Extended Source Sensitivity and Resolution Comparisons of Several HPGe Detector Types with Low-energy Capabilities

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Abstract

Recent advances in germanium crystal growth and detector construction techniques have made possible p-type germanium detectors with both the ability to detect low energy gamma rays (below 45 keV) and good resolution (FWHM and FW10M). Previously, low-energy sensitivity in coaxial detectors was accomplished using n-type (reverse electrode) construction, but large n-type detectors do not have the energy resolution of p-type (normal electrode) detectors. These new detectors can be large diameter and can be used for large-area samples such as filter papers, body counters and package monitoring. Isotopic ratio programs, such as MGA or PC/FRAM produce the best results when the peak shape in the spectrum has little or no low-energy tailing. A comparison of the sensitivity from 5.9 keV to 1.8 MeV for point source, filter paper and CTBTO geometries was done for these new detectors, planar, large n-type, thin n-type and other detector types. The results show the new detectors have sensitivity comparable to n-type detectors above 20 keV, with achievable peak shapes comparable to the best p-type detectors making them suitable for a wide range of high resolution applications with a variety of sample types, including safeguards and non-destructive assay.

Introduction

The first hyper-pure germanium (HPGe) radiation detectors were made as p-type diodes with a thick n-type contact on one surface of the germanium crystal and a thin p-type contact on the other surface. In the normal construction of a COAX or closed end COAX, the thicker contact is put on the outer cylindrical surface of p-type crystal material and the thinner contact is put on the inner surface of the cylinder, as shown in Fig. 1. The contacts are made in this way on p-type material to make the diode junction near the inner contact. Putting the junction near the inner contact gives the most uniform electric field inside the crystal and thus the best resolution.

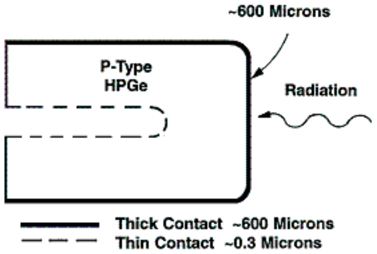

Figure 1 Closed-End Coaxial HPGe Detector.

The outer contact is from 600 to 1000 microns thick, depending on several factors, including the crystal size. Generally, the contact thickness increases with detector size. The contact layer does not produce a signal for gamma rays which are absorbed in it; it is a dead layer. The inner contact is about 0.3 microns thick. The outer contact completely absorbs low-energy photons, and these detectors have an efficiency which increases until it reaches a maximum at about 120 keV. The endcap material also absorbs low-energy photons, further decreasing the low-energy efficiency.

If the germanium crystal material is n-type, then the contact material can be reversed, that is, the thin contact can be put on the outside and the thick contact on the inside, as shown in Fig. 2. This still maintains the junction near the inner contact. The low-energy efficiency is increased because of the reduced thickness of the dead layer. In most cases, the endcap material is also made of a material with high transmission at low energies, such as beryllium metal foil or carbon fiber foil. However, the resolution (FWHM) is not as good for the n-type detectors as for the p-type detectors.

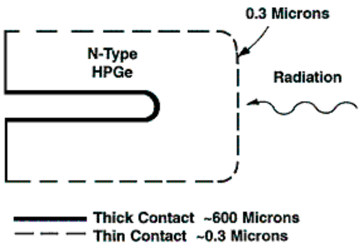

Figure 2 Reverse Electrode Coaxial Detector.

Recently, a new thin n-type contact has been developed for the front surface of p-type crystals, as shown in Fig. 3. This results in an increase in the sensitivity to low-energy photons to almost that of the n-type detectors while maintaining the good resolution of the p-type detectors. The low-energy efficiency for these detectors is adequate for applications where the lowest energy of interest is above ~30 keV. This includes the majority of nuclear safeguards applications. For energies below this, the normal n-type detector is still needed. These new detectors also have the low atomic number endcap material, usually carbon fiber. Another advantage of the new p-type detectors is the availability of larger volume crystals for higher efficiency detectors at high energies, and a larger maximum diameter of over 8 cm, all combined with excellent resolution and peak shape. These new detectors have been commercialized under the name ORTEC PROFILE series FX.

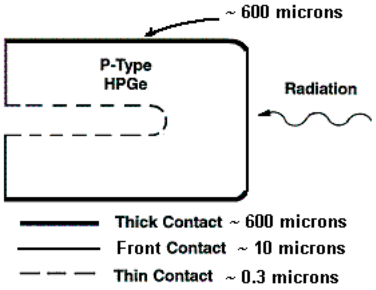

Figure 3 Thin Front Contact Detector.

The methods described in IEEE draft standard 325-2004 were used for all the measurements described here.

Methods

To compare the efficiency and resolution of the different types of detectors, one of each of the three types (GEM, GMX, FX) was selected such that they have similar physical diameters. Two other detectors were included in the comparison: an ACT II[1] and an FX with a larger diameter, but similar length to the other FX and the ACT II.

The detectors were positioned, one at a time, in a low-background shield to minimize external counts. The shield is 15 cm of lead, lined with 8 mm of copper and 1 mm of tin. The sources used were all NIST-traceable, and included mixed nuclide and single nuclide sources. The mixed nuclide sources contain ^{241}Am, ^{109}Cd, ^{57}Co, ^{139}Ce, ^{203}Hg, ^{113}Sn, ^{137}Cs, ^{60}Co and ^{88}Y. Single nuclide sources were used for ^{55}Fe, ^{109}Cd and ^{57}Co. The 22 keV efficiency was measured using the combined X-ray peak (21.99 and 22.16) from ^{109}Cd, with the intensity based on the yield ratio with 88 keV. The CTBTO sources are in the geometries specified by that agency for their samples and are 7 cm diameter by 5 mm and 15 mm thick. The matrix material is epoxy. The

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[1] ACT II is a 7 cm diameter by 27 mm deep LEGe detector from Canberra Industries, Inc

point sources are deposited on thin mylar, some have an evaporated aluminum coating on the mylar. The filter paper sources are paper filters in mylar film. The sources were held in position by low mass mounting to minimize scattering.

The “on endcap” spectra were collected with the sources directly on the thin entrance window of the detector. The spectra were collected for sufficient live time to have 1% or less counting uncertainty in the smallest peak used. True coincidence or cascade summing was ignored in these measurements. The correction for random summing was also not applied.

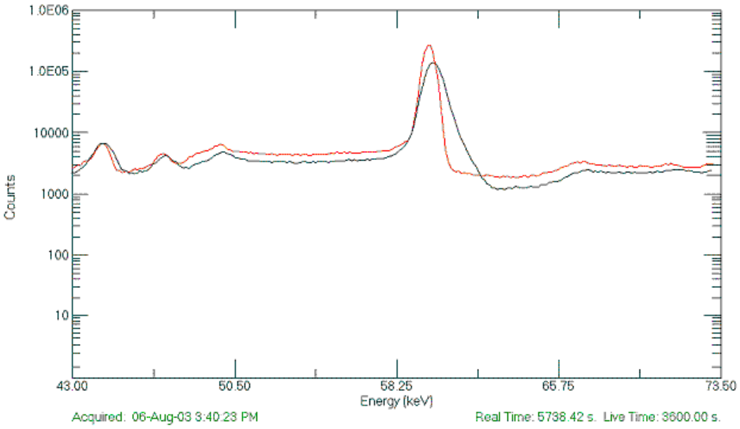

Figure 4 Different Peak Shapes for Different Detectors.

The close geometry for some of the samples, and the high count rates caused some spectra to have distorted peak shapes, making the peak area determination different for these cases as shown in Fig. 4. In addition, the differences in resolution among the detectors made the determination of the low energy peak areas. Shown in Fig. 5 are the spectra at 73 keV for three detectors. The FWHM and FW02M for the FX are 0.74 and 1.91 keV; the GEM are 0.94 and 2.3 keV; and the GMX is 1.14 and 2.73 keV. This indicates the need for the best resolution possible at low energies, when these are of interest in the spectrum.

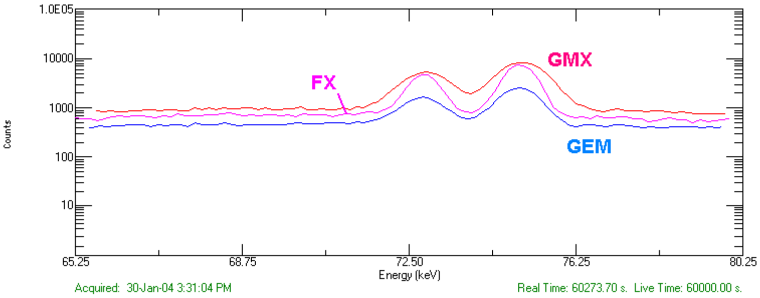

Figure 5 Comparison of Resolution for Three Detectors.

Table I. Detectors Measured

Detector Number	Type	Diameter (mm)	Length (mm)
N21879A	GMX	60.6	56.7
P41358A	FX	58.9	25.3
P11697A	GEM	60	83.9
ACT II	LEGe	70	27
P41321A	FX	85	30

Detectors

The detectors measured are shown in Table I. The top three detectors have similar diameters. The area of the front surface (diameter) is the major contributor to the low energy-efficiency. The ACT II detector has a depth similar to the FX, but a larger diameter. The last detector has a similar length, but a larger diameter.

The thick dead layer on sides of the GEM and FX detectors will reduce the active diameter by about 1.2 mm. The GMX has a thin contact on the sides as well as the front.

Results

Disk Source 15 mm x 7 cm

Figure 6 shows the absolute efficiency for the five detectors for the disk source on endcap. In Ref. 1, the efficiency of disk sources on endcap was shown to increase with increasing detector diameter until the detector is 130% of the source diameter. This is shown here, with the 85 mm detector having the highest efficiency. As expected the longer detectors have the highest efficiency at higher energies.

Figure 7 shows the low energy part of Fig. 6 expanded. Note that the GMX has the highest efficiency down to the lowest energy because it has the thinnest dead layer. The GEM has the lowest efficiency due to the thick dead layer and the other three are similar and show the differences in diameter of the detectors.

Efficiencies for other extended geometries are given in Ref 2.

Point Source at 25 cm

The point source efficiency at 25 cm distance is shown in Fig. 8. This measurement is shown for comparison with the traditional method of stating relative efficiency as the value for the 1.33 MeV line of ^{60}Co at 25 cm on axis from the front face of the endcap. Note that at this energy, the efficiency of the large diameter, short length detector is about the same as the smaller diameter, long length detector. While the smaller

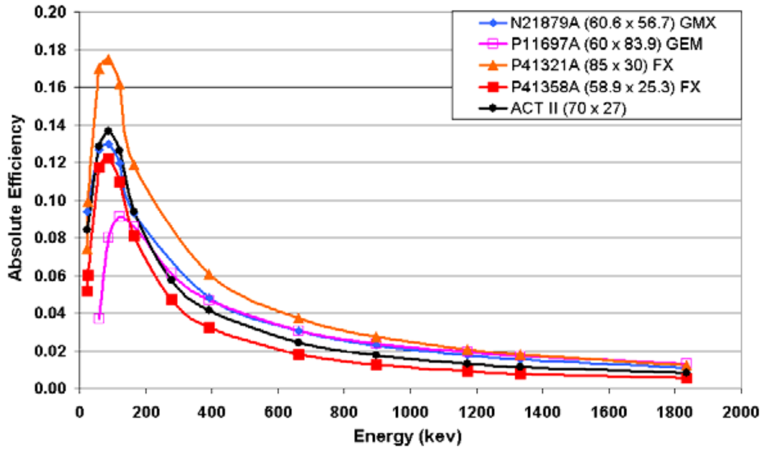

Figure 6 Absolute Efficiency for 15 x 70 mm Mixed Nuclide Source on Endcap.

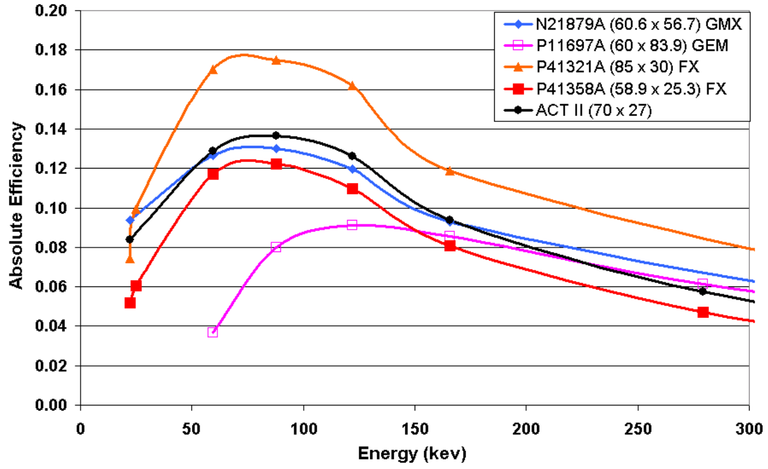

Figure 7 Expanded Low-Energy part of Fig. 6.

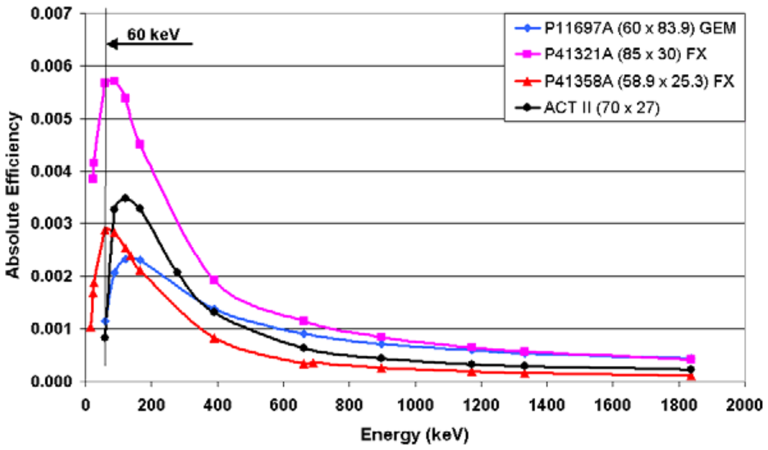

Figure 8 Absolute efficiency for Point Source at 25 cm from endcap.

FX and the ACT II have lower efficiency.

The resolution was measured for these detectors at FWHM, FW.1M (one-tenth maximum), FW.04M (one-twenty fifth maximum), FW.02M (one-fiftieth maximum) for energies from 22 keV to 2 MeV. The 22 keV line consists of two components, and is wider than a single line, but it included here for comparison. The 2.5 MeV peak is a sum peak, and it also wider than a normal peak.

The Resolution for the GMX detector is shown in Fig. 9. The close geometries show high resolution, which is due to pileup or summing of the low-energy gamma rays with the gamma rays of interest. This can be reduced by using a filter to absorb the low energy gamma rays. This is shown by the use of a 1 mm thick germanium filter. The close geometry for the extended sample still has an increase in resolution, which is attributed to the increase in the low-angle scattering into the active volume from gamma rays with high incidence angles. At the 25 cm distance, the gamma ray angle of incidence is all nearly perpendicular.

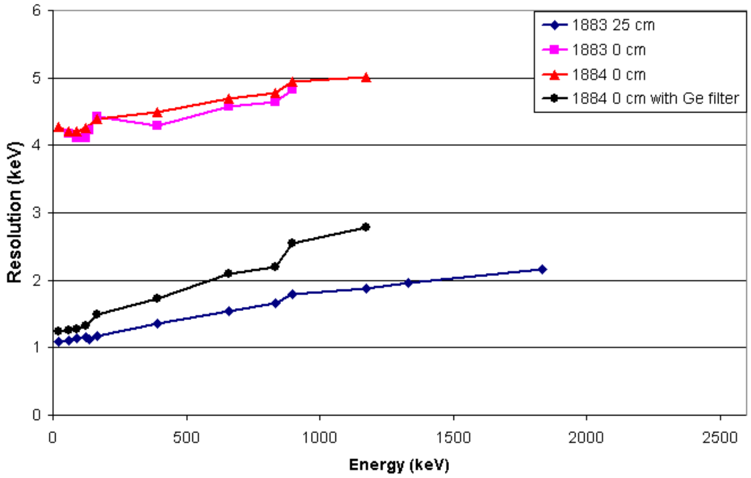

Figure 9 GMX Resolution (FWHM) for Different Geometries.

Figure 10 shows the resolution for all detectors for the point source at 25 cm. As expected, the GEM (p-type) detectors have better resolution than the GMX (n-type). The GEM FX detectors have better resolution than the GEM detector because they are smaller. This geometry is the normal geometry used in the specification of detectors (at 1332 keV).

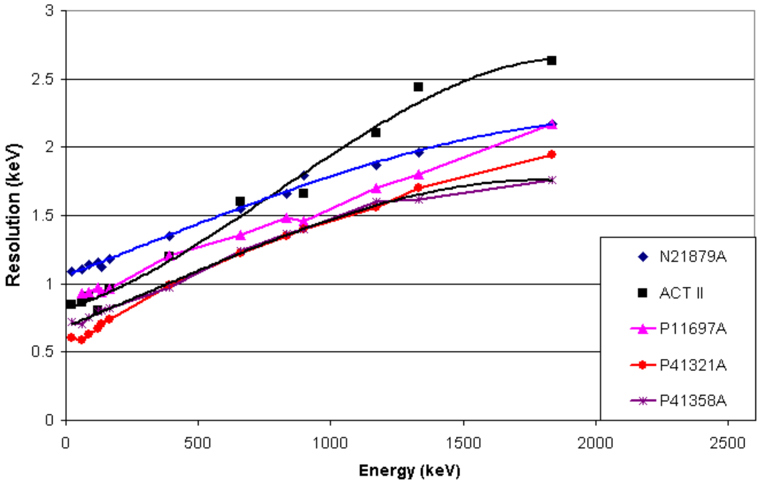

Figure 10 Resolution for Point Source at 25 cm.

Figure 11 shows the resolution for different geometries for the GEM FX detector. Note that the impact of the close, extended geometry is not as significant as for the GMX (Fig. 9), but is improved by the germanium filter. The low-energy sensitivity of the GEM FX does not extend as low as the GMX, so the summing is reduced.

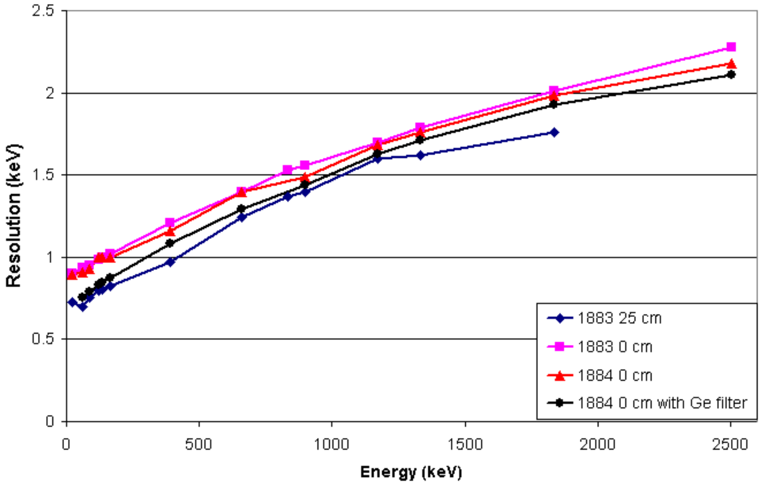

Figure 11 Resolution of One Detector for Different Source Geometires.

The quality of the peak shape for this detector is shown in Figs. 12 & 13. The peak shape in both geometries is nearly Gaussian, which is needed for peak separations in complex spectra. The isotopic ratio programs, such as MGA and PC FRAM, work best with resolutions lower than 700 eV at 200 keV, which these detectors have.

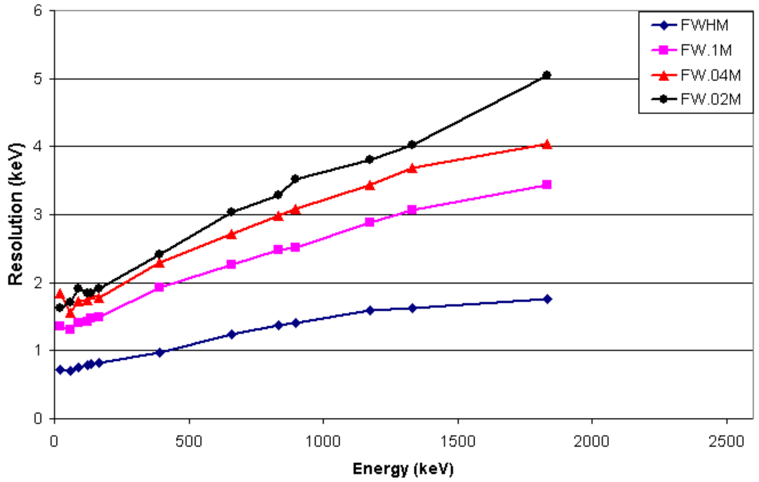

Figure 12 Peak Quality for Filter Paper Source for the GMX.

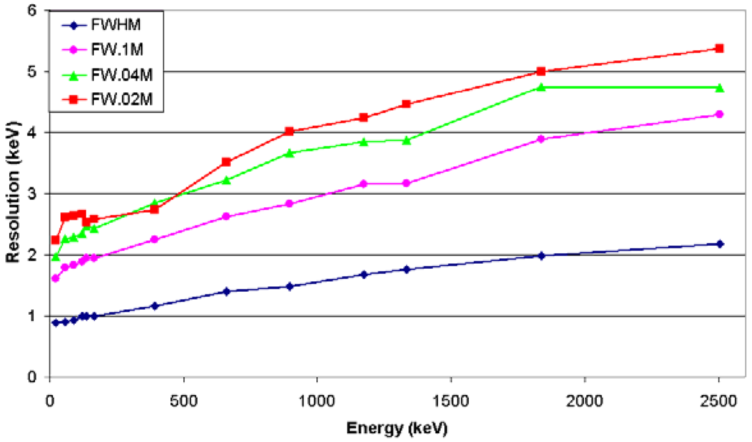

Figure 13 Peak Quality for Filter Paper Source for the FX.

Conclusions

The data show the new construction method can produce detectors with higher sensitivity or efficiency at lower energies than traditional p-type (GEM) detectors when installed in an endcap with a high transmission front window. The efficiency is not as high as a similarly sized GMX below about 30 keV, although this is not of interest in the majority of safeguards applications. The resolution and quality of the peak shape for the FX detector is excellent. The increased efficiency from 30 to 100 keV and improved resolution are useful in many applications including safeguards, where the ability to detect and separate both low- and high- energy gamma rays is important.

[1] R. M. Keyser, T. R. Twomey and P. Sangsingkeow, “Advances in HPGe Detectors For Real-World Applications,” Journal of Radioanalytical and Nuclear Chemistry, Vol. 244, No. 3 (2000) 641-647

[2] R.M. Keyser and T.R. Twomey, “Efficiency for Close Geometries and Extended Sources of a P-type Germanium Detector with Low-energy Sensitivity”, Modern Trends in Activation Analysis - 11, June 2004, Guildford, England