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Characterisation of a Si(Li) orthogonal-strip detector

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ABSTRACT

A Compton camera composed of an orthogonal-strip Si(Li) detector and an orthogonal-strip HPGe SmartPET detector is under investigation at the University of Liverpool. To optimise the performance of the system, it is essential to quantify the response of the detectors to gamma irradiation. Such measurements have previously been reported for the SmartPET detector and in this work we report on the experimental characterisation of the Si(Li) detector. Precision scans of the detector have been performed using a finely collimated ^{241}Am gamma-ray source to determine the uniformity and charge collection properties of the detector.

1. Introduction

A device that is capable of the precise identification and localisation of illicit nuclear materials is highly desired by threat detection agencies. Compton cameras are one such tool that can be deployed to identify and locate sources of gamma radiation [1–3]. Using this technology, gamma-ray spectroscopy techniques are employed to identify and locate the radiation source via the detection of characteristic gamma rays that deposit their full energy in the system. The interaction positions and energies are recorded for each fully absorbed gamma ray that interacts at least twice in the system, so that the well understood kinematics of Compton scattering can be used to reconstruct the gamma-ray path along a conical surface. Images showing the conical surfaces generated from many gamma rays are produced, and the radiation source location is identified as the maximum intersecting region of conical surfaces.

The system based at the University of Liverpool is composed of an 8 mm thick orthogonal-strip lithium-drifted silicon (Si(Li)) detector and a 20 mm thick orthogonal-strip High Purity germanium (HPGe) SmartPET [4] detector. The detector materials have been chosen due to their relative probabilities of Compton scattering and Photoelectric absorption of gamma rays with incident energies in the range 60 keV to 2 MeV, so as to maximise the probability that incident gamma rays will Compton scatter in the first detector and be fully absorbed in the second. The detectors also provide excellent energy resolution, low electronic noise levels and a low Doppler broadening [5] contribution by the Si(Li) detector to image degradation. Characterising the response of the detectors to gamma irradiation is essential to maximise the potential performance of the system. Several investigations have previously been undertaken for the SmartPET detector [4,6]. In this paper, we report on the experimental performance of the Si(Li) detector.

2. Experimental setup and methods

2.1. Detector specification

The Si(Li) detector was manufactured by Canberra France, and is shown in Fig. 1. Its unique design combines both proven technologies such as the low vibration and high reliability pulse-tube cryocooler (CANBERRA CryoPulse CP5), and new specialist developments such as the cryostat chamber configuration, which allows for a large number of electronic channels and minimum shielding materials.

The Si(Li) sensor has an active area of 3500 mm^2 and a depth of 8 mm, surrounded by a 5 mm guard ring, also of 8 mm depth. The crystal has a depletion voltage of +150 V and was operated at +430 V throughout the investigation. The detector is electronically segmented through orthogonal strips to give 13 AC (p-type) and 13 DC (n-type) contact strips with a strip pitch of 5 mm and separation of 500 μm, which provide position of interaction information. The strips have a length that varies according to location on the detector surface, as shown in Fig. 2. Each of the 26

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strips is instrumented with a charge-sensitive Canberra preamplifier, which has a cold FET (Field Effect Transistor) configuration and gain of 500 mV/MeV.

2.2. Detector performance

Utilising a scatter detector with excellent energy resolution is vital for good performance in Compton imaging, as the energy resolution can provide a significant source of uncertainty in the projected apex angle in the formation of conical surfaces, which results in a blurring of the reconstructed image [7]. A preliminary assessment of the energy resolution for each channel of the Si(Li) detector has been presented previously [8] and the present work aims to provide further detail. Therefore, the energy resolution of each channel of the Si(Li) detector has been measured using data acquired with a ^{241}Am source. Analogue electronics were used to process the preamplifier signals by sequentially inputting them to an Ortec 671 spectroscopy amplifier, with 6 μs shaping time. The output of the amplifier was then input to an Ortec ASPec-927 Multi Channel Analyser. The Full Width at Half Maximum (FWHM) of the 59.6 keV ^{241}Am photopeak was calculated from the acquired energy spectra and the results are presented in Fig. 3. A uniform distribution for each detector face can be seen for all channels, excluding DC01, which is a dead channel. The average energy resolution for the DC channels was measured to be 1.17 keV, with a maximum deviation from this value of 11%. The AC channels have a slightly elevated energy resolution, with a mean of 1.47 keV but a reduced maximum deviation of 7%.

The presence of high noise levels in the scatter detector of a Compton camera can significantly impact the sensitivity to low energy gamma rays, for example a 5 keV energy threshold is expected to yield a loss of 25%, for 141 keV gamma rays [8]. Typical sources of noise include electronic components such as the FETs, the capacitance of the strip segment, as well as mechanical vibration from the cooler. The peak-to-peak noise levels were measured in previous work to be approximately 2 keV for the DC channels, excluding DC02 which was 3.5 keV, and 2.5 to 4.5 keV for the AC channels [8]. These results are presented in Fig. 4, for completeness. It is suggested that the elevated noise measured for the DC02 channel is due to its proximity to the neighbouring DC01 channel, which is dead. These results are within the desired specification of 5 keV and therefore the reduction in sensitivity to low energy gamma rays in Compton imaging will be minimum.

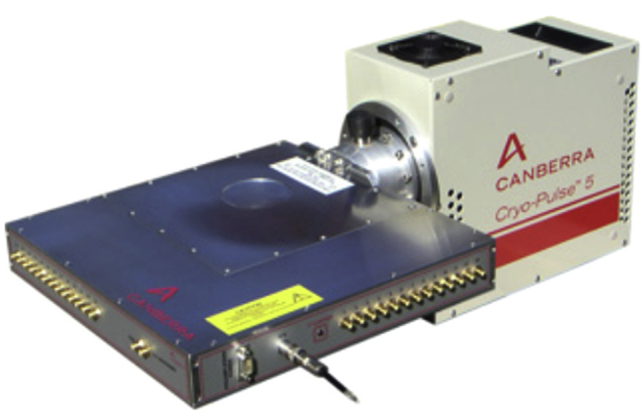

Fig. 1. Photograph of the Si(Li) detector and cryocooler.

2.3. ^{241}Am scan setup

Precision scans have been undertaken to quantify the detector response to gamma irradiation as a function of interaction position. An automated Velmex VXM X–Y positioning table was used to scan the detector by moving a 1 mm collimated ^{241}Am source in 1 mm steps, with a precision of 100 μm. The 26 preamplifier outputs of the AC and DC channels were input to four, ten-channel GRETINA digitiser cards [9], which digitised the signals using 14-bit, 100 MHz ADCs over an input range of ± 1 V. The acquisition was triggered using a logical OR of the 13 DC preamplifier outputs, so that pulse shape and energy data from all strips were only recorded when the energy deposited in at least one DC channel was more than the 10 keV CFD threshold.

2.4. Experimental measurements

Data sets have been acquired for the 1 mm collimated ^{241}Am source incident on the side (across the depth) and charge collecting faces of the detector. The detector was initially irradiated with the source scanned across the detector side in 1 mm steps of a 76×16 mm grid along the x–z axes, to investigate the depth of interaction sensitivity. The geometry of the side scan was such that the gamma rays were incident parallel to the DC channels, perpendicular to the AC channels and so that they entered closest to AC01. The co-ordinate system used in the measurements is shown in Fig. 2.

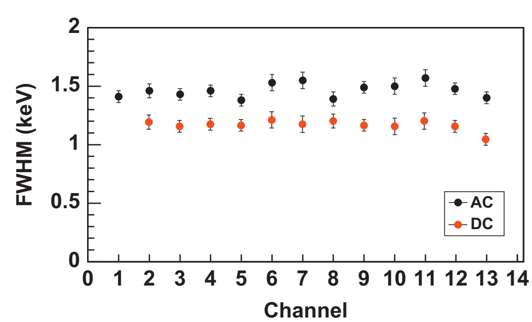

Fig. 3. Energy resolutions measured at 59.6 keV for each channel of the Si(Li) detector.

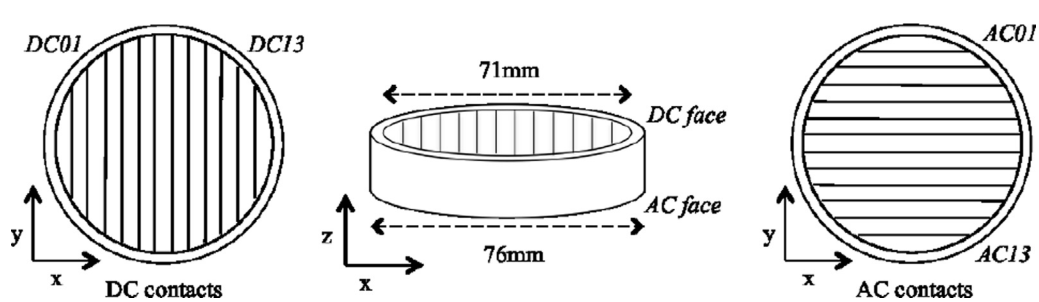

Fig. 2. Schematic diagram of the Si(Li) detector, depicting the electrode segmentation of the AC and DC contacts and defining the co-ordinate system used for characterisation measurements.