A position sensitive germanium detector for the measurement of angular deviation of annihilation radiation

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Abstract. To improve electron momentum sensitivity in Coincidence Doppler Broadening Spectroscopy (CDBS) measurements it is envisaged to measure the angular correlation of annihilation radiation along with the energy of both annihilation photons. For this purpose two position sensitive 36-fold pixelated, planar germanium detectors will be utilized. The position sensitivity of one of those detectors has been tested with a collimated gamma source. A data acquisition system consisting of 37 sampling analogue-to-digital converters with PC based on-line/off-line processing has been installed. A position sensitivity of 1.6 mm has been achieved.

1. Introduction

Currently two established positron annihilation spectroscopy (PAS) methods exist by which the momentum of the electron the positron annihilates with can be measured. Both measure different projections of the electron momentum. For Doppler Broadening Spectroscopy this is the longitudinal component derived from the energy of the annihilation quanta. Angular Correlation of Annihilation Radiation (ACAR) measures the angular deviation of both photons from 180° and therefore the full transverse component of the momentum.

Recent measurements with two germanium double-sided strip detectors (DSSD) by Williams et al. \cite{1, 2} yielded a position resolution of approx. 0.5 mm (FWHM) and showed that the coincident acquisition of the angular deviation along with the photon energy is possible with high resolution (0.5 mrad for the angular resolution and 1.63 keV for the energy resolution).

Milechina et al. \cite{3} showed that it is also possible to achieve a position resolution of 0.5 mm with a germanium detector whose front side has been pixelated into contacts of a size of 5 mm $\times$ 5 mm each.

To get a position resolution smaller than the size of a pixel it is necessary to analyse the induced charges that form especially in the next neighbour pixels during the time the charge carriers are travelling through the germanium crystal.

In this contribution we report on a test of the position resolution of a 36-fold pixelated, planar HPGe detector.
2. Experimental set-up
The germanium detector (Canberra EGPS 48*48*20-36 PIX) consists of a crystal with an active size of 48 mm × 48 mm and a thickness of 20 mm, which is located 5 mm behind a 1 mm thick aluminium window. On the front side the crystal is segmented into 6 × 6 pixel contacts (8 mm × 8 mm each). An additional contact on the backside of the crystal covers the full volume. Every single pixel as well as the full volume contact is connected to one of the 37 built-in, resistive, charge sensitive pre-amplifiers (Canberra PSC823C), with a decay constant of 50 µs. The pixels are specified with an (FWHM) energy resolution of 1.30 to 1.37 keV (mean value: 1.33 keV), and 2.80 keV for the full volume contact, at a photon energy of 662 keV. The pixel detector is operated at a bias voltage of +2500 V.

To determine the spatial resolution that can be achieved with the detector a collimated $^{137}$Cs gamma source (photon energy: 661.7 keV) mounted onto a x-y positioning stage with a travel range of 70 mm in both dimensions has been constructed. The collimator consists of two tungsten discs of a respective thickness of 20 mm and 10 mm stacked behind each other. A hole with a diameter of 0.8 mm has been eroded into the centre of both of them. The collimated source is mounted on a double axis stepper motor system (OWIS LTM 80) and can be positioned in front of the detector with a relative accuracy of 20 µm.

3. Electronic set-up
A fast data acquisition system has been set up for reading all 37 detector outputs and processing their signals at high count rates. The heart of the system is the 8-channel flash-ADC Struck SIS3302 whereof five modules are in operation for this detector. Each channel of the SIS3302 is sampling at a rate of 100 MHz, with a resolution of 16 bit per sample. These five modules are installed in a VME bus crate and can be accessed by a PC over a PCI Express to VME interface (SIS1100e/3104).

The signal height, and therefore the energy, of an event is calculated on a built-in FPGA on the ADCs using a moving average window algorithm with correction for the pre-amplifier’s decay time [4]. The trigger generated by the full volume channel is distributed to all other modules to trigger the pixel channels. Each channel then writes its event data to one of its two buffers. The data per event contain a time-stamp, a configurable length of raw data (0 to 1024 samples) and the calculated signal height. While the ADC is acquiring data into one buffer the other buffer can be read-out by the computer in the meantime. The maximum event rate feasible with this set-up depends on the number of raw samples saved per event. At 100 samples per event and channel approx. 9 kcps can be reached. By setting the trigger level of the full volume channel high enough to reject photons that didn’t deposit their full energy into the crystal, the use of the available bandwidth can be further optimized.

The data acquisition software on the computer is constantly polling all modules to check if a data buffer is full and then switching all modules through a VME broadcast at the same time to the other buffer. This ensures that the events in the channel buffers are synchronous to each other.

4. Data analysis
The acquired data is calibrated and processed on the computer. An in-house developed software analyses events that deposited energy in only one pixel and whose energies at the full volume contact and the pixel are in a range of 640 keV to 680 keV. These events are then analysed on-line but can also be stored for later off-line analysis.

When determining the position of the photon interaction in the detector one has to exclude pixels at the border of the active area of the crystal. Therefore only the inner 4 × 4 pixels are considered.
The acquired raw samples of all eight neighbours of the pixel of interest are then smoothed with a moving average algorithm. From the maximum value of such a smoothed signal its first value is then subtracted, to correct its offset. This difference corresponds to the height of the influence signal in the eight next neighbour pixels.

To get the position within the pixel in x direction the height of the influenced signals of the left ($I_l$) and the right ($I_r$) neighbour is used, whereas for the y direction the corresponding signals from the top ($I_t$) and bottom ($I_b$) neighbour pixel is taken.

The x and y positions within the pixel are calculated as the logarithm of the ratio of the relevant neighbour pixel intensities according to:

$$x = \log \left( \frac{I_r}{I_l} \right) \quad \text{and} \quad y = \log \left( \frac{I_t}{I_b} \right).$$

The positions are then added to a two-dimensional histogram when the sum of all eight next neighbour pixels exceeds an adjustable threshold.

5. Measurements
To test the position resolution, data has been acquired with the collimated source at several positions in front of the detector. Fig. 1 shows the two-dimensional histogram of events analysed with the algorithm described above. The sub-pixel coordinates x and y have been scaled with a constant factor before being added to the global coordinates X and Y of the respective pixel. This has been done to prevent overlapping of two adjacent pixels. In fig. 1 the collimated source has been positioned near the centre of pixel 22. When comparing the counts in pixel 22 and its next neighbours a background of 20% can be attributed to photons not being stopped in the tungsten.

Fig. 2 shows in detail two two-dimensional histograms of events within pixel 22. For both histograms the source was at the same y position but the x positions differ by 2.0 mm. Fig. 3 shows the projection of the events to the x axis.

For estimating the lateral resolution a Gaussian has been fitted to both projected histograms. With the known distance of 2.0 mm between both positions and the width of the Gaussian fit, a position uncertainty of $\Delta x = 1.6$ mm (FWHM) can be calculated.

Simulations with Geant 4 suggest a spread of the photon interactions in the crystal of approximately 1.07 mm. Assuming a gauss-like distribution would result into an x resolution of the detector of $\Delta x = 1.2$ mm.
6. Conclusion
A data acquisition system for a 36-fold pixelated HPGe detector has been developed and successfully tested. It enables sub-pixel resolution by analysing the influenced charges in the next neighbour pixels. The test measurements with a collimator with a relatively large aperture have shown that a lateral resolution of 1.6 mm can be reached. The actual value of the detector’s position resolution should be even better.

Used in coincidence with the second pixelated detector, this resolution will already be sufficient to improve the momentum information contained in CDBS experiments.

Acknowledgments
The authors want to thank Wolfgang Engl and Ricardo Riedel for the installation of the translation stage and for the help at constructing the collimator holder.

Funding from the BMBF (Project 05K10WNA-Posimethod) is gratefully acknowledged.

References
[1] Williams C, Baker W, Burggraf L, Adamson P and Petrosky J 2010 Nuclear Science, IEEE Transactions on 57 860–869 ISSN 0018-9499
[2] Williams C, Burggraf L, Adamson P and Petrosky J 2011 Nucl. Instr. and Meth. A 629 175–184
[3] Milechina L and Cederwall B 2005 Nucl. Instr. and Meth. A 550 278–291 ISSN 0168-9002
[4] Lauer M 2004 Digital Signal Processing for segmented HPGe Detectors, Preprocessing Algorithms and Pulse Shape Analysis Ph.D. thesis