Computer Physics
Communications

Development of a GAmma Ray BOx (GARBO)

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Abstract

Isomer decays, β-γ and electron-γ spectroscopy, α-γ fine structure studies, and Coulomb excitation are cases of nuclear structure experiments where the ideal detector is a compact, highly segmented, very efficient germanium (Ge) detector box. In order to develop such a structure, we are working on the R&D of large, segmented, High Purity planar Ge strip detectors (HPGeDSSD) which form the walls of such a box. We have developed a 92mm x 92mm x 20mm HPGeDSSD, which has 16 x 16 orthogonal strips of 5mm width. We are in the process of designing a focal plane detector for the Argonne Fragment Mass Analyzer (FMA) which consists of a 5 sided box, each side having a HPGeDSSD backed by a large segmented clover HPGe detector. MCNP simulations indicate this detector would have an efficiency of ~60% for 122 keV gamma rays and ~15% for 1.33 MeV radiation, which is ideal for studying the decays of nuclei far from stability that are usually produced with very low cross sections.

Keywords: Germanium Detectors; Gamma-ray spectroscopy; Monte Carlo simulations

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1. Introduction

The field of low-energy nuclear physics research is one where progress is intimately tied to technological developments. For example, advances in accelerator technology and highly selective mass separators are opening the way for the exploration of nuclei far from stability. Similarly, much of the recent progress in nuclear structure research has been powered by the development of large arrays of highly efficient germanium detectors. A prime example of a modern detector array is the national Gammasphere facility [1], which consists of 110 large High-Purity Germanium (HPGe) detectors surrounded by Bismuth Germanate (BGO) Compton suppression shields. This system is optimized for high-spin spectroscopy experiments, where there is typically a high multiplicity of gamma rays (~10-20) emitted in the decay of the nuclei being studied. The segmentation of the array is exploited to provide a highly selective trigger for high-multiplicity gamma-ray cascades and for good Doppler shift correction. On the other hand, as the research effort focuses on nuclei further away from stability where yields are low, multiplicities are small, and the ions may be slow moving or stopped, large arrays of Compton suppressed HPGe detectors may no longer be the optimum solution.

Isomer decays, β-γ spectroscopy, α–γ fine structure studies, electron-γ coincidence spectroscopy, and low-energy Coulomb excitation are examples of nuclear structure experiments where the ideal detector is a compact, highly segmented, efficient germanium detector box. For these types of experiments, it is essential to have large solid-angle coverage in order to have a high probability of detecting the few gamma rays that are emitted. A simple geometry consisting of a "box" of HPGe detectors in close proximity to the target is an effective way of implementing such a system. A disadvantage to using large detectors in close proximity is the possibility of multiple "hits" in the same detector. This problem can be solved by segmenting the detectors, which also allows some "tracking" of the γ rays to ensure that they originated from the center of the box and not from any background sources. This capability is very important for low cross section studies. The position sensitivity thus gained can also be used for the Doppler-shift correction of γ rays emitted from moving nuclei. In order to develop such a structure, we have been working on the R&D of large, highly segmented, High Purity planar Germanium strip detectors (HPGeDSSDs) which will form the walls of such a box.

2. The DSSD detectors

The DSSD detectors have been fabricated by Ortec and we have received 3 prototypes thus far. The HPGe crystal used in our latest prototype is shown in figure 1. The crystals are 92 mm x 92 mm x 20mm, and are segmented into 16 strips of 5.3 mm width on each side. The front face has boron implanted contacts about 0.6 micron thick while the back face consists of lithium implanted contacts 800 microns thick.

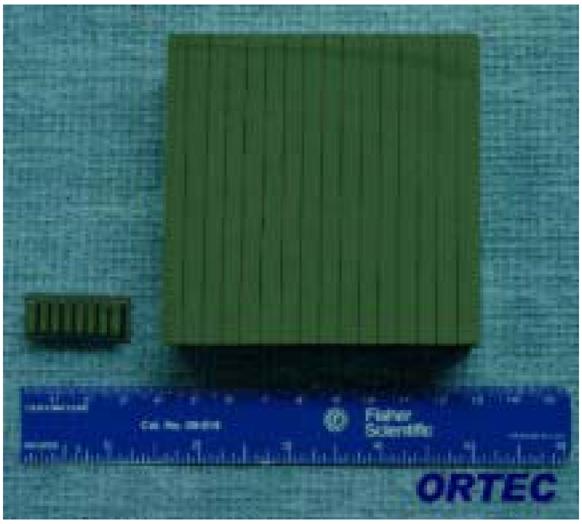

Fig. 1. Photograph of the HPGe crystal used in our DSSD detector. The vertical segmentation of detector is visible on the front face. The back face has orthogonal segmentation.

The performance of our latest detector prototype has been tested with collimated calibration sources and in an in-beam experiment. The tests show that the energy resolution and detection efficiency are good and relatively uniform across the segment strips. Our tests of digital pulse processing of real and image charges have clearly demonstrated the potential of locating interactions to better than 2 mm in all dimensions. The preamplifiers currently have warm FET's. Source measurements show that the resolution vs. strip number for the lithium side of the crystal is about 1.5 keV at 122 keV and about 2 keV for the boron side.

We have performed simulations to predict the gamma ray detection efficiency for the DSSD prototype using the Monte-Carlo code MCNP [2]. The simulations include the effects of the dead layers formed by the contacts on the crystal as well as the mechanical support structures and canning materials.

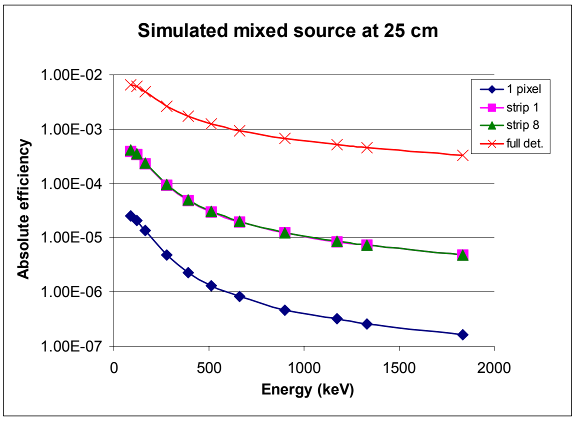

Fig. 2. Results of MCNP simulations for the DSSD prototype photopeak efficiency.

The source gamma-ray energies were chosen to correspond to those obtained from a standard mixed source (88 keV-1836 keV) and a 25 cm source-to-detector distance was used for direct comparison to the "standard" 3" x 3" NaI detector at 1.333 MeV. The results of the simulation for a single "pixel", strips in the middle and edge of the DSSD, and for the entire detector are shown in figure 2. As seen from the figure, large gains in efficiency are predicted going from individual pixels, to individual strips, to the entire detector. The predicted total photopeak efficiency at 1.333 MeV is 4.56×10^{-4}, which is 38% relative to a 3"x 3" NaI detector.

The simulations indicate that by summing over interactions in all strips for a given incident photon, the gain in efficiency over a single strip is roughly 16x for low-energy photons (88 keV), whereas at the highest photon energies, the gain is on the order of 70x. This can be understood from the fact that the low energy photons tend to deposit their energy in a single interaction, which is then contained within a strip. The gain in efficiency for the entire detector is simply the number of strips (16) times the efficiency of a single strip. However, for the case of high-energy photons, the energy deposit occurs in multiple interactions that can register in different strips. The photopeak efficiency obtained by summing the energy deposited in all strips significantly exceeds 16 times the single strip efficiency. This clearly points out the need to develop highly selective algorithms for "tracking" and reconstructing the gamma-ray energy deposition and for disentangling multiple hits.

We have performed preliminary efficiency measurements using a NIST traceable mixed calibration source and the agreement between the predicted and measured single-strip efficiency is good to about 10%. We are in the process of developing routines to analyze the data from the 32-input measurement that will allow the reconstruction of the energy deposit within individual pixels and for the full detector.

3. The Gamma Ray Box (GARBO)

In order to design a compact, highly efficient detector array for use in nuclear physics experiments, we have investigated an arrangement consisting of an inner box of DSSD detectors surrounded by large volume "clover" HPGe detectors. A possible experimental arrangement is shown in figure 3. The close geometry of the box gives large solid-angle coverage while the segmentation of the DSSD's provide excellent position sensitivity. Good efficiency for high-energy photon detection is obtained by combining signals from the DSSD's and the corresponding large-volume clover detectors.

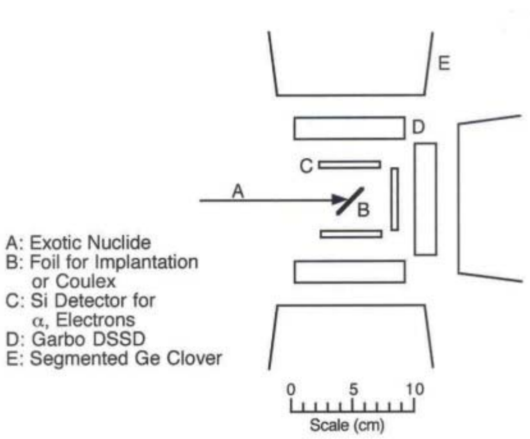

Fig. 3. Schematic diagram for detector arrangement.

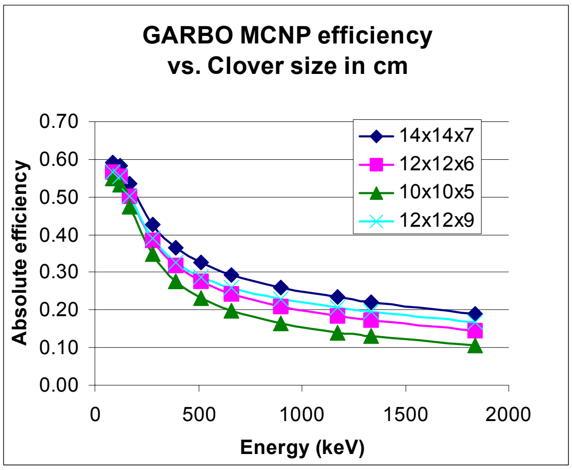

Fig. 4. Calculated photopeak efficiency for the GARBO detector array as a function of gamma-ray energy for various clover detector sizes.

Simulations using MCNP were performed for the geometry shown in figure 3. In order to simplify the calculations, the clover detectors were approximated by solid blocks of HPGe material in aluminum cans and the DSSD's were represented by blocks of HPGe in very compact containers. Furthermore, the material inside the box was approximated by 2 mm of aluminum. While the prototype DSSD's are much less compact than the idealized ones, in principle it should be possible to construct DSSD's similar to those used in the simulations. At this stage, we are interested in determining through simulation what kind of performance may be achievable.

The results of the simulations are presented in figure 4. The calculations were performed for various sizes of the clover detectors in order to optimize detection efficiency and cost. The energy deposition was tallied for the combination of a DSSD and the clover detector directly behind it (a module). The photopeak efficiency varies from about 60% at low energies to about 15% for 1.33 MeV radiation. These values compare very favorably to those obtained for Gammasphere. In principle, even higher efficiency and better peak-to-total ratios can be obtained by tracking the gamma-rays throughout the entire array.

4. Summary and conclusions

We are in the process of developing a compact, highly efficient array of gamma-ray detectors. Prototype segmented HPGe DSSD's have been constructed and tested. MCNP simulations indicate that if the DSSD encapsulation can be reduced in size, their combination with large-volume clover detectors can yield very high detection efficiencies. In practice, highly selective tracking algorithms will need to be developed to fully exploit the position sensitivity and efficiency promised by this detector arrangement. If realized, this array would be ideal for many physics experiments at the FMA and those expected to be performed at the proposed Rare Isotope Accelerator (RIA) facility in the future.

Acknowledgements

This work was supported by the U. S. Department of Energy, Nuclear Physics Division, under Contract Nos. W-31-109-ENG-38.

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