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Characterization of charge sharing and fluorescence effects by multiple counts analysis in a Pixie-II based detection system

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Abstract

In X-ray photon counting detectors (XPCD), implementing thick CdTe semiconductor sensors and small pixel sizes ($< 100\mu m$), charge-sharing and fluorescences emitted by Cd and Te are responsible for multiple counts from a single interacting photon. These effects can impair the imaging and spectroscopic performance of XPCDs. Multiple counts can be partially or totally discriminated by properly setting the energy threshold implemented by the XPCD system. Using monochromatic radiation and the Pixirad-I/Pixie-II CdTe XPCD, this work characterizes and quantifies clusters of multiple counts as a function of energy and threshold.

Keywords: X-ray Photon Counting Detectors, charge-sharing, multilpe counts

1. Introduction

This work presents a systematic study of multiple counts detection in the Pixirad-I/Pixie-II X-ray photon counting detector (XPCD). Pixirad/Pixie-II is a hybrid XPCD made by coupling a 650 μm thick CdTe semiconductor sensor with the readout electronics. The basic module has an active area of $30.7\times24.8\ mm^2$, covered by a honeycomb matrix of 512×476 pixels with 60 μm horizontal pitch and 51.96 μm vertical pitch [1]. The main sources of multiple counts of this XPCD are: (i) the charge-sharing effect that occurs when the charge cloud generated by a single interacting photon spreads over neighboring pixels; (ii) the production of fluorescence photons by Cd and Te k-shells that occurs when photons with energies above CdTe k-edges ($E_{K_{Cd}} = 26.7\ keV$ and $E_{K_{Te}} = 31.8\ keV$) are employed. When a fluorescence photon with energy E_f is induced, the primary photon generates two separate events with energies $E - E_f$ and E_f. These two events can be collected either by neighboring or distant pixels. In CdTe, the main fluorescence photons have energies of $E_{Cd} = 23.1\ keV$ and $E_{Te} = 27.4\ keV$ with mean free paths respectively of $\lambda_{E_{Cd}} = 124.4\ \mu m$, and $\lambda_{E_{Te}} = 61.6\ \mu m$.

The basic idea of this study is to acquire large stacks of images, where only a few photons interact in the whole sensor. In this way it is possible to observe, in a single image, the presence of "clusters" of pixels of different sizes, each of which originates from a single interacting photon. In a cluster each pixel counts one signal. The size of a specific cluster is expected to depend on the energy and the interaction point of the photon, the amount of charge sharing, the possible fluorescence effect, and the discriminator threshold. By counting the clusters of different size that are present across the entire stack, we statistically characterized the dependence of the multiple counts by the energy of the photons and the discriminator threshold that are the only two parameters that can be varied when using the detector in a usual imaging task.

2. Materials and methods

Measurements have been performed with a monochromatized X-ray beam at the SYRMEP (SYnchrotron Radiation for Medical Physics) beamline of Elettra synchrotron (Trieste, Italy). The selected energies were 18, 22, 26, 27, 30, 34, 36, and 38 keV. The beam has been attenuated by means of aluminum sheets of different thickness to have a very low fluence rate at the detector. The detector was used at $400V$ with an acquisition time of 10 ms. The combination of the low fluence rate and short acquisition time made the probability of detecting two or more uncorrelated photons in neighboring pixels negligible.

We studied the distribution and size of the clusters as a function of the discriminator threshold (th). For each energy (E) we performed a threshold scan in the range $th = [2keV, \ldots, E]$, with steps of $1keV$. For each combination of E and th, 10^3 images were acquired. Images were analyzed with a specifically developed analysis routine, which detects and quantifies the clusters occurring across the entire stack. In this analysis, a cluster is defined as a set of adjacent pixels counting a signal. N_p is the total number of counts (counting pixels), and N_c the is the number of clusters.

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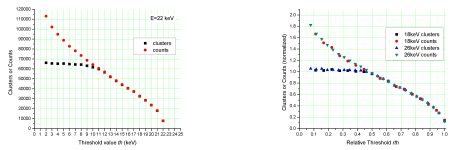
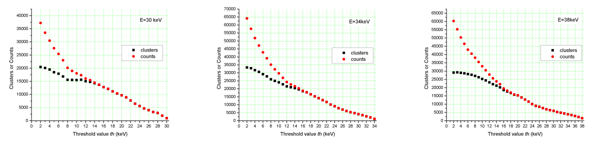
3. Results and discussion

Fig. 1(a) shows the plot of N_c and N_p as a function of th for photons with $E = 22\ keV$. In this case, being $E < E_{k_{Cd}}$, multiple counts are due to the charge sharing only. Assuming that the charge cloud at the pixels is smaller than the pixel area, in a honeycomb matrix the charge can be collected/shared by 1, 2, or 3 neighboring pixels, with the possibility to detect double, or triple counts from a single interacting photon. The plot in Fig. 1(a) shows that: for $th < 11\ keV$, N_c is almost constant (preserved detection efficiency), while the number of counts increases as th decreases. For $th = E/2 = 11\ keV$ each photon is counted once ($N_c = N_p$) by a single pixel and the counting pixel is the one receiving the highest fraction of charge shared by neighboring pixels. For $th > 11\ keV$, no multiple counts are detected and $N_c = N_p$. In this latter case, all the shared events are gradually discriminated with the increase of th, with a consequent loss of detection efficiency (decreasing number of N_c). This behavior is common for all the energies below $E_{k_{Cd}}$ as shown by Fig. 1(b), where the plots of the relative number of clusters and counts as a function of the relative threshold (i.e. th/E) superimpose for the two energies of $E = 18\ keV$ and $E = 26\ keV$. Fig. 2 reports a few cases where the emitted Cd (Fig. 2 (a)) and Te (Fig. 2 (b) and (c)) fluorescence photons represent an additional source of multiple counts. Fig. 2 (a) shows the plot of N_c and N_p as a function of th for $E = 30\ keV$. For this energy only Cd fluorescence photons are emitted. Referring to Fig. 2 (a), three cases can be observed. For $th \leq E - E_{Cd} = 7\ keV$ up to 2 clusters can be generated by a single interacting photon which splits in two events with energy $E - E_{Cd}$ and E_{Cd}. Multiple counts related to each cluster are detected as well. For $7\ keV < th < E/2 = 15\ keV$, all the primary events which deposit an energy $E - E_{Cd}$ are rejected, while the relative fluorescence photons are detected in separate cluster. In this case, the detection efficiency is preserved as each interacting photon is counted once. However, the spatial resolution is impaired since the fluorescence photon is detected far from the point where the primary interaction occurs. For $th > E/2$ we observe the same behavior described for the case shown in Fig. 1(a), where only charge-sharing occurs. For energies above $E_{k_{Te}}$, the scenario of multiple clusters and counts is further complicated by the emission of Te fluorescence photons. In this regime (Fig. 2 (b) and (c)) it is not possible to find a range of th for which N_c reaches a plateau and where the detection efficiency is preserved, as the energy of the primary event can be split into up to 3 separate events with energies $E - E_{Te}$, $E - E_{Cd}$, and $E_{Te} - E_{Cd}$.



(a) (b)

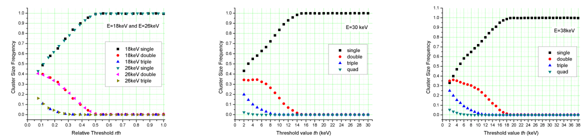
Figure 1: (a) Plot of N_c and N_p as a function of th for $E = 22\ keV$; (b) plot of the relative number of clusters and counts.



(a) (b) (c)

Figure 2: plot of N_c and N_p as a function of th for (a) $E = 30\ keV$, (b) $E = 34\ keV$, (c) $E = 38\ keV$.

In Fig. 3 we report the relative distribution of the clusters, by size, as a function of the threshold to input energy ratio th/E. Results in Fig. 3 (a) show that, for $E < E_{k_{Cd}}$ the plots of number and size of the detected clusters against the relative thresholds are independent from the energy of the impinging photons. In particular, when the relative threshold is set to 0.1, the relative frequencies of clusters corresponding to single, double and triple counts are respectively of 0.4, 0.4 and 0.2. Triple and double counts are rejected respectively for $th \geq E/3$ and $th \geq E/2$. Otherwise, when imaging with photons having energy above $E_{k_{Cd}}/E_{k_{Te}}$ (Fig. 3 (b)/(c)), clusters of more than 4 pixels are observed. In this case, the number and the maximum size of the clusters increase with the energy of the impinging photons.



(a) (b) (c)

Figure 3: relative distribution and size of clusters as a function of the relative threshold for (a) $E = 18/26\ keV$, (b) $E = 30\ keV$, (c) $E = 38\ keV$.

4. Conclusions

Multiple counts detection/rejection directly affect the spatial and the spectral resolutions as well as the detection efficiency and noise response of XPCDs [2, 3]. The results presented in this work show how the size and occurrence of multiple counts can vary as a function of the energy and threshold for the Pixirad/Pixie-II XPCD, thus helping in the selection of the optimal thresholds for specific imaging tasks.

References

[1] P. Delogu et al., Characterization of pixirad-1 photon counting detector for x-ray imaging, JINST 11 (01) (2016) P01015–P01015. doi:10.1088/1748-0221/11/01/p01015.

[2] V. Di Trapani et al., Characterization of the acquisition modes implemented in pixirad-1/pixie-iii x-ray detector: Effects of charge sharing correction on spectral resolution and image quality, NIM(A) 955 (2020) 163220. doi:10.1016/j.nima.2019.163220.

[3] V. Di Trapani et al., Characterization of noise and efficiency of the Pixirad-1/Pixie-III CdTe X-ray imaging detector, JINST 13 (12) (2018) C12008–C12008. doi:10.1088/1748-0221/13/12/c12008.