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Technical note

First achievement of less than 1 mm FWHM resolution in practical semiconductor animal PET scanner

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Abstract

An animal PET scanner using CdTe detectors was developed for the purpose of biomedical study using mice and rats. A spatial resolution of 0.8 mm FWHM within the central 20 mm-diameter of the field of view (FOV) was obtained by small CdTe elements of 1.1 mm × 5.0 mm × 1.0 mm. This spatial resolution is the first achievement of a practical semiconductor animal PET scanner. The determination of the depth of the γ interaction in the detector was carried out by the use of two detector layers. The FOV is 64 mm in diameter and 26 mm in axis. Fine [^{18}F]FDG images of the heads of a mouse and a rat, where the cerebral cortex, the gray matter and the corpus striatum could be respectively distinguished, were successfully obtained. This work inspires the dawn of the high resolution semiconductor PET scanner age as the next generation.

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Keywords: Positron emission tomograph; CdTe; Semiconductor detector; High resolution; Animal PET

1. Introduction

Positron emission tomography (PET) using small animals such as rats and mice is very useful not only for biomedical research of metabolism and disease mechanisms but also for the development of new drugs. Animal PET scanners [1–4] using scintillation detectors have been developed for this purpose. The present best spatial resolution (FWHM) in scintillator PET scanners is 1.3 mm FWHM at the center of the field of view (FOV) and under 2 mm FWHM within the central 5 cm diameter of FOV [5]. This resolution is sufficient for PET studies using rats but not mice. The spatial resolution of PET scanner strongly depends on the size of the detector. The semiconductor detector can be downsized to the mm scale which allows a high spatial resolution of less than 1 mm FWHM. Several semiconductor detectors, namely Si, Ge, GaAs, CdTe, CdZnTe and so on are proposed as detectors for PET scanners. Projects for high resolution PET scanner using Si [6], Ge [7] and CZT [8] semiconductor detectors are now in progress. We have recently developed a very high resolution animal PET scanner using CdTe detectors and report here its performance.

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2. System description

2.1. Detector gantry

We adopted the Schottky barrier diode CdTe detector with Indium and Platinum electrodes [9]. This detector gives a good S/N ratio, an adequate time resolution (~6 ns FWHM) for the coincidence measurement in PET and also a high sensitivity for 511 keV γ-rays. The detector bias was 500 V/mm. Here, we took care of the polarization effect of CdTe detector. The charge collection capability of the CdTe detector was gradually reduced by this effect but could be recovered by the reset of the detector bias. During the measurement, we refreshed the detectors at intervals of 30 min. One detector unit is composed of two arrays of 16 CdTe detectors (1.1 mm × 5.0 mm × 1.0 mm), respectively, separated by a track of 0.1 mm width × 0.2 mm depth. Fig. 1 shows a schematic view of the CdTe strip detector unit. The rear array is shifted by 0.6 mm with respect to the front one. Owing to this arrangement, three cross lines of response (LORs) can be allowed in the interval of 1.2 mm and data sampling for the tangential axis of sinogram can be done in steps of 0.3 mm. The two-detector layers structure allows for determining and for accounting the depth of the γ interaction (DOI) in the detector. The detection efficiency of the detector unit (CdTe 10 mm thick) is 0.41 for 511 keV γ-rays. The detector unit is fixed on a glass epoxy base 0.2 mm thick and 16 detector units are stacked as one detector block. A total of 32 signal lines from one detector unit are connected to one ASIC. The thickness of the socket for the detector unit is 1.7 mm, therefore the packing ratio is 0.50. Fig. 2 shows a schematic view of a detector bucket consisting of a detector block and ASIC amplifier unit (16 detector units = 1 detector bucket). Fig. 3 shows the complete detector arrangement and photographs of the detector gantry. The detector gantry consists of 10 detector buckets and its bore diameter is 70 mm (10 detector buckets = 1 detector gantry). The FOV diameter is 64 mm and its axial length is 26 mm. In taking account of the angular fluctuation effect of γ-rays [10], positron distribution [11] and detector width, the spatial resolution of 0.7 mm at the center can be expected for this geometrical specification.

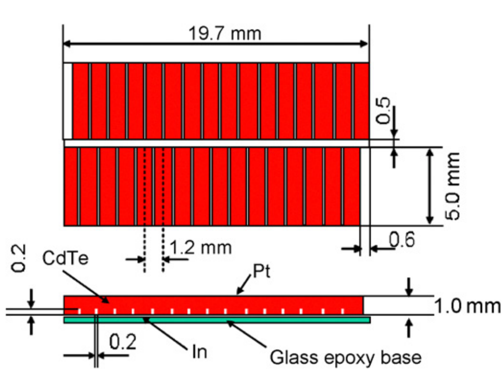

Fig. 1. Schematic view of one CdTe strip detector unit.

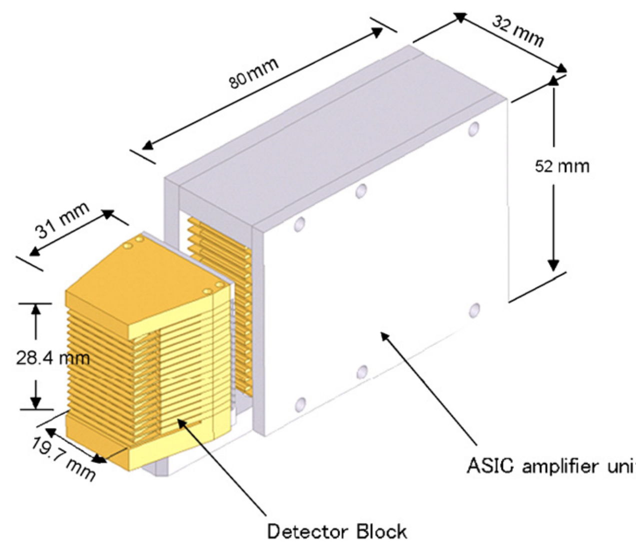

Fig. 2. Schematic view of detector bucket.

2.2. Data acquisition system

The data acquisition system consists of 10 digital processing boards which each have FPGAs and connect to 10 detector buckets (Fig. 4). FPGAs are used to record the detection time and detector position of γ-ray. One ASIC contains 32 preamplifiers which connect to 32 detectors of one detector unit and a total of 16 ASICs are mounted in one detector bucket. Event signals are processed through the ASIC and only the signals above the threshold level are sent to FPGA. The threshold level is controlled by a host computer and was set at 215 keV in this work. FPGAs encode the detection time of γ-rays with a clock signal of 100 MHz. Due to this clock performance, the coincidence time window of the PET is limited to 20 ns. The host computer determines the LOR using the detection time and detector position from the FPGAs and forms sinograms which are sorted in a list mode. The image reconstruction using Maximum-Likelihood Expectation-Maximization (ML-EM) [12] method is carried out by a personal computer.

3. Performance characteristics

3.1. Spatial resolution and sensitivity

A ^{22}Na point source of ~0.5 mm diameter was used to measure the spatial resolution. Fig. 5 shows the profile of the point spread function and the spatial resolution as a function of distance from the center of the gantry. The positron images of the point source were obtained by the filtered back projection method. The tangential resolution of 0.74 mm FWHM was obtained at the center of the FOV.