Improved Efficiency at Low Energies with P-Type High Purity Germanium Detectors

Kyle T. Schmitt, Gregor Geurkov, *Member, IEEE,* Elaine G. Roth, *Member, IEEE,* Timothy R. Twomey, and Teresa Underwood, *Member, IEEE*

***Abstract*—The absolute efficiency performance of a High Purity Germanium (HPGe) gamma-ray detector at low energies (aside from geometric considerations) is dominated by attenuation outside the active volume of the germanium crystal. For applications where neutron damage is not a concern, p-type detectors have several attractive features including energy resolution performance. However, the outer contact usually takes the form of a thick n+ contact. Owing to the otherwise beneficial high attenuation coefficient of germanium, little to no transmission of photons in the energy range between 3 and 50 keV is apparent. A new Stable Thin Front Contact (STFC) has been developed by ORTEC for p-type coaxial and semi-planar HPGe detectors. The contact is both thin and highly stable. It improves efficiency at low energies and allows detection down to 3 keV with p-type detectors. Another principal advantage is no dead-layer growth at room temperature (if detector is stored "warm" for a prolonged period of time) due to migration of the n+ contact into the Germanium crystal. A comparison of modeled and measured efficiency versus energy data will be presented using various detector geometries for different spectrometry applications.**

***Index Terms*—Germanium, Semi-conductor radiation detectors, Gamma-ray detectors, X-ray detectors.**

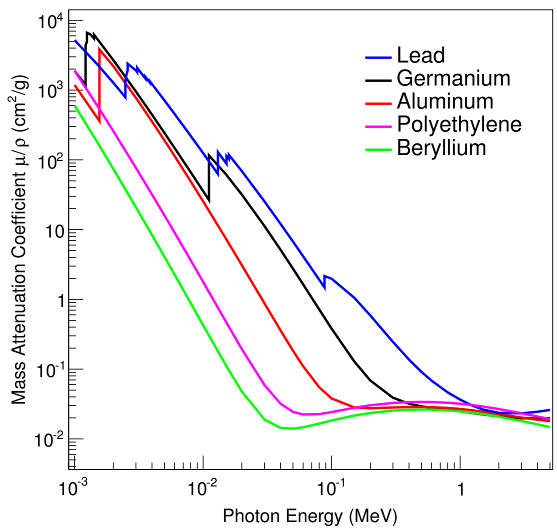

Fig. 1. Mass attenuation coefficients for a variety of materials[1].

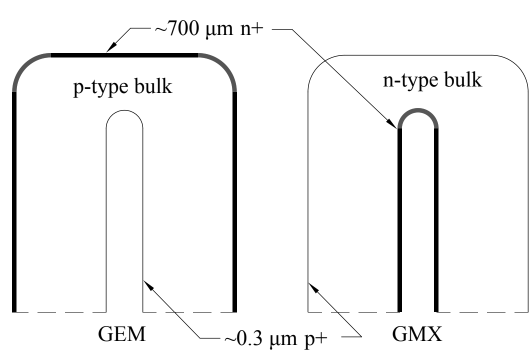

Fig. 2. Conventional HPGe detector configurations.

I. Introduction

DETECTORS based on High Purity Germanium (HPGe) technology have long been the gold standard for γ-ray detection with regard to high resolution performance. The resolution advantage is particularly beneficial in applications where nuclide identification is of interest.

Conventionally, HPGe detectors take the form of a closed coaxial diode with highly doped contacts on the inner and outer surfaces. The charge carriers that contribute to the signal originate exclusively from the depletion region, and the inactive region on the surface of the crystal acts as an attenuating layer to incoming photons.

Photons in the energy regime associated with nuclear decay are generally attenuated more strongly at lower energies and by materials with increasing atomic number. The dramatic variation of mass attenuation coefficients across photon energy and material composition is evident in Fig. 1[1].

Detectors with an n+ inner contact, n-type bulk, and a p+ outer contact have a thin boron-implanted entrance window ($\sim 0.3\ \mu$m). ORTEC GMX series detectors follow this pattern. There is a substantial advantage in energy resolution for detectors that have an inner p+ contact, p-type bulk, and an outer n+ contact. The conventional and most practical method of producing the outer n+ contact, however, results in a thick dead layer of lithium-diffused germanium ($\sim 700\ \mu$m). This is the case for an ORTEC GEM series detector. These two configurations are illustrated in Fig. 2.

For historic reasons, HPGe coaxial detectors are specified by their relative efficiency at 1332 keV, measured with a point source 25 cm from the detector end cap[2]. This standard originated at a time when HPGe detector manufacturers had less control over crystal dimensions. Two detectors with the same IEEE relative efficiency might have varying diameters and lengths. Consequently, this specification sheds little light on the sensitivity of the detector for other energies and

All authors are with ORTEC/AMETEK, Oak Ridge, TN, 37831 USA e-mail: gregor.geurkov@ametek.com.
Manuscript received December 5, 2014

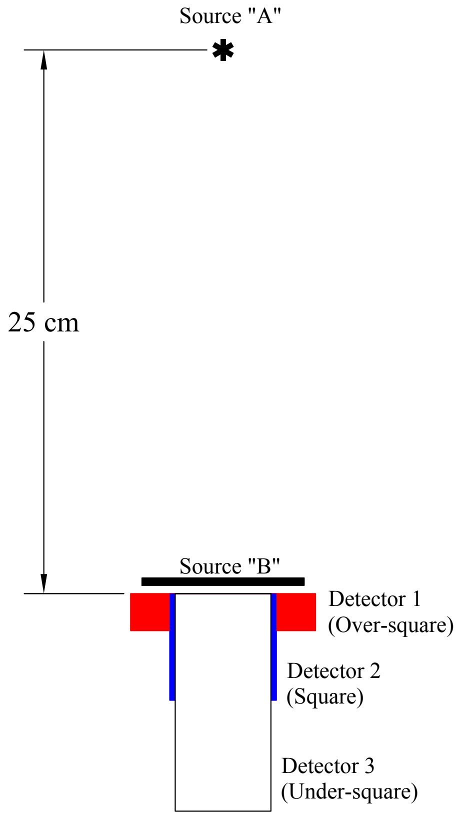

Fig. 3. Schematic representation of three detectors with the same IEEE relative efficiency (source "A" at 1332 keV), but widely different absolute efficiencies with respect to low-energy source "B".

geometries.

This limitation is evident for detectors with an extended, low-energy source near the endcap. In this configuration, a detector with an over-square crystal geometry (diameter $>$ length) would yield superior absolute efficiency compared to a detector with an under-square crystal geometry (diameter $<$ length). This variation in absolute efficiency is illustrated schematically in Fig. 3.

The ORTEC PROFILE-GEM-S and PROFILE-GEM-C series of detectors are a recent innovation developed to address these considerations. Specifically, both series of detectors take advantage of the premium resolution achieved by p-type detectors and of a new thin front contact, resulting in superior detection efficiency at photon energies down to 3 keV. Detectors in the PROFILE-GEM-S series have dimensions optimized for efficiency at low photon energies, while detectors in the PROFILE-GEM-C series have dimensions optimized for efficiency at higher photon energies, up to several MeV.

To quantify this effect, photopeak efficiency data was measured with a GEM-S8530 detector, a GEM-C7080 detector, and comparable GEM and GMX detectors using a variety of source geometries. Data were produced by measurement and by Monte Carlo simulations performed using the Monte Carlo N-Particle eXtended (MCNPX) software package[3]. Comparisons will be made and conclusions will be drawn regarding the suitability of these options for a variety of applications.

II. Methods

Empirical efficiency measurements were taken with a point-like mixed gamma source. Efficiencies were calculated for point-like, filter paper source, and Marinelli beaker geometries. The data for point-like and filter-paper source geometries were produced for three detectors: a PROFILE-GEM-S8530, a GEM50, and a GMX50. The dimensions for a PROFILE-GEM-C7080, a GEM70, and a GMX70 were used for the calculations in Marinelli beaker geometries.

The point-like source was acquired from Eckert and Ziegler Analytics. The source contained ^{57}Co, ^{60}Co, ^{88}Y, ^{109}Cd, ^{113}Sn, ^{139}Ce, ^{137}Cs, ^{203}Hg, and ^{241}Am, with activities calibrated to within 5% uncertainty. The source was placed on axis with the detector endcap at a distance of 25 cm from the entrance window. Signal processing was performed with ORTEC analog electronics. The data were recorded and analyzed with ORTEC Maestro software. In each case, the system was allowed to count long enough to accumulate at least 5000 counts in each peak reported.

Monte Carlo calculations were performed with the MCNPX software package. All relevant portions of the detector system were included in the simulation, including cryostat material and germanium dead layers between the source and the active volume of the detector and inside the inner coaxial contact. All point source calculations were performed with the source on axis and 25 cm from the outside of the cryostat. Filter paper sources were modeled as a paper disk directly on the endcap with a diameter of 10 cm, a thickness of 0.2 mm, and a density of 1 g/cm^3. Marinelli-style sources were modeled after GA-MA brand 1-liter polypropylene Marinelli beakers with diameters to match the detector endcaps, filled to a volume of 800 ml. The attenuating material inside the beaker was modeled as water.

Cryostat and crystal dimensions are specified for each detector in Table 1.

III. Results

Measured and calculated detection efficencies for the point source configuration are plotted in Fig. 4. The uncertainties displayed for the measured data include source activity and counting uncertainties. Additional uncertainty was assigned to the data points at 22 keV for source self-attenuation. The calculated data are in agreement with the measured data to within 10%. The efficiency curves meet near the ^{60}Co transition at 1.33 MeV. The larger solid angle coverage of the GEM-S8530 yields a sizeable advantage at lower energies.

Fig. 5 displays calculated efficiencies for the filter paper geometry. The data for the GEM-S8530 exhibit superior efficiency at all energies calculated. The GMX50, with a thin outer contact, is more efficient than the GEM50 at low energies. The germanium absorption edge is evident in the dramatic increase in efficiency for the GEM-S8530 and the GMX50 below 11 keV.

TABLE I
DETECTOR DATA

Model	S8530	GEM50	GMX50	C7080	GEM70	GMX70
Endcap Diameter	108 mm	83 mm	83 mm	83 mm	95 mm	83 mm
Window Material	Carbon Fiber	Aluminum	Beryllium	Carbon Fiber	Aluminum	Beryllium
Window Thickness	0.76 mm	1.0 mm	0.5 mm	0.76 mm	1.0 mm	0.5 mm
Front Dead Layer	< 10 μm	~ 700 μm	~ 0.3 μm	< 10 μm	~ 700 μm	~ 0.3 μm
Side Dead Layer	~ 700 μ m	~ 700 μm	~ 0.3 μm	~ 700 μm	~ 700 μm	~ 0.3 μm
Crystal Diameter	85 mm	66 mm	63 mm	70 mm	72 mm	62 mm
Crystal Length	33 mm	64 mm	83 mm	85 mm	89 mm	83 mm

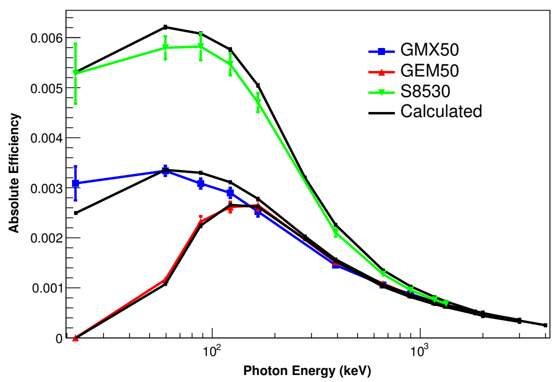

Fig. 4. Measured and calculated efficiency versus photon energy for a point source at 25 cm.

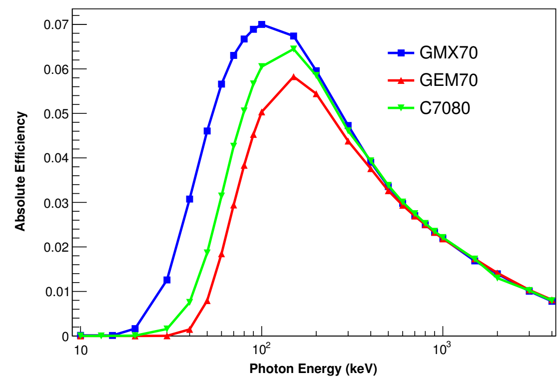

Fig. 6. Calculated efficiency versus photon energy for an aqueous source in a Marinelli beaker.

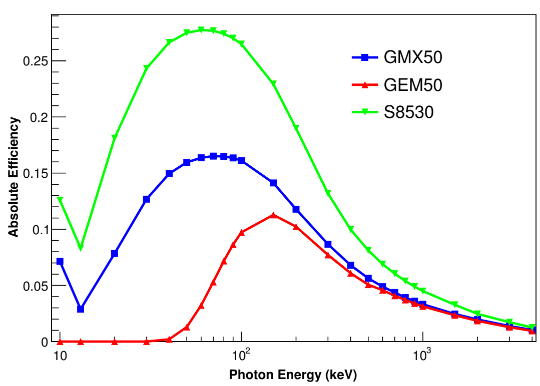

Fig. 5. Calculated efficiency versus photon energy for a filter paper source on endcap.

Calculated data for a GMX70, a GEM70, and a GEM-C7080 with the aqueous source in a Marinelli beaker are presented in Fig. 6. All three curves are separated by less than 20% above 100 keV. Below 100 keV, the efficiency is dominated by the thickness of the contact on the outer diameter of the detector. The substitution of a shallow implant in the GMX70 yields a substantial advantage at those energies.

IV. CONCLUSION

The measured and calculated data demonstrate two dramatic effects. First, the solid angle covered by the detector with respect to the source has a strong effect on efficiency. The area of the front window of PROFILE-GEM-S8530 detector is almost double that of the GEM50 and GMX50 detectors. That advantage is evident in the data for the point-like and filter-paper source geometries.

Second, the data for GEM (p-type) and GMX (n-type) detectors quantify the advantage in transmission realized with a shallow dead layer. The sensitivity of GMX detectors is vastly improved over GEM detectors at energies below 50 keV.

For detectors with common relative efficiency at 1.33 MeV and 25 cm, efficiencies for other energies and geometries can vary considerably.

Consideration should also be given to energy resolution, where p-type detectors have the advantage. The detectors in the PROFILE-GEM-S series possess advantages in efficiency and energy resolution for low-energy sources in front of the endcap. PROFILE-GEM-C detectors share those advantages, and add efficiency at higher energies in those geometries. For Marinelli geometries, GMX detectors offer the highest efficiency at low energies.

This means that when matching a detector to a particular application, one should consider the energy range of interest and the counting geometry. As has been discussed, HPGe detectors should not be specified on the basis of relative efficiency alone. Crystal dimensions can radically affect the solid angle and absolute counting efficiency. A new thin front contact enables samples with photon emissions as low as 3 keV to be counted in optimized geometry.

Acknowledgment

The authors wish to thank R.W. Peel and Dave B. Johnson, who played prominent roles in the development of this new product.

References

[1] J. H. Hubbell and S. M. Seltzer, *Tables of X-Ray Mass Attenuation Coefficients and Mass Energy-Absorption Coefficients from 1 keV to 20 MeV for Elements Z = 1 to 92 and 48 Additional Substances of Dosimetric Interest*[Online]. Available: http://www.nist.gov/pml/data/xraycoef/index.cfm

[2] *IEEE Standard Test Procedures for Germanium Gamma-Ray Detectors*, IEEE Standard 325, 1996.

[3] L. S. Waters, J. Hendricks, and G. McKinney, MCNPX version 2.7.0, 2005.