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Energy Response of a room-temperature Cadmium Telluride (CdTe) Photon Counting Detector for Simultaneous and Sequential CT and SPECT

Introduction

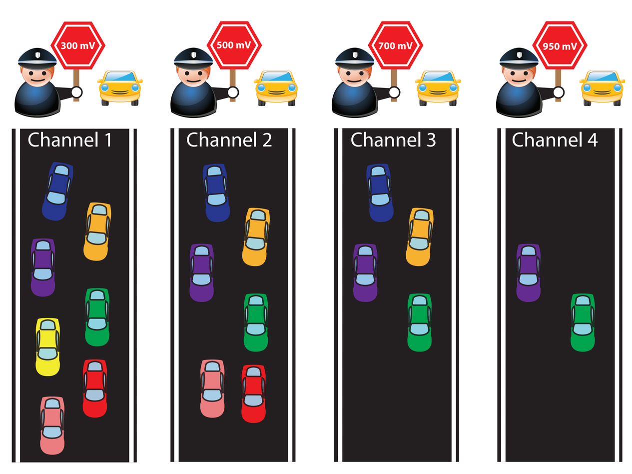
Semiconductor radiation detectors have been widely investigated as a promising alternative to scintillator-based detectors. An energy-resolving Cadmium Telluride (CdTe) photon counting detector was developed by DxRay, Inc. (Northridge, CA, USA)[1,2]. The CdTe detector was designed with the dedicated application specific integrated circuits (ASICs), which allow fast signal formation and multiple energy thresholds per detector element.

Purpose

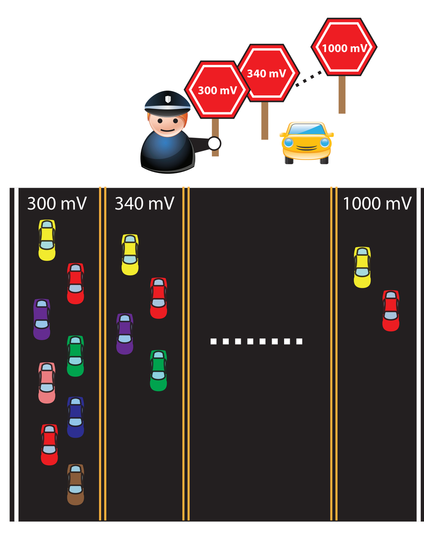
In this study, the energy response of the CdTe detector is investigated. The goal of this study is to develop a robust method to generate an energy spectrum for any incident radiation source. The measured energy spectrum can be useful to set up appropriate energy thresholds when imaging an object with a given radiation source. The CdTe detector could be potentially used for simultaneous and sequential single photon emission computed tomography (SPECT) & x-ray computed tomography (CT) acquisition.

CdTe Photon Counting Detector

- Detector element size: 1 × 1 × 1 mm^3
- 64 × 4 detector elements
- Room-temperature operation
- Low leakage current & noise floor
- 4 energy thresholds per detector element
- Maximum count rate of 6.8 × 105 cps/mm^2



Imaging mode. Each detector element records photon counts into four individual pulse height discriminators as pulse height (mV) is proportional to photon energy (keV). For each frame, a channel counts photons with a pulse height above a threshold value.

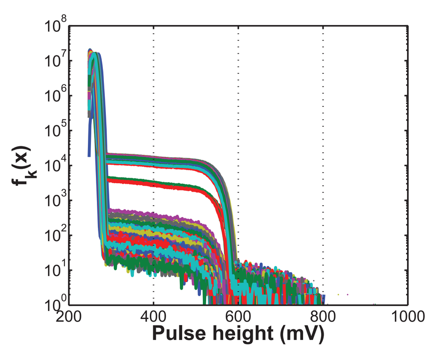


Spectrum mode. Each channel of a detector element records photon counts by stepping the threshold value across the dynamic range. In each frame, the number of counts above the threshold is recorded. The number of counts as a function of threshold value gives rise to the integrated spectrum of an incident radiation source.

Spectral Reconstruction

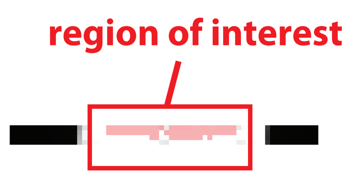
(1) Acquire spectrum-mode data

$f_k(x)$: the integrated count at each threshold

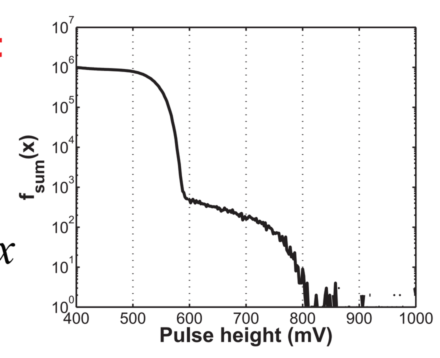


(2) Data summation over pixels of interest

$f_{sum}(x)$: the composite integrated count

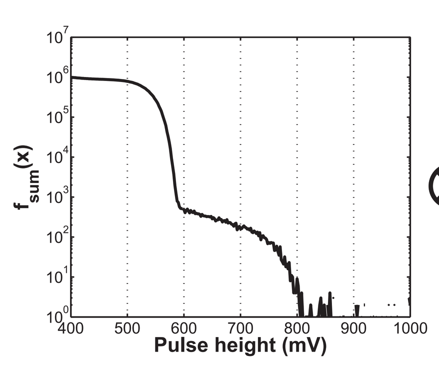


$$f_{sum}(x) = \int_k f_k(x)dx$$



(3) Data denoising

$$g(x) = f_{sum}(x) \otimes h(x)$$



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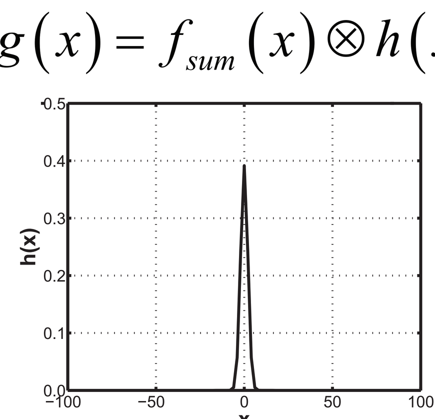

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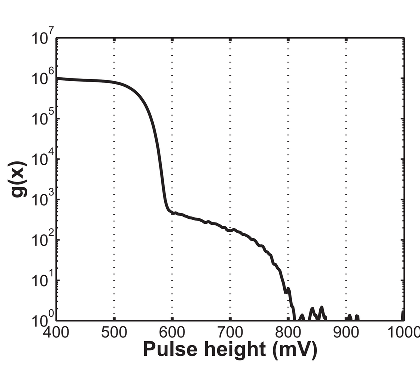
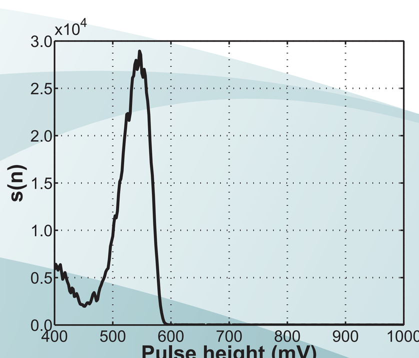


(4) Central finite difference (4th-order accuracy)

$$s(n) = \left(\frac{dg}{dx}\right)_n \approx \frac{-f(n+2)+8f(n+1)-8f(n-1)+f(n-2)}{12\Delta x}$$



Energy Calibration & Resolution

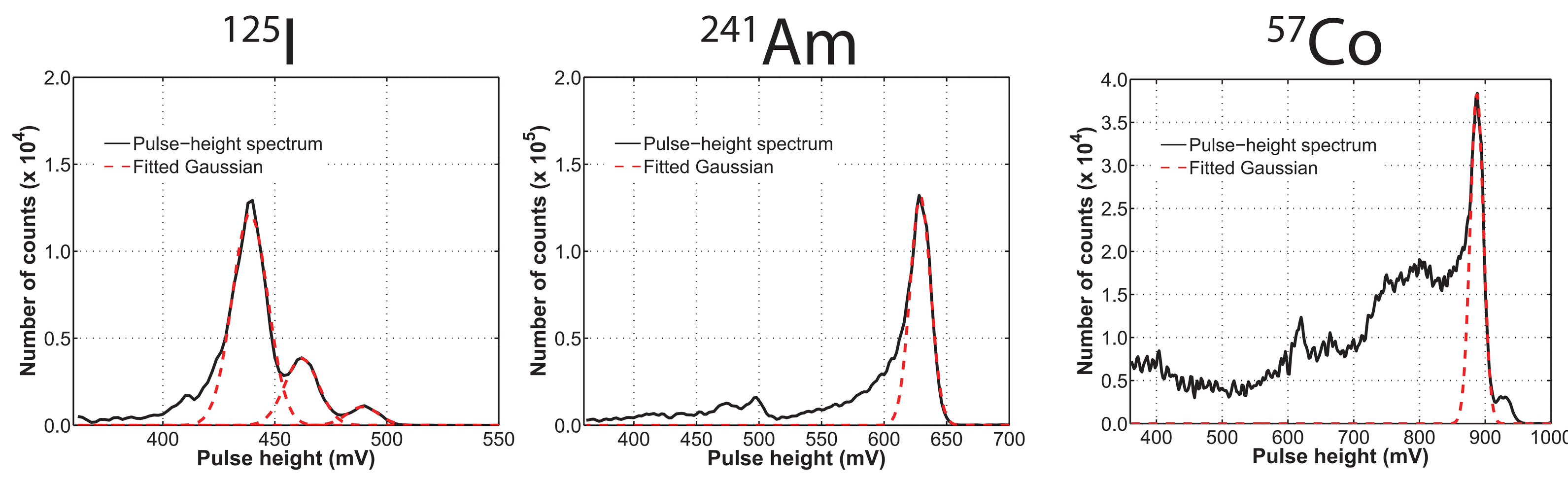


Figure 1. The pulse height spectrum measured with the CdTe photon counting detector for ^{125}I, ^{241}Am, and ^{57}Co source. Gaussian function was fitted to the photopeak(s) of each source for energy calibration.

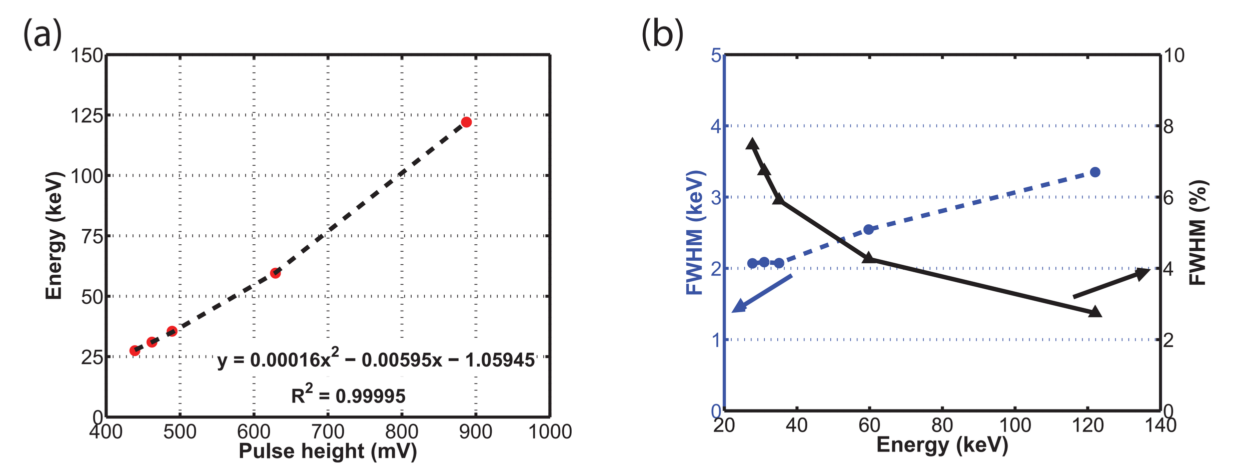


Figure 2. (a) The relationship between energy (keV) and pulse height (mV) recorded by the CdTe detector is illustrated. (b) The full-width-half-maximum (FWHM) in keV and percent is shown as a function of energy (keV) incident to the CdTe detector.

Energy Spectrum with Multiple Radiation Sources

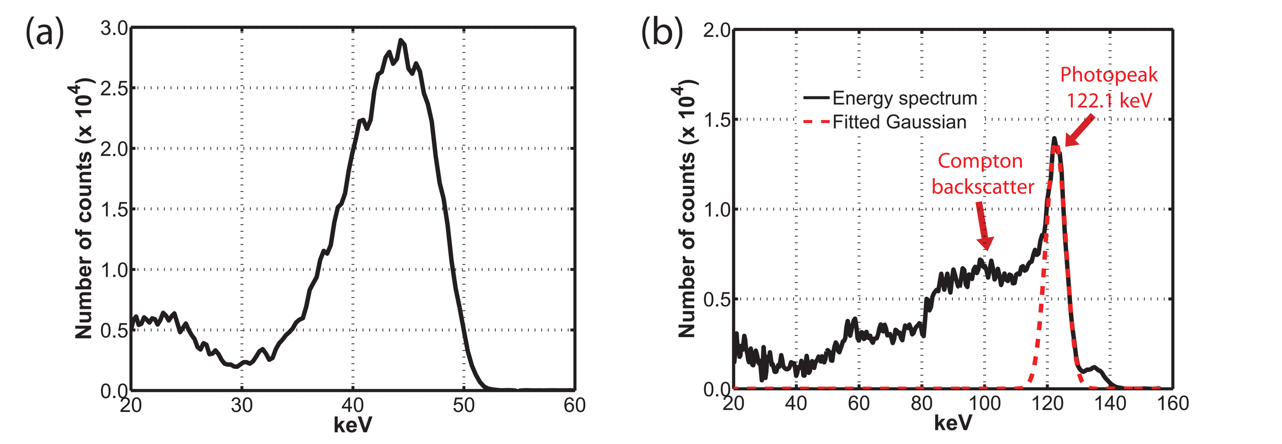


Figure 3. The energy-calibrated spectrum of (a) 50-kVp x-ray source (0.1 mA & 0.1-mm Cu filter, Oxford Instruments, UK) and (b) ^{57}Co source (2.1 mCi) are shown. The FWHM at the photopeak of the ^{57}Co source is 3.51 keV (2.86%) from the Gaussian fit.

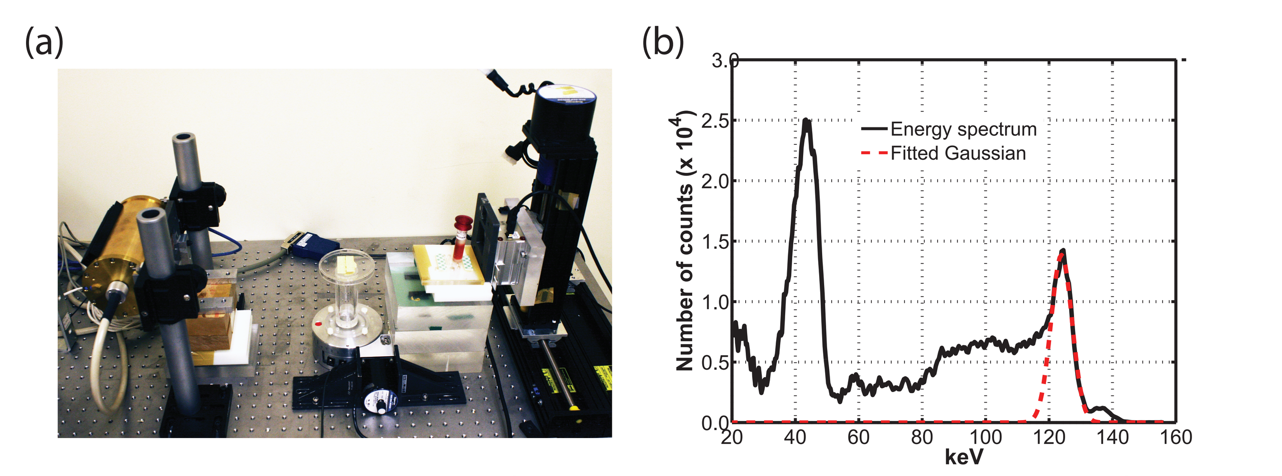


Figure 4. (a) The experiment setup of simultaneously acquiring energy spectra of 50-kVp x-ray and ^{57}Co source is shown. (b) The energy spectrum of 50-kVp x-ray and ^{57}Co source is illustrated. The FWHM at the photopeak of ^{57}Co source in the multiple-source acquisition is 3.60 keV (2.90%).

Conclusion

In this study, we developed a robust method to measure the energy spectrum using a CdTe photon counting detector. The CdTe detector was shown to have excellent energy resolution (2.0 - 3.3 keV), which is not compromised when multiple radiation sources are present. This method could be useful to provide energy information to specify the appropriate energy thresholds when imaging with different radiation sources, such as SPECT/CT imaging applications.

Acknowledgment

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References

[1] J. S. Iwanczyk, E. Nygard, J. C. Wessel, N. Malakhov, G. Wawrzyniak, N. E. Hartsough, T. Gandhi, and W. C. Barber, "Optimization of room-temperature semiconductor detectors for energy-resolved x-ray imaging," in Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC), 2011 IEEE, 2011, pp. 4745-4750.

[2] W. C. Barber, E. Nygard, J. C. Wessel, N. Malakhov, N. E. Hartsough, T. Gandhi, G. Wawrzyniak, and J. S. Iwanczyk, "Photon-counting energy-resolving CdTe detectors for high-flux x-ray imaging," in Nuclear Science Symposium Conference Record (NSS/MIC), 2010 IEEE, 2010, pp. 3953-3955.