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Measurement of some characteristics of the BEGe detector

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Abstract: Nowadays, semiconductor detectors, in general, and high purity gemanium detectors (HPGe) in particular are widely used in various fields of experimental nuclear physics. In gamma ray experiments, energy resolution and the efficiency are very important characteristics of detectors. In this paper, the gamma standard sources such as ^{137}Cs, ^{57}Co, ^{60}Co, ^{54}Mn, ^{133}Ba, and ^{109}Cd were used to study the characteristics of the BEGe 3050 detector. The methods of determining the absolute photo- peak efficiency and the dependence of the energy resolution on γ-ray energy are presented.

1. Introduction

Broad Energy Ge (BEGe) detector can be used to measure gamma-rays with energy from 3 keV to 3 MeV [1]. Because of having excellent resolution, the BEGe spectrometry is employed for analysis of environmental samples and determination of radioisotope concentration. Before using it for above purposes, operating characteristics must be studied.

1.1. Energy resolution

In many applications of radiation detectors, the aim is to measure the energy distribution of the incident radiations. The energy resolution is a measure of the dectector's ability to distinguish between closely spaced lines in the spectrum. The energy resolution is presented in the term of the Full Width at Half Maximum (FWHM) of the peak. The better the resolution, the narrower the peak, and so what few counts are in the peak will be concentrated in a fewer channels. Those will then stand out more distinctly above the background continuum [2].

The overall energy resolution achieved in germanium system is normally determined by a combination of three factors: the variation in charge production (W_P), variation in charge collection

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(W_C) and the contribution of electric noise (W_E). The FHWM of a typical peak in spectrum due to the detection of a monoenergetic gamma ray can be synthesized as[2,3]:

$$FWHM^2 = W_p^2 + W_C^2 + W_E^2 \qquad (1)$$

Each of these terms can be replaced by the mathematical representation, gives:

$$FWHM = \sqrt{p^2E + c^2E^2 + e^2} \qquad (2)$$

where p, c, e are constants relating to production, collection and electronic noise, while E is γ-ray energy (in keV).

The electronic noise at preamplifier input makes a significant contribution to the energy resolution of a semiconductor detector system. By choosing an appropriate amplifier shaping time constant, we can minimize this contribution. The shaping time is defined as the necessary time for the pulse to reach from 0.1 to 0.9 of the maximum height [5].

1.2. Absolute photo - peak efficiency

Absolute photopeak efficiency relates the number of detector pulses to the number of gamma rays emitted by the source, and can be specified as follows:

$$\varepsilon = \frac{N}{A \cdot I_\gamma \cdot t} \qquad (3)$$

where : ε is the absolute efficiency value at energy of E,

N is the area of the photopeak of energy E,

A is the activity (disintegration per second) of the gamma source ,

I_γ is the gamma emission probability,

t_m is the live time of the counting, in second.

The absolute efficiency curve is the function of gamma energy E_γ, and can be fitted with the following equation for BEGe 3050 detector [2, 5]:

$$\varepsilon = \exp\left(\sum_{i=0}^{4} a_i \left(\ln\left(\frac{E_\gamma}{E_0}\right)\right)^i\right) \qquad (4)$$

where ε is the detection efficiency, a_i represents the fitting parameters, and E_γ is the energy of the photo peak, while E_0 = 1 keV.

2. Experimental setup and measurements

The BEGe-3050 detector which was located in Department of Nuclear Physics (Hanoi University of Sciences). It was produced by Canberra Company. Physical characteristics of detector are: active diameter is 80.5 mm; active area is 5000 mm^2; thickness is 31 mm; distance from window is 5 mm. Carbon Composite window is 0.06 mm. The detector was placed inside a low background lead shield. The integrated signal processor consists of a pulse height analysis system to transform pulse, which are collected and stored by a computer-based MCA. The data was analyzed by Genie2000 computer program. Data stored in 16384 sequential channels. The detector cross-section and materials made up each part of it is shown in the Figure 1 [1].

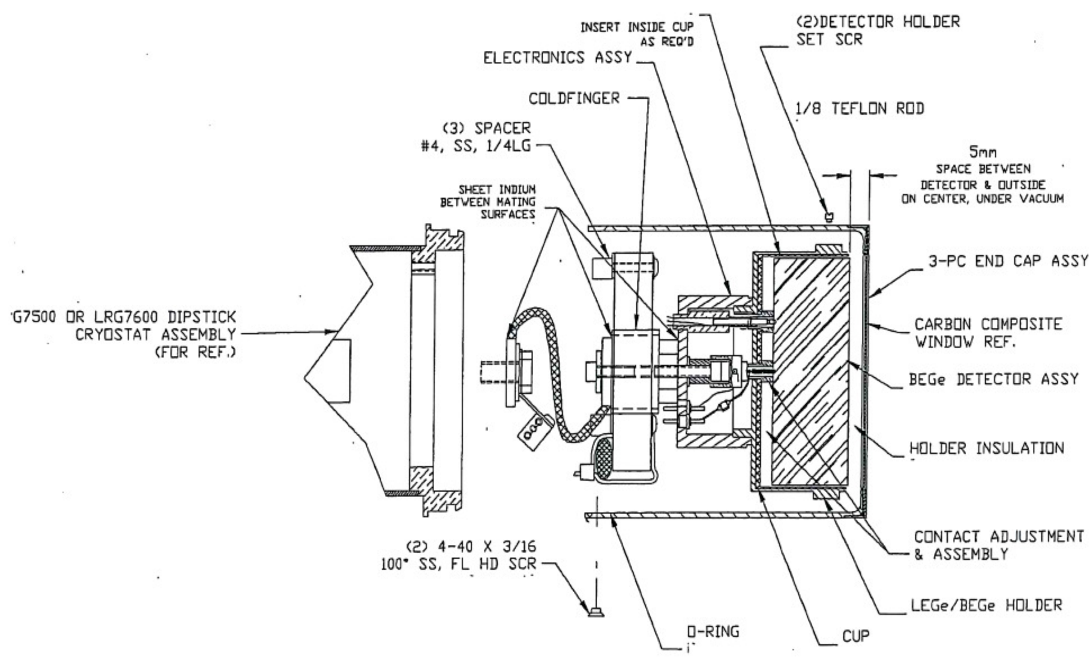

Fig.1. The cross-section of BEGe-5030 detector.

To choose the optimum shaping time constant, we use the ^{137}Cs and record the change of FWHM value at 661.657 keV when alter the shaping time constant. The dependence of FWHM on the shaping time is presented in Fig.2. From Fig.2 we can see that, the optimum shaping time for low counting is 6 μs, besides this value tends to be 4 μs for high counting.

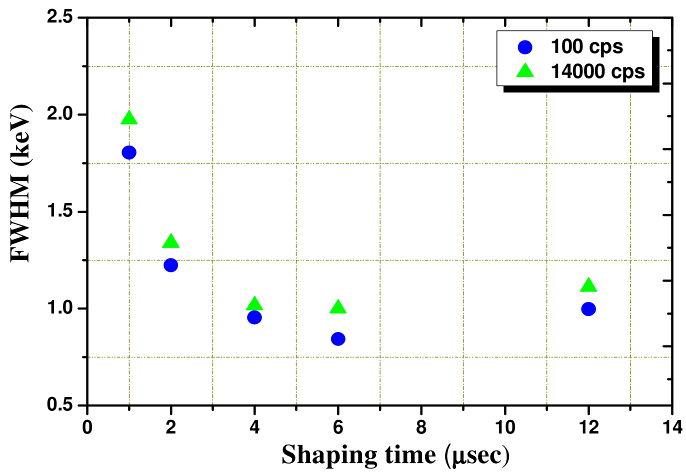

Fig.2. The dependence of FWHM on shaping time. The higher curve is for 14000cps ADC input, the lower curve is for 100 cps ADC input.

During our experiment, the gamma spectra were measured with: bias voltage of 4000V, shaping time of 6 μs and the coarse gain is 20, the fine gain is 10 [5]. This paper, we used the IAEA gamma standard sources including ^{137}Cs, ^{60}Co, ^{57}Co, ^{109}Cd, ^{133}Ba, ^{54}Mn. The parameters of each source are listed in table 1. The spectra of these sources were taken with the same experimental geometry

Table.1. The results of determining energy resolution and parameters of gamma sources.

Sources	A_{ref} (Bq)	Date reference	E_γ (keV)	I_γ %) [7]	FWHM (keV)
Co-57	3.70E+04	1/7/2010	122.0614 136.4743	85.6 10.68	1.133 1.148
Co-60	3.70E+04	1/7/2010	1173.237 1332.501	100 99.985	1.705 1.761
Cd-109	3.70E+04	1/7/2010	88.04	3.61	1.091
Na-22	3.70E+04	1/7/2010	1274.53	99.944	1.741
Mn-54	3.70E+04	1/7/2010	834.848	99.976	1.573
Cs-137	3.70E+04	1/7/2010	661.657	85.1	1.494
Ba-133	3.70E+04	1/7/2010	53.161 80.997 160.613 223.234 276.398 302.853 356.017 383.851	2.199 34.06 0.645 0.45 7.164 18.33 62.05 8.94	1.059 1.086 1.159 1.210 1.251 1.271 1.309 1.328

In each measurement, the spectra recording time is long enough to make sure the statistic error of peak area less than 1%. Measurement results are given in table 1. In table 2, N is number of counts in the photo-peak and t is counting time (in second).

3. Results and discussion

From experimental results, the energy calibration curve wase abtained by applying the method of least squares, as shown in Fig.3. To abtain the dependence of the FWHM on gamma energy, the experimental data have been fitted by using Equation 2, with c^2 = -4.3006E-7; p^2=0.00213; e^2=1.00961. The dependence of FWHM on gamma energy was shown in Fig 4.

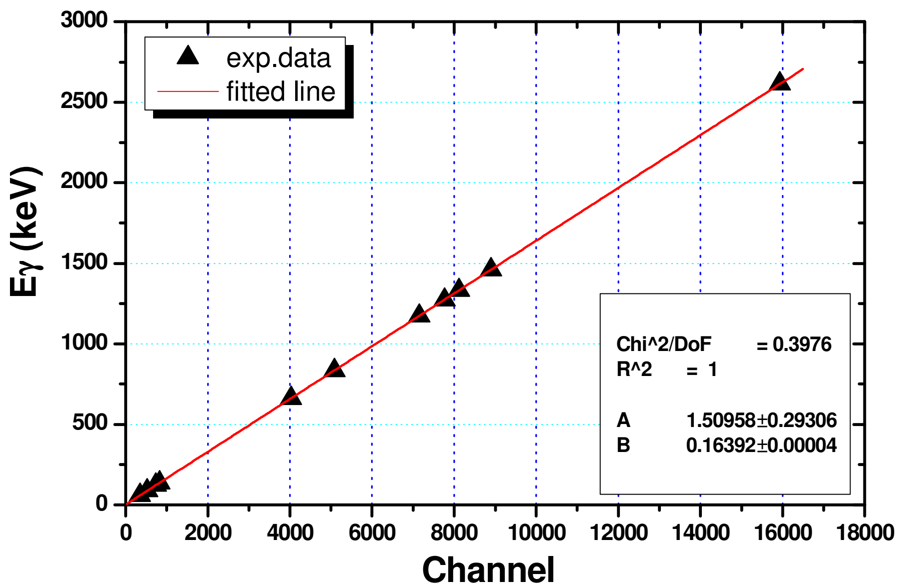

Fig.3. The energy calibration line for the BEGe-3050 detector.

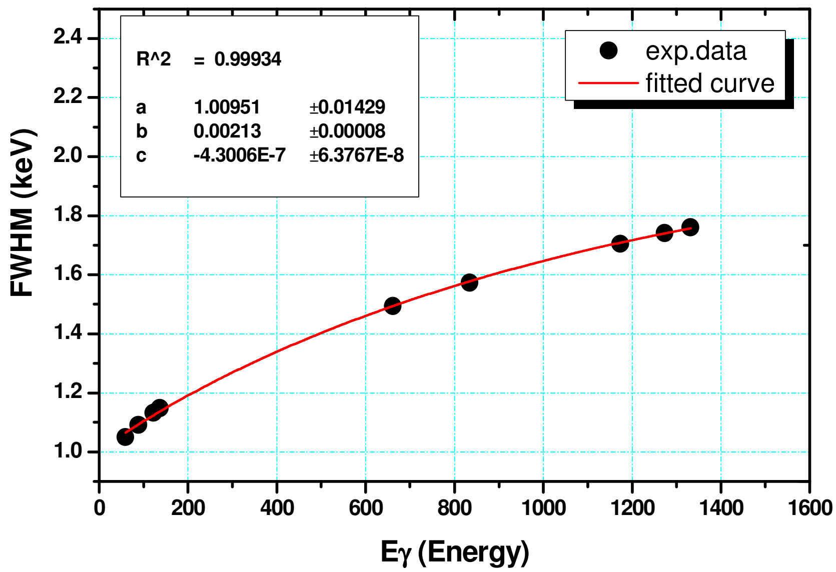

Fig.4. The dependence of FWHM of BEGe-3050 detector on gamma ray energy.

Table 2. The experimental photo- peak efficiences of the BEGe-3050 detector

Eγ (keV)	d = 4.4 cm			d = 12.4 cm		
	Counts	t (s)	Efficiency	Counts	t(s)	Efficiency
53.161	19061	1171.3	0.0420±0.0009	8453	1785.6	0.0090±0.0006
80.997	5.93E5	1171.3	0.0442±0.0019	2.18E5	1785.6	0.0106±0.0002
88.04	44862	1669.05	0.0441±0.0020	12693	1818.96	0.0115±0.0003
122.061	126739	311.38	0.0489±0.0011	127547	1187.4	0.0129±0.0045
136.474	16610	311.38	0.0514±0.0012	16537	1187.4	0.0134±0.0039
276.398	63447	1171.3	0.0246±0.0074	36686	1785.6	0.0085±0.0001
302.853	1.54E5	1171.3	0.0213±0.0017	85849	1785.6	0.00779±0.00015
356.017	4.63E5	1171.3	0.0189±0.0010	25169	1785.6	0.00675±0.00014
383.851	7.57E4	1171.3	0.02150±0.00057	3.33E4	1785.6	0.00620±0.00013
661.657	127897	322.38	0.0130±0.0003	15389	127.13	0.00397±0.00086
834.848	29048	232.03	0.0108±0.0002	12701	345.81	0.003177±0.00069
1173.23	108996	589.82	0.0603±0.0013	13537	238.53	0.001853±0.00040
1274.53	44865	321.7	0.0055±0.0002	12670	241.26	0.00208±0.00045
1332.50	96376	589.82	0.0053±0.0001	12353	238.53	0.00169±0.00037

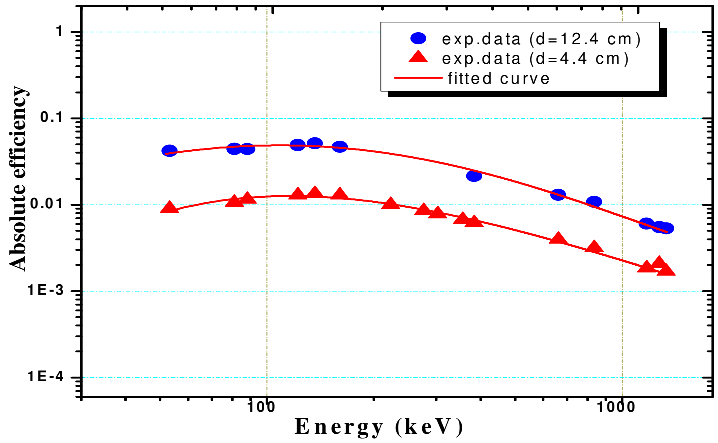

Fig.5. The efficiency curves of the BEGe-3050 detector with different geometries.

From the obtained counting numbers in the photo-peak and according to the eq.(3), absolute efficiency were calculated. Absolute efficiency curves determined at different source to detector distances of 4.4 cm and 12.4 cm. They are showed in table 2. From our calculated results, the absolute efficiency curves of the BEGe-3050 detector were obtained by applying the method of least square. Our calculated results absolute efficiency were fitted by using the eq.(4), which was showed in Fig 5.

The effects such as deadtime, random summing, true coincidence, were also corrected. The least square fit to this data gave a statistical error of 1%.

The results of shaping time, energy resolution and efficiency are in good agreement with measurement nuclear data. The results have the meaning for checking the spectrometry, and for particular applications such as environmental analysis, research on basic science. Especially, because of having good resolution in the region of enegy below 100keV, it can be use for determining the abudance of uranium material. The errors of the result was calculated by the error propagation formula.

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