Development of Germanium Strip Detectors for Environmental Remediation[1]

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Abstract

We present the initial results of the first germanium strip detector array for the imaging and high-resolution spectroscopy of gamma-ray sources. The array consists of four detectors, 5 x 5 x 1 cm each with 25 strips on each side. The detectors are daisy-chained to hybrid preamplifiers to reduce the number of channels of electronics. Good spectroscopy and imaging are achieved. We also present results from the development of an amorphous germanium contact technology as an alternative to the lithium contact technology. A prototype 25 by 25 strip detector was manufactured with this new technology and demonstrates good spectroscopy and imaging.

I. Introduction

High resolution, position-sensitive germanium detectors offer excellent capabilities for the detection, identification and characterization of radioactive isotopes. These detectors provide enhanced capabilities over existing systems and have direct applicability in the areas of Decontamination and Decommissioning (D&D), Nuclear Materials, Spent Nuclear Fuel (SNF), Mixed Waste, as well as for basic laboratory nuclear physics and gamma ray astrophysics. Germanium strip detectors are made by segmenting the contacts of a planar germanium detector. The two-dimensional information is gained by segmenting orthogonally on each side of the detector. One dimension is determined by which strip is collecting the electrons and the other dimension by the strip collecting the holes. The energy measurement is obtained from the amplitude of either the electron or the hole signal.

These detectors can be used to create images of radioactive sources by placing them behind collimators or coded apertures. They can also be used in Compton cameras. The preferred method is dependent on the application: the source energy, dimension and intensity guide the choice of aperture. Intense sources can be heavily collimated but not weak ones. Diffuse sources are not well imaged with coded apertures but point sources are. High energy sources (> 1 MeV) are better imaged with a Compton camera because of the difficulty in making opaque masks or collimators at these energies.

We previously presented results from a germanium strip detector with 25 strips on each side (Inderhees et al., 1996, Phlips et al. 1996). We have now constructed the first array consisting of 4 such detectors and present initial test results with the array. We have also been developing the use of amorphous contact technology as an alternative to the Lithium contact technology (Luke et al, 1994, 1999).

II. Amorphous Ge Contacts

The goal of the amorphous contact effort is to extend the single element (pixel) amorphous technology developed by Luke et al. (1994, 1999) to double-sided orthogonal strip detectors. Amorphous contacts provide multiple advantages over the current lithium contact technology:

- It can achieve a finer pitch than with the Lithium diffusion technology
- The dead layer associated with the Lithium is eliminated
- It has the potential to reduce the cost of producing germanium strip detectors.
- It makes the detectors more resistant to temperature cycling.

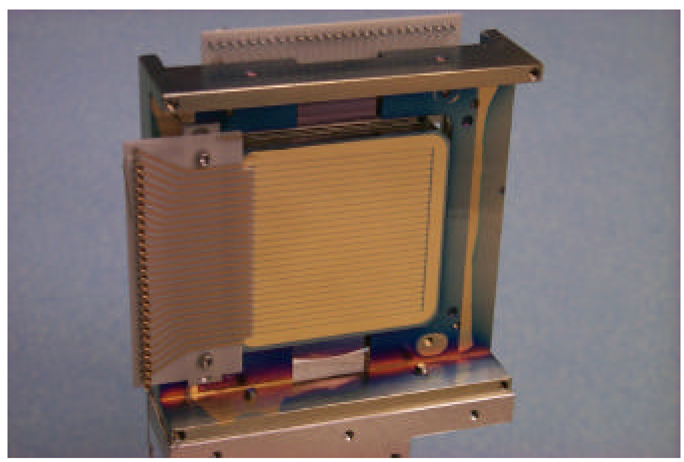

Figure 1. Germanium detector with amorphous contacts. Each side has 25 strips with 2 mm pitch and 5 cm length.Both sides have a guard ring. The detector is held by a germanium lip extending out beyond the guard ring.

We have fabricated the first orthogonal strip detector with dimensions appropriate for field use. The detector has an active volume of 50 mm × 50 mm × 10 mm and has 25 × 25

[1] The germanium strip detector development is supported by the Department of Energy Environmental Management Science Program.

strips (see Figure 1). The strips have a width of 1.8 mm and a pitch of 2 mm, leaving an inter-strip separation of 0.2 mm. Both faces of the detector have a guard ring that is ~ 5 mm wide. The detector is currently undergoing tests. The resolution is ~2.5 keV FWHM, and is dominated by electronic noise. The noise is a little higher than normal because of the non-optimal cabling used with the test cryostat. A spectrum from an ^{241}Am source obtained from a single strip is shown in Figure 2. This strip has an energy resolution of 2.3 keV. The left shoulder on the peak is not due to charge collection problems, but is due to scattering in passive material between the source and the detector. Higher energy gamma rays are not as sensitive to this material, as shown in Figure 3. The figure shows a spectrum from a ^{137}Cs source as measured by a strip.

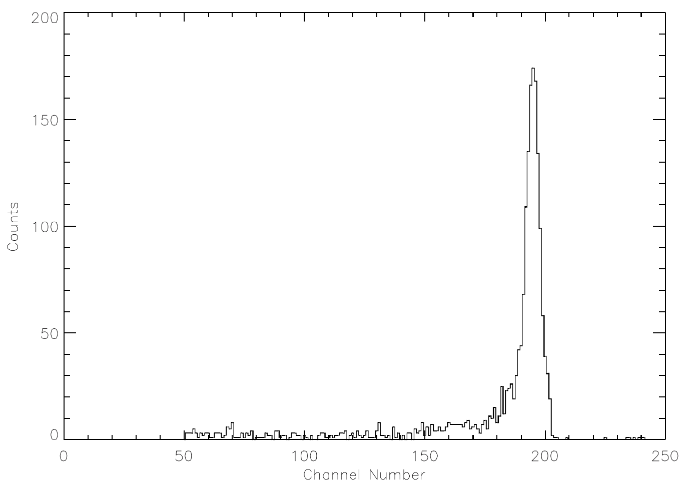

Figure 2: Spectrum of 60 keV photons from ^{241}Am as detected by a single strip. The low energy shoulder is due to passive material between the source and the detector.

The narrow photopeak still has ~2.5 keV energy resolution but the left shoulder is gone. The photopeak to Compton shelf ratio is small because this spectrum is from a single 2 mm wide strip.

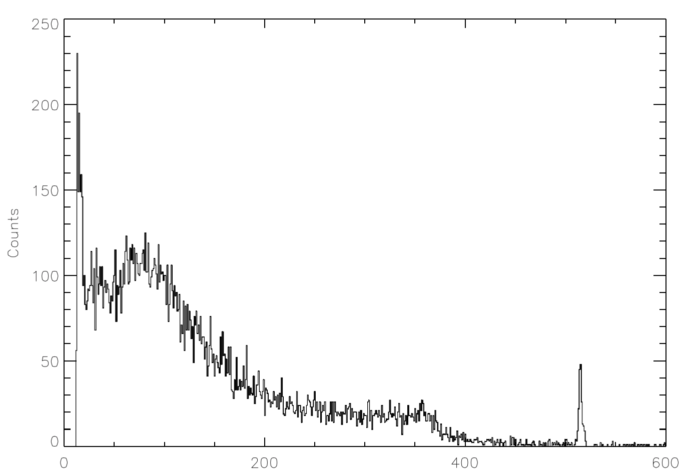

Figure 3: Spectrum of 662 keV photons from ^{137}Cs as detected by a single strip in amorphous-contact detector. Combining energies from multi-strip events increases the "photopeak" to Compton ratio.

To demonstrate the position resolution, we scanned a collimated ^{241}Am beam across a number of strips starting at one edge. The source was collimated in one dimension to be 500-600 micron wide, and was un-collimated in the other dimension. The source was scanned in steps of 203 microns across the detector. The resulting normalized count rates in the various strips are shown in Figure 4. The 2 mm strips are clearly mapped by the source, including the edge strip. The roll-off between strips is mainly due to the width of the collimated beam and to a small rotational misalignment between the strip direction and the collimator. A more detailed study of the events incident between 2 strips still needs to be done.

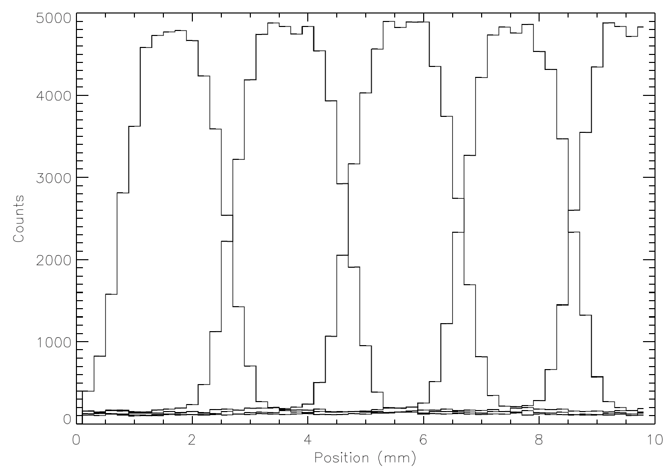

Figure 4. Scan of 60 keV photon beam across a face of the detector. The ~500 micron-wide beam was scanned in steps of ~ 200 microns. The leftmost strip is the edge strip, showing no strip distortions even for the edge strip.

Comparing the performance of this detector to our previous generation of detectors with identical strip geometry but different contact technology, we can see no difference in performance between the amorphous contacts and the standard combination of lithium and boron contacts. Further tests include studying the temperature dependence of the detector performance, studying the inter-strip charge sharing, and monitoring the sturdiness of the contacts through several annealing cycles.

III. Detector Array

We acquired a 2×2 array of germanium strip detectors with conventional lithium and boron contact technology. The array was built by Eurisys Mesures of France. The individual detectors have an active volume of 50 mm $\times$ 50 mm $\times$ 10 mm and have 25 strips on each side. The full array in its cryostat is shown in Figure 5. The array is readout using 100 commercial hybrid preamplifiers, NIM shaping amplifiers, CAMAC ADCs and a PC. For the first time, this array tested the possibility of daisy-chaining strips while still achieving excellent spectroscopy.

The energy resolution is ~2.5 keV FWHM on individual strips as expected, proving the possibility of daisy-chaining.

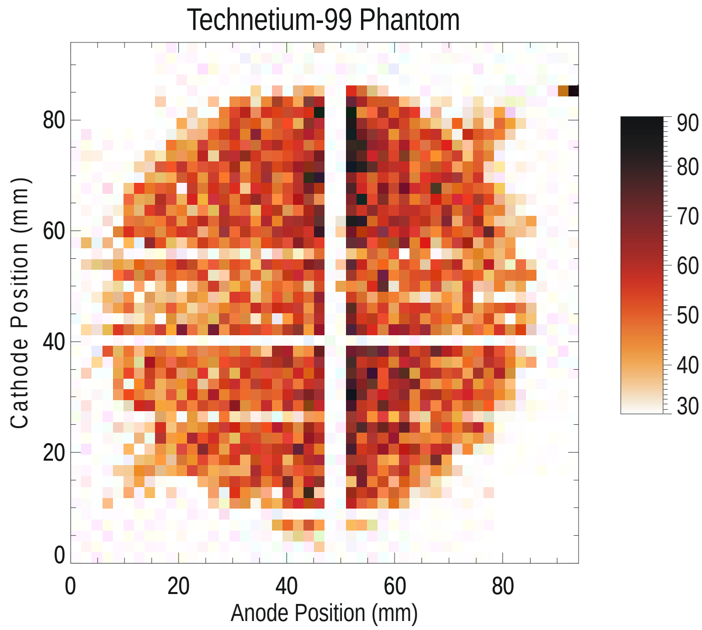

Figure 6. Image of ^{99}Tc phantom measured at 140 keV with the detector from the previous figure and a collimator. Uniform disk of 8 cm diameter of source material. Fill tubes are seen in upper right and lower left corners.

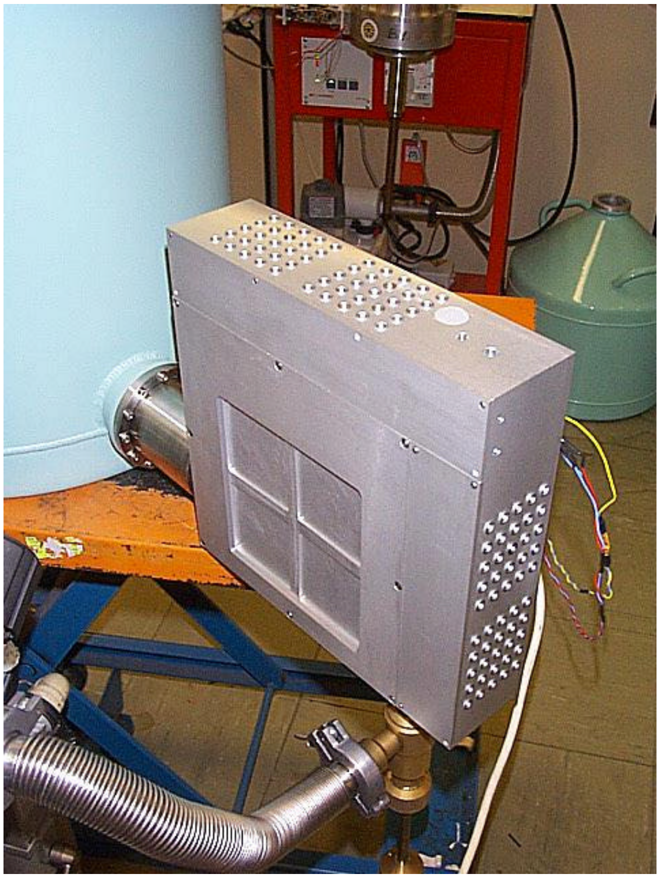
Figure 5: Array of 4 Ge detectors in cryostat. The 2 x 2 array has 2 mm position resolution. The strips are daisy-chained on both faces of the detector. Hybrid preamplifiers are mounted next to the detector, inside the metal box but outside the cryostat.

There is a small difference in the amplitude of the pulse heights depending on which detector in a daisy-chain was hit. This effect is being investigated but is probably due to a slightly different capacitance between the strips on the different detectors.

We designed and manufactured a tungsten collimator to use in conjunction with the detector array. The collimator is a parallel hole collimator, meaning it neither magnifies nor shrinks the size of the pixels from the source to the detector. This collimator therefore images objects of the same size as the detector. Other collimators can be manufactured as the applications demand. The collimator has a two-dimensional pattern of 400 micron square holes, with a pitch of 500 micron. The collimator was 0.6 cm thick. Since the pitch is much smaller than the strip pitch on the detector, the collimator does not have to be aligned accurately with respect to the detector.

The image of a medical phantom with a circular pattern (8 cm diameter) filled with ^{99}Tc is shown in Figure 6. The protrusions on the top right and bottom left of the circle are real. They are created by notches in the phantom cavity that were also filled with the radioactive ^{99}Tc. The vertical strip of low flux in the image at ~45 mm is caused by a structural support in the cryostat that blocks two of the strips. The horizontal strip at ~40 mm is caused by a bad channel on the detector. This will be corrected when the detector is refurbished later this year.

IV. Laboratory Demonstrations

We have started testing the 2×2 germanium array in the laboratory and have demonstrated good spectroscopy and imaging with various isotopes. As an initial test of the system with isotopes of interest to the end users, we imaged a piece of uranium (^{235}U). The piece, shown in Figure 7, was roughly rectangular, with dimensions of ~2 by 3 cm.

The image shown in Figure 8 was obtained using the collimator and detectors described above, and selecting a narrow energy window around the 185 keV line in the measured spectrum (Figure 9). The shape of the imaged object is clearly reconstructed, as expected. This energy windowing capability is essential for isolating and imaging a particular element, especially in a high background environment. A similar demonstration is also planned with a ~1 cm cube of plutonium (^{239}Pu). The plutonium measurements will be done with a thicker (1.2 cm) version of the collimator.

V. Discussion

The goal of this program is to develop reliable high-resolution detectors of useful size to address a broad range of environmental remediation needs. To this end we have demonstrated that amorphous contact technology provides the same quality detectors as conventional contact technology. We

Figure 7. Photograph of ^{235}U sample. The sample is ~ 2 by 3 cm, and is a few mm thick.

have demonstrated that multiple germanium detectors can be daisy-chained and preserve the energy resolution. We have also demonstrated that multiple strip detectors can be mounted in a common cryostat. Our next generation detector array will combine all these elements and increase the size of the detectors. We are planning to build a 2 x 2 array of detectors, each with active area of > 8 x 8 cm and a thickness of 2 cm. This will provide us with an active area > 250 cm^2 and an

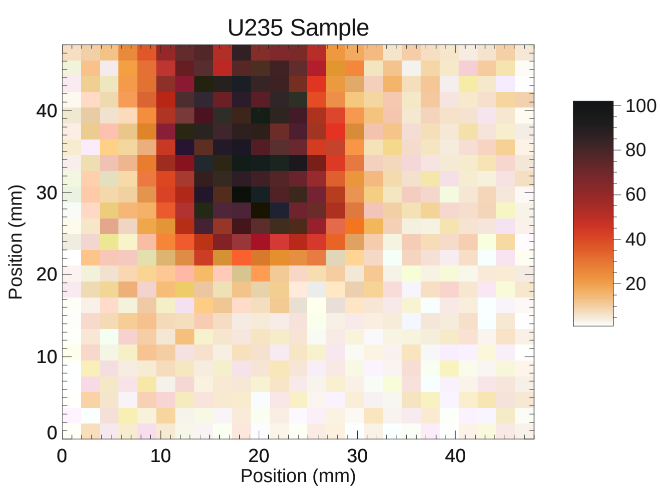

Figure 8. Image of ^{235}U sample from previous figure as measured in 185 keV gamma rays. Image pixels are 2 x 2 mm.

active volume of > 500 cm^3. This array will be the prototype for units that could be deployed in the field. The strip pitch is yet to be finalized depending on the most likely application. We are also planning to implement three-dimensional imaging in the array by using time of arrival techniques as demonstrated by Momayezi, Warburton and Kroeger (1999),

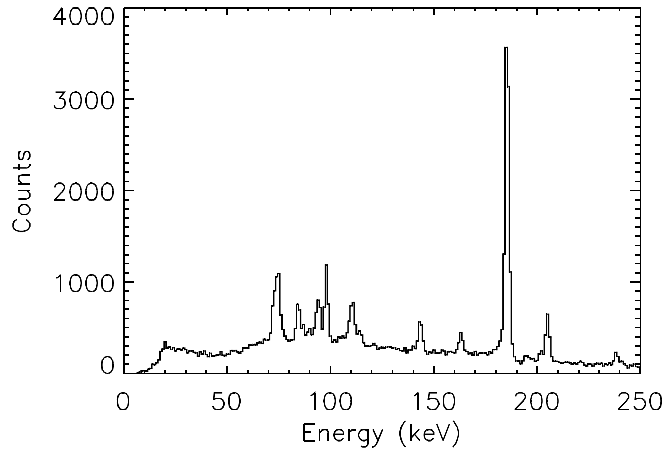

Figure 9. Complete ^{235}U spectrum measured while collecting the image in the previous figure. The image is in the gamma ray line at 185 keV only.

and by Amman and Luke (2000). The third dimension, the depth of an interaction within a strip detector, is determined by the relative time of arrival of electrons and holes on the two faces of the detector. This measurement is performed by using timing electronics on the preamplifier outputs and can achieve sub-millimeter accuracy. The hardware can be developed independently of the detector itself and can be retrofitted on existing detectors.

VI. Acknowledgements

We would like to acknowledge the help of E. Simson and J. Ampe in the design and construction of the electronics for the laboratory tests.

VII. References

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