normalized according to height of the Am peak. The left side plateau near Am peak is clearly lower for higher bias voltage. The energy resolution improves as well.

Influence of detector thickness

The energetic resolution is described by σ (sigma) parameter of Gaussian fit of peak in the spectrum (see Fig. 1 right). The energy resolution doesn't directly depend on sensor thickness. We demonstrate this by spectra in following pictures measured with different sensor thicknesses.

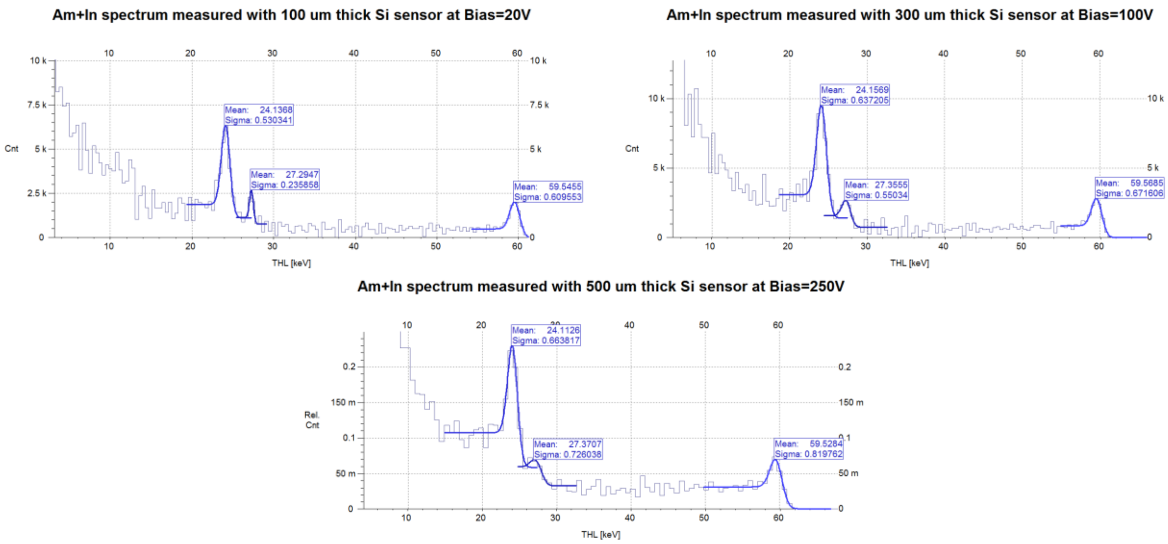

Fig. 3. The spectra of the same source (^{241}Am + In XRF) measured with silicon sensors of different thickness and bias voltage. We see that the energy resolution is not really influenced by sensor thickness (if bias voltage is high enough). In the first two images we see that the 100 µm sensor at 20 V performs very similarly to 300 µm at 100 V. The bias voltage for 500 µm thick sensor should be larger than 250 V used here.

Other detector materials?

For comparison we show the energy spectrum measured with 1 mm thick CdTe sensor. The radiation source is different in this case since Cd and Te cause their own X-ray flourescences. The resulting spectrum quality is very similar to Silicon case shown in Fig. 3.

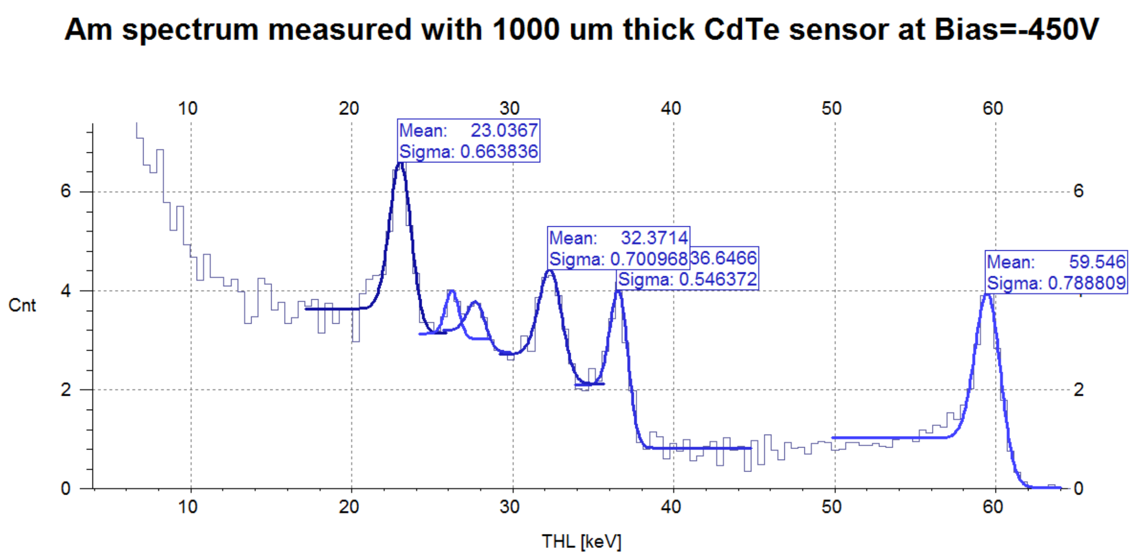

Fig. 4. The spectrum of ^{241}Am gamma source measured with 1 mm thick CdTe sensor with Schottky contacts biased to -450 V. There are many peaks except of main 59.54 keV gamma line of ^{241}Am. They are K_α X-ray fluorescent peaks of Cd and Te and their respective escape peaks. Less pronounced are K_β flourescent peaks of both materials.

Can be the annoying charge sharing effect removed from the measured spectra?

Yes. There is very simple method called Van Cittert deconvolution. If the algorithm is applied to spectrum in Fig. 4 we get the result is as shown in Fig. 5. More details about this method will be given in specialized white paper.

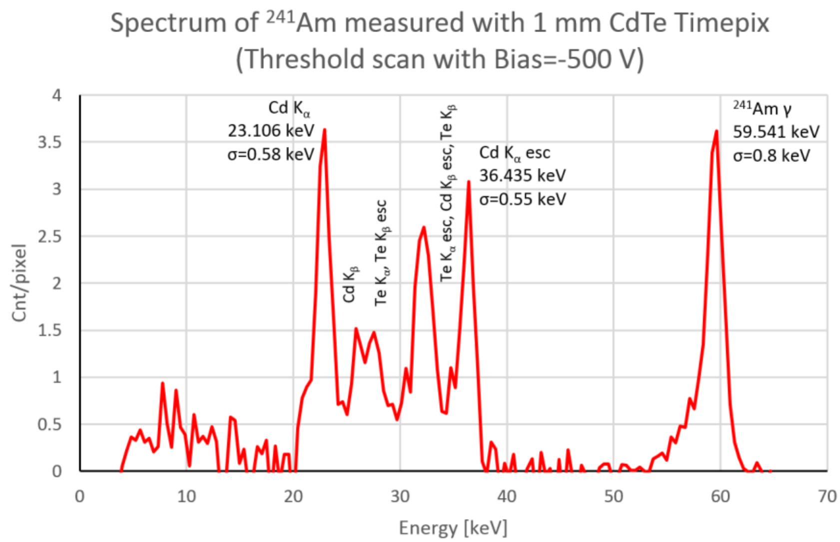

Fig. 5. The same spectrum as shown in Fig. 4 after removal of charge sharing background using Van Cittert algorithm.