

P-TYPE POINT CONTACT GERMANIUM DETECTORS FOR LOW-LEVEL COUNTING

Ethan L. Hull¹, Richard H. Pehl¹, James R. Lathrop¹, Peggy L. Mann¹, Ronnie B. Mashburn¹, Bruce E. Suttle¹,
Harry S. Miley², Craig E. Aalseth², and Todd W. Hossbach²

PHDs Co.¹ and Pacific Northwest National Laboratory²

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ABSTRACT

Germanium detector arrays are needed for low-level counting facilities. The applications in such user facilities include the characterization of low-level radioactive samples. In addition, the same detector arrays can perform important fundamental physics measurements, including the search for rare-events like neutrino-less double-beta decay. Recently, relatively large detectors (~ 700 g) having relatively small (~ few mm) p+ contacts are being investigated as a possible detector basis for these detector arrays. A detector having a small, relatively low capacitance, p+ contact has been fabricated as a demonstration. The development and properties of the detector system are discussed.

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OBJECTIVES

Germanium detector arrays are useful in low-level counting facilities. The practical applications in such user facilities include the characterization of low-level radioactive samples. In addition, the same detector arrays can also perform important fundamental physics measurements, including the search for rare events like neutrino-less double-beta decay (Miley et al., 1991; Miley, et al., 1990; Majorana Collaboration White Paper, 2003; and Goulding et al., 1984). Coaxial germanium detectors having segmented outer contacts could provide the next level of sensitivity improvement in low background measurements. The segmented outer contact allows performance of advanced pulse-shape analysis measurements. These techniques can be used to discriminate between multiple Compton-scattered gamma-ray events and single-point beta-decay events. Because of their complexity, segmented coaxial detectors are expensive and available only after relatively long lead times. Improved detector segmentation techniques have shown promise toward making segmented p-type coaxial germanium detectors more readily available for low-level counting facilities (Hull et al., 2007). Recently, the Majorana collaboration and the dark-matter community have shown interest in relatively large volume p-type germanium detectors having a very small p+ contact (Barbeau et al., 2007). These detectors could serve as simpler—ultimately lower background—alternatives to the segmented coaxial detector approach for low-background counting. The small p+ contact makes the preamplifier signal exhibit pronounced charge collection signatures. These signatures enable a good deal of position resolution and background discrimination using only a single electronic channel. The fabrication complexity and manufacturability of these p-type point-contact detectors must be addressed for these detectors to be considered viable for a large detector array.

RESEARCH ACCOMPLISHED

PHDs Co. has been investigating the viability of p-type point contact detectors. The pursuit has been a combination of experimental detector fabrication, cryostat fabrication, integration, and testing. The design of the p-type point contact detector allows a relatively large active germanium volume to be instrumented with a relatively small charge-collection contact. A diagram of the MJ70 detector is shown in Figure 1. The detector has a 72.2-mm diameter and is 37.3-mm long. The hole for the p+ contact is 1.5-mm in diameter and is 1.5-mm deep. The p-type bulk germanium depletes from the lithium-diffused n+ contact toward the small p+ contact. In principle, all the charge carriers created in the detector bulk should be collected at the central p+ contact. This detector design should have a capacitance of only ~ 1 pF at the small p+ contact when the detector is fully depleted.

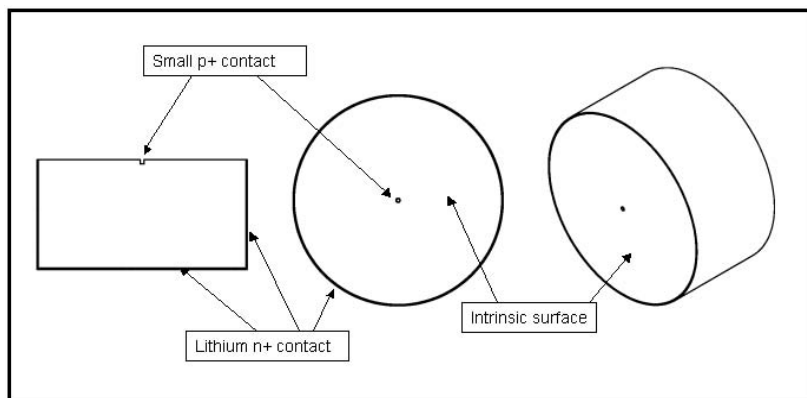


Figure 1. The MJ70 detector is an example of a p-type point-contact germanium detector.

The geometry of the MJ70 detector is similar to a closed-end coaxial detector except that the hole is very short and has a very small diameter relative to the other dimensions of the detector. This makes the capacitance of the detector relatively small, lending itself to relatively low-noise performance. The small p+ contact makes the charge collection process have very distinct features. Most of the charge signal is induced in the small p+ contact during the last few millimeters of charge-drift path toward the p+ contact. The current signal (the derivative of the charge signal) has very distinct spikes occurring when the carriers reach the contact. This feature allows discrimination between multiple gamma-ray interactions and single point-like beta-decay interactions. Because the bulk germanium is p

type, holes are collected on the small p+ contact, making the detector relatively insensitive to electron trapping problems that still exist today in detector grade germanium (Hull et al., 2005).

Figure 2. The MJ70 detector as it was ground. The p+ contact is later fabricated in the small hole in the center of the intrinsic surface.

PHDs Co. has developed, fabricated, and delivered the completed MJ70 prototype detector system. MJ70 is fabricated from a p-type germanium cylinder having a measured net electrically active impurity concentration of $6.3 \times 10^9 / \text{cm}^3$ above and $4.8 \times 10^9 / \text{cm}^3$ below the crystal. The crystal was ground to a 72.2-mm diameter and a 37.3-mm length. The hole for the p+ contact was ground to a 1.5-mm diameter and a 1.5-mm depth.

The idea was to attempt to obtain reasonably good charge collection by fabricating a detector that approximates a hemisphere, having similar charge collection distances in all directions. The corners at the closed end were left square. Generally these corners are rounded off, beveled, or bulletized for coaxial detector fabrication to improve the charge collection from gamma rays interacting in these regions of the detector. In this case, the maximum detector mass is desired, and some poor charge collection in the corners may be tolerable as a tradeoff. The detector has a lithium diffused n+ contact around the outside of the detector and a very small metal evaporated nickel p+ contact for charge collection. A photograph of the crystal with the small hole is shown in Figure 2. The detector is held in a PHDs Co. MJX cryostat specifically made to hold, cool, and instrument these point-contact detectors. The MJX cryostat holding MJ70 is shown in Figure 3.

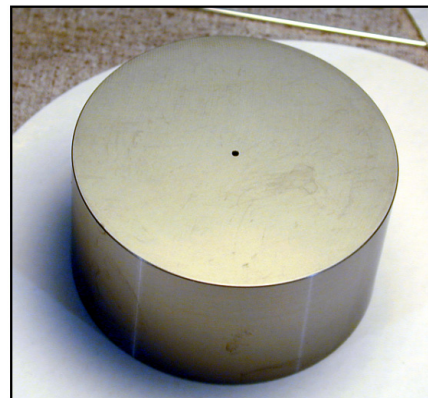


Figure 3. The MJX cryostat holds, cools, and instruments p-type point contact detectors like MJ70.

Numerous detector fabrication attempts were made. Problems with the intrinsic surface of the detector and the very small p+ contact were thought to be the main difficulty. In addition, the cryostat required several modifications. Finally, the detector depleted at a voltage of +1880 V and was operated at a voltage of +1980 V with minimal leakage current. The

detector successfully cycled from the cryogenic temperature ($\sim 83 \text{ K}$) to room temperature and back again with no increase in the leakage current or degradation in the detector performance. The spectroscopy from the detector was quite reasonable given the geometry of the detector. Figure 4 shows a ^{60}Co and ^{241}Am spectrum from MJ70 using a peaking time of 5 microseconds. The functioning detector and cryostat were successfully delivered and operated at Los Alamos National Laboratory in June 2008.

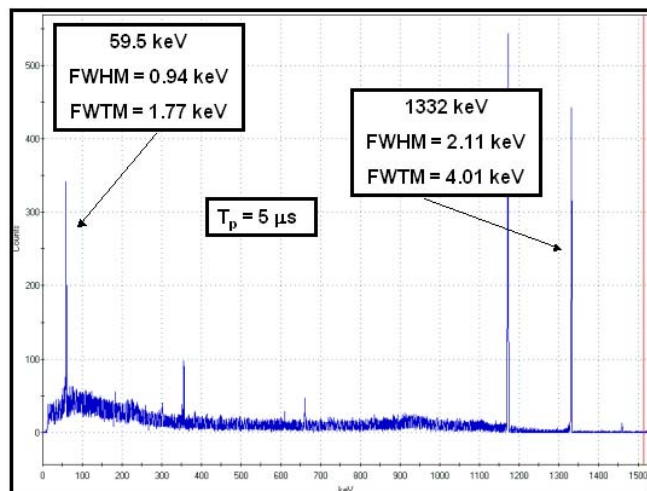


Figure 4. The gamma-ray energy spectrum from MJ70 shows reasonable charge collection considering the geometry of the detector.

CONCLUSIONS AND RECOMMENDATIONS

From the point of view of detector fabrication, the p-type point contact detector design seems quite viable as a basis for large low-background counting arrays. PHDs Co. will continue the evaluation of this technology with the fabrication of other detectors having different aspect ratios compared to MJ70 to see how far the limits of charge collection can be pushed before the energy resolution is impacted.

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