Characterising a Planar Germanium Strip Detector for Medical Imaging Applications

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Introduction

Abstract

The characterizing of a gamma-ray detector for medical imaging is presented. This planar germanium strip detector is a prototype for a project that is aimed at tackling present deficiencies in Positron Emission Tomography (PET) detectors. Namely the high proportion of rejected events from Compton scattering, and present spatial resolution; important for imaging small animals. The use of High Purity Germanium (HPGe) strip detectors configured as PET detectors has the potential to provide improved spatial resolution and give excellent energy resolution enabling gamma-ray tracking to be used.

PET with planar HPGe detectors

Present technology limits the spatial resolution of a PET detector to the size of the crystals within the detector. Decreasing the crystal size and increasing the number of crystals only increases the complexity of the electronics and the algorithms needed. The use of segmented HPGe detectors in conjunction with digital Pulse Shape Analysis (PSA) is being researched extensively to improve position sensitivity and to locate interactions in three-dimensions for use in gamma-ray tracking. This will enable the interaction position of a gamma-ray photon to be identified with a much higher precision than is possible with the detector strips alone. The excellent energy resolution of germanium offers the possibility of improving system efficiency by utilizing scattered events rather than dismissing them.

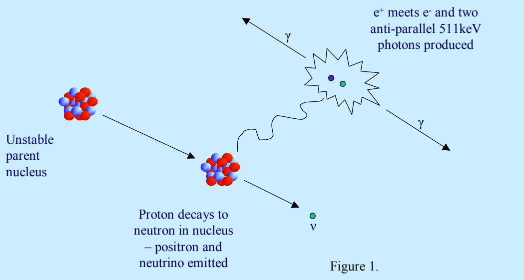


Figure 1.

What is PET?

Positron emission tomography (PET) is an in vivo method of imaging. In vivo meaning it images using a method of administering a radioactively labelled compounds that will have an uptake in the organ/function of interest in the body. The radioactive isotope will decay from inside the body henceforth the decay products can be detected outside of the body and reconstructed to give imaging information.

PET is a particular type of imaging that uses a specific nuclear decay to a positron. An unstable parent nucleus will decay emitting a positron and a neutrino. The positron will travel a short distance before meeting an electron and an annihilation event takes place. This event produces two back-to-back 511keV gamma rays. It is these gamma rays that are detected in PET.

Planar Germanium Detector

The prototype detector for the imaging project was the GREAT planar detector, on loan from the GREAT spectrometer. The detector is a 24 x 12 germanium orthogonal strip detector. The crystal is fully depleted at +600V and operating voltage is +800 V.

A 5mm safeguard ring surrounds the full rectangular anode and is connected to the polarisation voltage. Similarly, the cathode has a 5mm safeguard ring; connected to the ground.

Figure 2.

Anode configuration

- Lithium diffusion: 0.7mm deep
- 12 horizontal strips
- Strip width: 5mm
- Inter strip distance: 0.7mm

Cathode configuration

- Boron ion implanted: $0.3x10^{-3}$mm deep
- 24 vertical strips
- Strip width: 5mm
- Inter strip distance: ~0.1mm

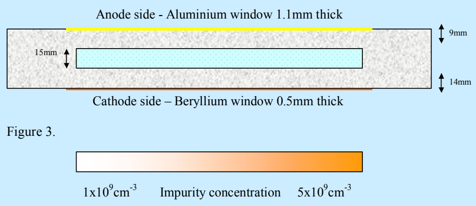


Figure 3.

The detector casing is aluminium with a thin (0.5mm) beryllium window in front of the boron implanted side (cathode) and a thin (1.1mm) aluminium window on the lithium diffused side (anode).

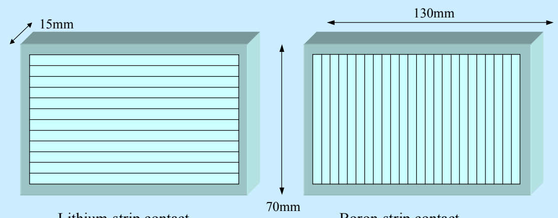


Figure 4.

Position Sensitivity

Orthogonal strips on either side of the detector allow the positioning of an interaction in two dimensions to at least the width of the strips, 5mm x 5mm for the GREAT planar. Extra positional information beyond the strip width and into the detector volume can be gained by using pulse shape analysis techniques.

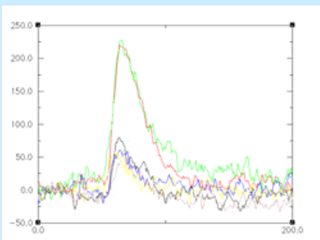


Figure 17.

Image Charge Analysis

A real interaction in one strip induces transient signals on the adjacent strips. The size of these transient signals depends on the position, relative to the strip boundary, of the real interaction. This provides a method of improving position sensitivity to less than a strip width. Those image charges shown in Figure 17. are from both sides of the detector, cross talk is apparent.

The depth of the interaction into the detector volume will be determined using one of the two following methods.

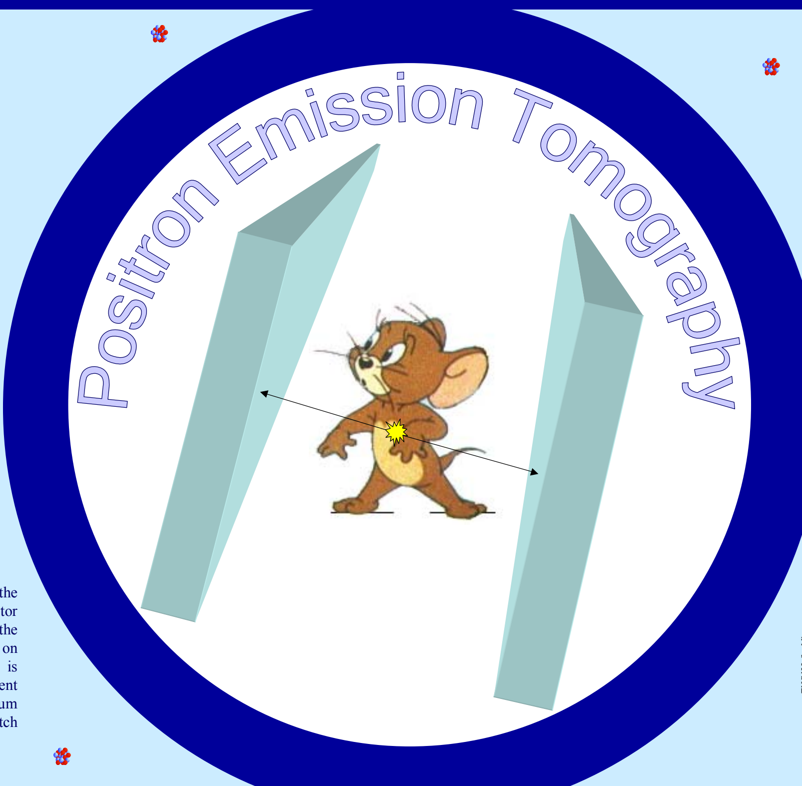
Rise Time

Different interaction positions in a HPGe detector produce different shaped charge pulses. To discriminate between the shapes of the pulses, hence the interaction position, the shape of the pulse can be quantified by its rise times. Usually these are the times taken for the charge pulse to reach 30, 60 and 90% of its maximum height.

OR

Time Difference

Another method of determining the depth of interaction in a planar detector is the difference in time it takes for the electrons and holes to be collected on opposite sides of the detector. This is only possible because of the excellent energy resolutions of germanium detectors making it possible to match events on both contacts.



Analogue Performance

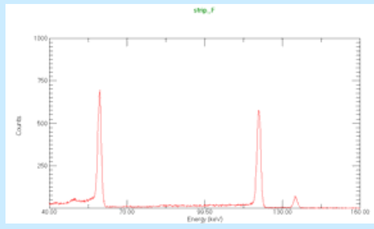


Figure 5.

The analogue performance of the GREAT planar was tested on arrival at Liverpool in December 2002.

The energy spectrum in Figure 5. was collected during a calibration run using Am-241, Co-57 and Cs-137. Strip F shown is a centre horizontal strip; low energy tailing can be seen on the photopeaks.

The energy resolutions were found using a shaping time of 3µsec and baseline restore high due to the sensitivity of the detector to microphonics.

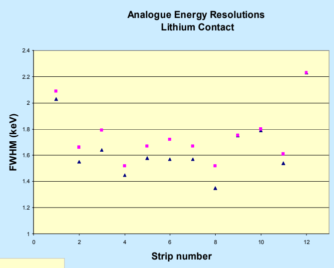


Figure 6.

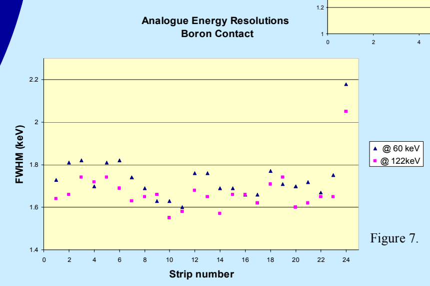


Figure 7.

The strip resolutions vary between 1.6–1.8keV with the exception of the contacts edge strips, whose resolutions worsen at the edges to between 2.0–2.3keV, both using 60keV and 122keV photopeaks.

Results

A 2-D intensity per position plot is shown in Figure 16. This was produced from the coarse scan data; 2mm collimator, 2mm steps and 3 minutes/position. It was demanded that only 122keV gamma rays were included, i.e. a tight energy gate was placed for photopeak interactions. A collimated source was passed across the surface of the detector; passing across strips and strip boundaries. From the intensity variations on the plot it is apparent that there may be charge sharing between the strips. This effect will be investigated more by looking more closely at one strip using the fine scan data shown in Figure 14.

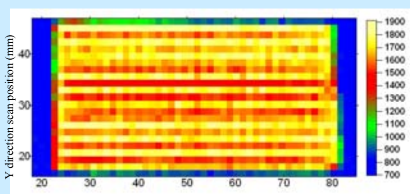


Figure 16.

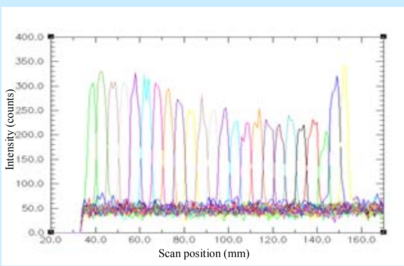


Figure 14.

A magnified plot of the intensity per position from the fine scan data can be seen in Figure 15. The fine scan was acquired using a 1mm collimator, 1mm steps and staying at each position for 5 minutes. The central overlap area shows the spread of the beam from the collimator and will be taken into account when determining the charge sharing between the strips.

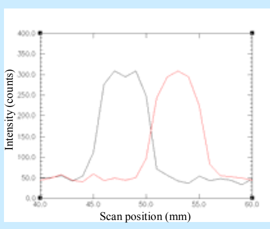


Figure 15.

Figure 13. shows the detector fold. It can be seen that on both the AC and DC contacts the highest fold is 1 (~80%). A one percent difference between the events collected on the two contacts has been observed; the one percent losses occurring on the DC contact. The FADC's (event-by-event fold) show a majority of 69% of all events/interactions within the detector, having fold 2.

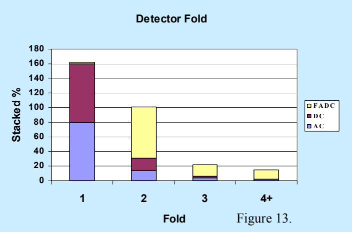


Figure 13.

Tests for cross talk were performed using a pulsar into the test inputs on both contacts of the detector. Figure 12. shows an induced charge on an adjacent strip to the input signal on the AC contact. Cross talk is observed as a shift in the baseline. The same test performed on the DC contact proved to be inconclusive within the observed noise. Another measure for cross talk is to add back scatters from adjacent and non-adjacent strips, shifts in the photopeak of the adjacent add-back spectra are attributed to cross talk. Figure 11. shows spectra from fold 1 (AC and DC) detected events and fold 2 (DC). The black plot is the fold 1 spectrum, which is used for reference. The red and blue plots are fold 2 add-back spectra; adding back scatters from adjacent and non-adjacent strips respectively. The adjacent 662keV photopeak shows a 3keV downward shift in energy. This is also true for the AC contact strips, not shown.

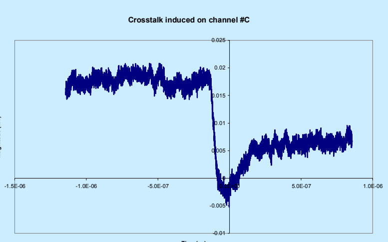


Figure 12.

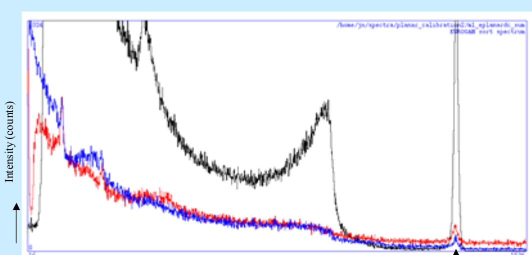


Figure 11.

Scanning and digitized pulseshapes

To improve the position sensitivity of a detector using pulse shape analysis a scan must be made of the surface of the detector. This will enable a calibration of the pulse shapes and variations in charge collection to be found. A schematic of the scanning apparatus used for the GREAT planar is shown in Figure 8.

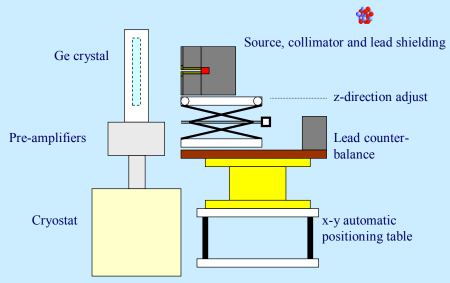


Figure 8.

Scan set-up for the GREAT planar detector

The pre-amplifier signal from the detector must be digitized for pulse shape analysis to be used. This was achieved using GRT4 VME cards developed be Daresbury Laboratory. Each card has four channels, each containing:

- 14 bit 80Mhz FADC (flash analogue to digital converter)
- Two dedicated Xilinx Spartan 2 FPGAs
- First contains circular buffer, traces in this buffer are tagged with 16 bit header and 48 bit timestamp
- Second is used to for data processing
- Cards can be used in either a differentiated or non-differentiated configuration.

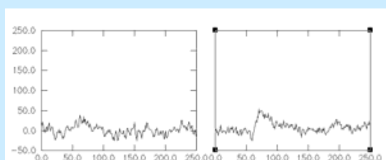


Figure 10.

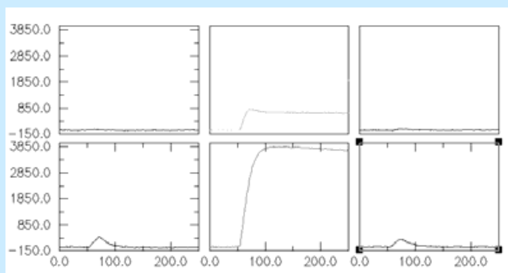
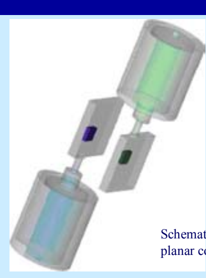


Figure 9.

Example pulse shapes can be seen in Figures 9. and 10. Figure 9. shows a 662keV photoelectric interaction within the detector. The full energy event can be seen on one of the DC strips; shown with its adjacent strip image (transient) charges. The energy for the same interaction has been collected over two of the AC strips. The image charges on the AC strips are considerably smaller than those on the DC strips; Figure 10. is a magnification of these image charges.

Further Work

Further work on the GREAT planar detector will include full image charge and rise-time analysis to conclude the calibration of the crystal volume. The detector is being characterized in parallel to an EXOGAM clover detector. The results of both detectors will be combined to test measurements made with the two detectors in a Compton camera configuration.


Schematic of two-planar configuration

The project has now commissioned three planar germanium strip detectors that will begin arriving in late 2003. Each of the detectors will have an active area of 60x60 mm^2. These detectors will allow the investigation of the feasibility of using this type of detector for improving small animal PET and will also be used in a Compton Camera configuration to investigate their use for Single-Photon Emission Computed Tomography (SPECT).