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An experimental characterisation of a Broad Energy Germanium detector

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ABSTRACT

The spectroscopic and charge collection performance of a BE2825 Broad Energy Germanium (BEGe) detector has been experimentally investigated. The efficiency and energy resolution of the detector have been measured as a function of energy and the noise contributions to the preamplifier signal have been determined. Collimated gamma-ray sources mounted on an automated 3-axis scanning table have been used to study the variation in preamplifier signal shape with gamma-ray interaction position in the detector, so that the position-dependent charge collection process could be characterised. A suite of experimental measurements have also been undertaken to investigate the performance of the detector as a function of bias voltage and we report on anomalous behaviour observed when the detector was operating close to the depletion voltage.

1. Introduction

Broad Energy Germanium (BEGe) detectors are commercially available detectors that can be used to detect gamma rays in the energy range of 3 keV–3 MeV. The detectors offer excellent energy resolution and low noise performance due to a low electrode capacitance of $\sim$1 pF, which is a result of their unique electrode structure. BEGe detectors are used in a wide variety of commercial applications [1,2], including environmental sample counting, dosimetry and characterisation of nuclear waste, as well as in academic research, such as the GERDA [3] project.

We have measured the spectroscopic performance of a standard BEGe detector and experimentally characterised the charge collection processes through pulse shape parameterisation. The motivation is to develop novel background rejection algorithms which utilise knowledge of the position dependent pulse shape response to improve the minimum detectable activity for low energy gamma rays. The first stage of the project is to characterise the pulse shape response for BEGe detectors of various sizes, which will facilitate algorithm development. In this paper, we report on the experimental characterisation of the first detector.

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2. Detector configuration

The detector under investigation is a BE2825 detector, which is manufactured by CANBERRA [4]. The p-type High-Purity Germanium (HPGe) detector has a cross-sectional area of 28 cm^2 and a thickness of 26 mm, which is slightly more than the nominal BE2825 thickness of 25 mm. A schematic illustration of the detector configuration is shown in Fig. 1. The detector is mounted inside an aluminium cryostat so that the top face is 5 mm beneath a 0.6 mm thick carbon epoxy entrance window. Transmission as low as 10 keV is facilitated by the entrance window. The reported depletion voltage of the detector is +3500 V and the recommended operating voltage is +4000 V. The unique electrode structure is such that a lithium-drifted n+ contact surrounds the crystal, excluding a region at the centre of the detector bottom, where a boron-implanted p+ contact is located. Following a gamma-ray interaction, electron–hole pairs are generated and swept through the detector in a trajectory defined by the electric field. The holes are collected at the p+ contact on the bottom of the detector, whilst the electrons move towards the n+ contact. The signal generated on the p+ contact is read out by a CANBERRA 2002CSL charge-sensitive preamplifier with a gain of 100 mV/MeV.

The shape of the preamplifier signal is defined by the weighting potential inside the detector. The instantaneous current i induced on the p+ contact by the motion of charge carriers through the

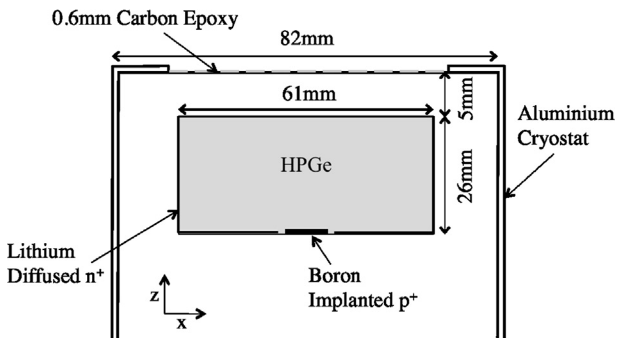

Fig. 1. Schematic diagram of the detector and cryostat. Materials within the cryostat are not shown as the configuration is unknown.

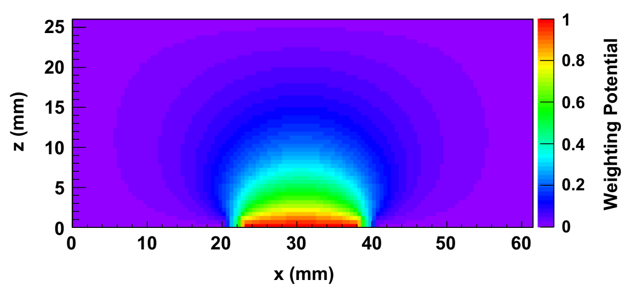

Fig. 2. Weighting potential calculated for a BE2825 detector. The plot shows a cross-sectional view through the symmetry axis.

detector can be calculated using the Shockley Ramo Theorem [5,6],

$$i = q\vec{v} \cdot \vec{E_w} \tag{1}$$

where $\vec{v}$ is the velocity of a carrier of charge q and $\vec{E_w}$ are the weighting field. The induced charge Q on the electrode can be calculated with knowledge of the variation in weighting potential φ_0 across the charge carrier path,

$$Q = q\Delta\varphi_0. \tag{2}$$

The weighting potential in the BE2825 detector has been calculated using the AGATA Database Library (ADL) [7] and the corresponding map through the symmetry axis is shown in Fig. 2. It can be seen that the weighting potential is weak in the bulk of the detector, excluding the region close to the p+ contact. For gamma-ray interactions that occur close to the n+ surface contact, the induced signal will initially be small whilst the holes drift towards the p+ contact, then will rise sharply as the charge traverses the region of increased weighting potential. In contrast, the signals generated for interactions close to the p+ contact are expected to initially have a fast leading edge, followed by a period of slower charge collection. The position dependent response of the preamplifier signals has been investigated experimentally and is described in detail in Section 4.

3. Spectroscopic performance

The spectroscopic performance of the detector has been measured, when biased at the recommended operating voltage. The charge-sensitive preamplifier signal was input to an Ortec 671 spectroscopy amplifier with a shaping time of 6 μs and was pole zero corrected. The noise level was measured to be 1 mV_{pp}, which is excellent for a germanium detector due to the low capacitance of the p+ readout contact. The absolute efficiency and energy resolution (Full Width at Half Maximum (FWHM)) were measured using uncollimated gamma-ray sources ^{241}Am; ^{137}Cs; ^{60}Co and ^{152}Eu, independently positioned 25 cm above the centre of the entrance window. Analysis was only carried out for photo peaks which corresponded to a gamma ray with emission probability greater than 2%.

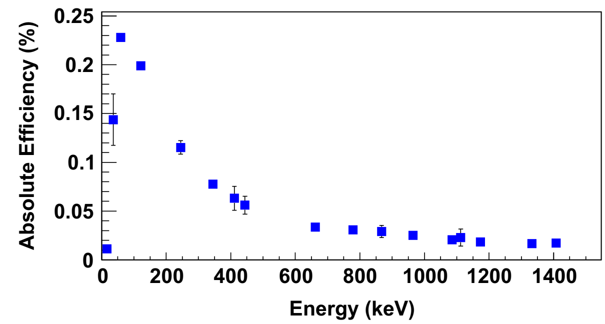

Fig. 3. Absolute efficiency as a function of energy.

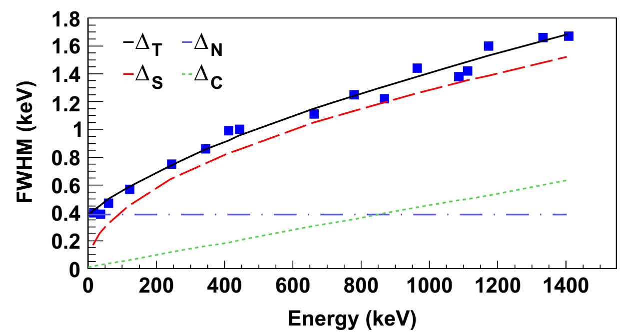

Fig. 4. Measured energy resolution (FWHM) as a function of energy. The curves show the calculated contributions to the total FWHM, Δ_T, where Δ_N, Δ_S and Δ_C represent the contributions due to electronic noise, statistical fluctuations in the number of produced charge carriers and incomplete charge collection, respectively.

3.1. *Absolute efficiency*

The measured relationship between absolute efficiency of the detector and gamma-ray energy is presented in Fig. 3 and is typical of a germanium detector, such as those compared in Ref. [4]. In the plot, the absolute efficiency increases as a function of energy until it reaches 0.23%, at the turning point of 59.6 keV. In this energy region, the probability of transmission through the cryostat entrance window and n+ contact increases as a function of energy and for those gamma rays that pass through, there is a high probability of absorption in the detector. Beyond this turning point, the absolute efficiency decreases as a function of energy, as absorption within the detector becomes less probable for the higher energy gamma rays.

3.2. *Energy resolution*

The energy resolution has been plotted as a function of energy in Fig. 4. The FWHM increases from 0.5 keV at 59.6 keV to 1.7 keV at 1408.1 keV and is slightly improved over the manufacturer's specification, which was 0.7 keV at 122.0 keV and 1.7 keV at 1332.5 keV. A fit of $(FWHM)^2$ as a function of energy, E, has been produced using a second order polynomial:

$$(FWHM)^2 = 0.143 + (1.623 \times 10^{-3}E) + (1.977 \times 10^{-7}E^2). \tag{3}$$

The parameters of this fit can be used to quantify the factors which contribute to the total energy resolution Δ_T of a germanium