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Hybrid pixel-waveform CdTe/CZT detector for use in an ultrahigh resolution MRI compatible SPECT system

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Abstract

In this paper, we will present a new small pixel CdTe/CZT detector for sub-500 μm resolution SPECT imaging application inside MR scanner based on a recently developed hybrid pixel-waveform (HPWF) readout circuitry. The HPWF readout system consists of a 2-D multi-pixel circuitry attached to the anode pixels to provide the X-Y positions of interactions, and a high-speed digitizer to read out the pulse-waveform induced on the cathode. The digitized cathode waveform could provide energy deposition information, precise timing and depth-of-interaction information for gamma ray interactions. Several attractive features with this HPWF detector system will be discussed in this paper. To demonstrate the performance, we constructed several prototype HPWF detectors with pixelated CZT and CdTe detectors of 2–5 mm thicknesses, connected to a prototype readout system consisting of energy-resolved photon-counting ASIC for readout anode pixels and an Agilent high-speed digitizer for digitizing the cathode signals. The performances of these detectors based on HPWF are discussed in this paper.

Keywords

MR compatible SPECT; CdTe/CZT; Hybrid pixel-waveform readout

1. Introduction

The CdTe and CdZnTe (CZT) detectors have been widely used for biomedical imaging. These detectors have the potential of offering the combination of excellent energy resolution, good spatial resolution and adequate detection efficiency for gamma rays emitted by common single photon emitters. We have recently developed a novel energy-resolved photon-counting (ERPC) sensor that offers a very-high spatial resolution, an excellent energy resolution for future SPECT applications [1]. A prototype MR-compatible SPECT system based on CdTe ERPC detectors has also been developed in our group and preliminary study demonstrates a very promising high resolution imaging performance inside the MR scanner [1,2].

Although we have achieved relatively good detector performance and imaging capability, the current generation detectors have several intrinsic limitations, especially when very small pixels are used (sub-250 μm). The first major challenge is how to obtain good energy resolution in such circumstance. With smaller and smaller pixels being used, the charge sharing and charge lost would severely degrade the charge collection efficiency and therefore the energy resolution. The limitation of current detector fabrication process and the

intrinsic charge lost between small pixels makes the energy resolution deterioration inevitable. As a side effect, the lack of precise energy information from small pixels and the multiple pixel events will lead to unreliable estimation of the depth-of-interaction. In addition, to simplify the pixel readout circuitry is desirable when pushing towards detectors with smaller and smaller pixels in medical imaging applications.

To alleviate these challenges above, we are developing two versions of small pixel CdTe detectors with 350 μm and 100 μm pixels read out by hybrid pixel-waveform scheme. This readout system consists of a 2-D multi-pixel circuitry attached to the anode pixels to provide the X–Y positions of interactions, and a high-speed digitizer to sample the waveform induced in the cathode. This configuration offers several attractive features for very small pixel detectors, and benefits the analysis of charge collection inside MR scanner. Firstly, the cathode waveform could provide reasonably accurate energy information using digital processing techniques that takes into account the effect of charge trapping, different drifting velocities of charge carriers. Secondly, this method could provide reliable DOI by measuring the electron drifting time from sampled waveforms. The DOI information could substantially improve the charge collection analysis inside strong magnetic field since large fraction of incident gamma ray is not perpendicular to the crystal surface. Finally, the HPWF readout system requires a highly simplified circuitry for handling the large number of anode pixels. It will potentially allow one to pack more readout channels per unit area with future generation CMOS ASICs.

In this paper, the prototype MR compatible HPWF detectors are constructed and evaluated. The waveform based energy resolution and DOI derivation will be investigated to validate the new detector performance.

2. Method

The prototype HPWF-CdTe/CZT detector and a design module are shown in Fig. 1. The CdTe/CZT detector is bump-bonded onto ERPC readout ASIC [1] with the same pixel patterns ($350 \times 350 \mu\text{m}^2$). Each pixel channel has pre-and shaping amplifiers, a discriminator and peak/hold circuitry. The cathode signals will be read out with a dedicated digital waveform sampling circuitry.

3. Results

By fitting and digital shaping cathode waveforms, the energy deposition, electron and hole drifting time, and the interaction timing can be derived [3]. The depth-of-interaction can be derived by electron and hole drifting time. Fig. 2 shows the cathode sample waveforms fitting results with a Na-22 source irradiating on a 2 mm thickness CdTe detector. The DOI resolution is estimated to be 0.3 mm with the 2 mm detector. The depth information will help to more precisely derive the detector charge collection process inside strong magnetic field [2], which will potentially improve the SPECT image taken inside the MR scanner. The Na-22 energy spectrum can also be derived by digital shaping the cathode waveforms and the result is shown in Fig. 3.

4. Conclusions

The HPWF detector configuration offers an excellent spatial, energy, timing and DOI resolutions with a relatively simple pixel readout circuitry. We are currently applying this technique to next generation small pixel CdTe detectors with 350 μm and 100 μm pixel size to construct ultrahigh resolution MR compatible SPECT and PET system.

References

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Fig. 1.
A prototype HPWF CZT/CdTe detector (up) and a design module of compact HPWF detector (down).

Fig. 2. DOI derivation based on cathode waveform fitting. The DOI is from the cathode side. Six cases here represent interactions happened in different positions. (For example, top middle is a standard scenario, bottom middle interaction happens close to the cathode, top left is a multiple interaction scenario).

Fig. 3. Na-22 energy spectra measured with sampled cathode waveforms, the correction represents the hole trapping compensation with different DOI.