Investigation of add-back effects in a segmented Clover detector*

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Abstract The resolution and the summing characteristics of an EXOGAM segmented Clover germanium detector has been studied for use it in γ spectroscopic experiments. The measurements have been performed with standard radioactive sources of ^{152}Eu, ^{133}Ba and β-delayed γ-rays from ^{176}Ir decay. The data analytic results, realized by software, are presented in this paper.

Key words Clover detector, energy resolution, summing characteristics

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1 Introduction

In the near future, the production of radioactive beams, such as those which will be provided by HIRFL (Heavy Ion Research Facility in Lanzhou) [1, 2], will open a wide field for the spectroscopy of nuclei far from the valley of stability. There have been consistent efforts in recent years to produce high-resolution and high-efficiency detectors for γ-rays to study the level structure of residual nuclei produced in heavy ion fusion-evaporation reactions. Precision γ-ray spectroscopy with High-Purity Germanium (HPGe) detectors is an important part of the research programme at virtually all nuclear physics accelerator laboratories [3]. The Compton-suppressed HPGe detectors，which have been used for more than two decades, have relatively low γ detection efficiencies. The necessity to have higher efficiencies led to the development of Compton-suppressed Clover detectors in the last decade [4–6]. The characteristics of the Clover detector-consisting of four crystals placed side by side in a single housing - have previously been extensively studied in several papers [7, 8]. The potential to sum γ-ray energies deposited in multiple crystals for the reconstruction of the photo peak events is the largest advantage of the use of a Clover detector. The total full-energy peak efficiency in add-back mode has been provided by Monte Carlo simulations and experimental measurements. It is proved that a highly efficient Clover detector is well suited for detecting the relatively small number of events of interest. The Clover detector would also be suitable for the Particle Induced Gamma-ray Emission (PIGE) analysis and neutron-induced Prompt Gamma Activation Analysis (PGAA) because of the high-energy efficiency [4]. In addition, the polarization-sensitive Clover detector can be applied to measure the linear polarization of γ rays [9, 10]. In the present paper, based on the analysis of experiment data, we report on the resolution and the summing characteristics of an EXOGAM segmented Clover germanium detector in the Institute of Modern Physics of the Chinese Academy of Sciences.

2 The EXOGAM segmented Clover detector

The EXOGAM segmented Clover detector [11]

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developed by CANBERRA EURISYS consists of four closely-packed coaxial N-type HPGe detectors in a common cryostat, arranged like a four-leaf Clover. Each of the four individual germanium crystals A, B, C, D, has a 60 mm×60 mm cross-section and 90 mm length. Each crystal is electrically segmented in four regions. This represents a total of 16 different segments in one Clover detector and each segment can be used as a separate detector with an independent output. These outputs can be externally added through hardware electronics or software to give an energy output which will look like the output of a single large detector. However, the timing characteristics of the added signals will be similar to that of each individual detector. Moreover, the localization of the interaction point can be provided when one segment fires. The geometry of the crystals inside the aluminum vacuum chamber is shown in Fig. 1. A common high voltage supply provides a positive bias of +3500 V(max) to the inner side of the crystal with P-type contact in all the four crystals. The HPGe crystals are maintained at a very low temperature by a liquid nitrogen dewar.

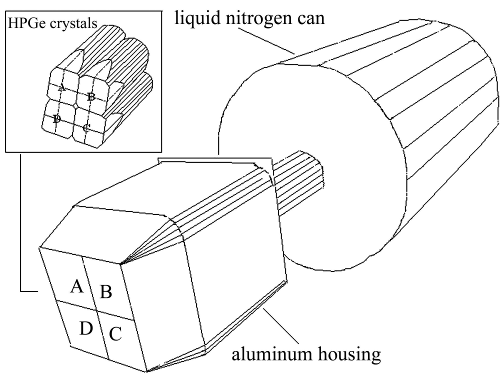

Fig. 1. Schematic view of the geometrical arrangement of HPGe crystals in a segmented Clover detector.

3 Experimental set up and measurements

The experiment was carried out at the Sector-Focusing Cyclotron (SFC) accelerator at the National Laboratory of Heavy-Ion Accelerator in Lanzhou. Gamma rays from standard γ-ray sources or fusion-evaporation reaction ^{146}Nd(^{35}Cl, 5nγ)^{176}Ir were detected by an EXOGAM segmented Clover detector. The reaction products collected by a programmable helium-jet recoil fast tape transport system [12–14] or radioactive sources ^{152}Eu and ^{133}Ba are placed at about 10 cm from the front face of the detector. The energy outputs from four pre-amplifiers corresponding to four crystals (A, B, C and D) in the Clover detector were amplified using four spectroscopy amplifiers (Ortec mod.673). The timing signals from the Clover preamplifiers are given to four timing filter amplifiers (Ortec mod.474) and then to a constant fraction discriminator (Ortec mod.CF8000). The timing signals independent of the pulse amplitudes from CF8000 are delivered to an octal gate and delay generator (Ortec mod.GG8000). An AND function is applied to these adjusted output signals from GG8000 by using a quad 4-put logic unit (Ortec CO4010), providing a logic signal whenever at least two of the HPGe crystals responds to a γ-photon. The logic signal from CO4010 is delayed and widened by another GG8000 to obtain the resulting coincidence gate signal. Signals from the amplifiers are digitized using an analog-to-digital converter (ORTEC ADC) which is gated by the coincidence gate signal. List-mode data containing the time and energy messages of all events were collected in singles and coincidence mode and stored on a computer hard disk through a multiparameter data acquisition system (MPA-3) purchased from Germany.

4 Data analysis and discussion

From the list-mode data the single projections of ^{152}Eu and ^{133}Ba standard sources for each of the four detectors were obtained. These projections were used to obtain the parameters for matching the gains for each of the four detectors to precisely 0.5 keV/channel. The gain matched data for all the four detectors were used for all subsequent analysis, realized by software. From the consideration of the singles projections obtained for each of the four detectors, the energy resolutions of Clover C and D are too poor to study their add-back effects. However, it is fortunate that Clover A and B are good enough, so that the energy resolution and the summing characteristics of two-fold events can still be studied. Hence, during the off-line analysis, if the crystals A and B are fired simultaneously, their gain matched signals are processed by programs.

In precision γ-ray spectroscopy experiments, excellent energy resolution is important to provide high sensitivity to weak γ rays. For a single HPGe crystal, the γ-ray energy resolution $\delta E_{\gamma_{\rm crystal}}$ is given by the full-width at half-maximum (FWHM) of the photo peak. It is well known that $\delta E_{\gamma_{\rm crystal}}$ can be written as [3]

$$\delta E_{\gamma_{\rm crystal}} = \sqrt{\delta E^2_{\gamma_{\rm E}} + \delta E^2_{\gamma_{\rm D}} + \delta E^2_{\gamma_{\rm X}}}\ , \qquad (1)$$

where δE_{γ_E}, δE_{γ_D}, δE_{γ_X} represent respectively electronic noise, the intrinsic resolution of the detector and incomplete charge collection. However, for a Clover-type detector, the above energy resolution formula cannot directly be applied when the energy of a photo peak depositions in more than one crystal. For instance, in the present situation that two crystals are added to obtain an added-back photo peak event, the peak width $\delta E_{\gamma_{c2}}$ will be

$$\delta E_{\gamma_{c2}} = \sqrt{\delta E_{\gamma_{cryst}}(E_1)^2 + \delta E_{\gamma_{cryst}}(E_2)^2}\,, \qquad (2)$$

here $E_\gamma = E_1 + E_2$, the energy deviation will be different for each event and the average of many such events will give the FWHM of the add-back scheme for two-crystal photo peak events. It can be understood easily that the energy resolution of the add-back photo peak will be worse than that of one single crystal. In Fig. 2 we compare a typical energy resolution of 260.3 keV photo peak obtained from a single HPGe crystal A or B with that of the summation of two crystals. As expected, it is seen that there is a slightly higher FWHM (3.9 keV) in the add-back spectrum compared to that in a single crystal spectrum (2.2 keV or 3.1 keV). Similarly, the further effective resolution of the four-crystal Clover scheme can therefore be approximated by [3]

$$\delta E_{\gamma_c} = P_1 \delta E_{\gamma_{c1}} + P_2 \delta E_{\gamma_{c2}} + P_3 \delta E_{\gamma_{c3}} + P_4 \delta E_{\gamma_{c4}}\,, \quad (3)$$

where the coefficients P_1, P_2, P_3 and P_4 are the probabilities of one-, two-, three-, and four-crystal events, and depend on E_γ. Furthermore, when the γ rays are emitted from nuclei with a non-zero velocity, a contribution of Doppler effects will be considered [15].

The summing characteristics are one significant feature for a segmented Clover detector. A γ ray is detected in a Clover either through absorption of full energy in a single crystal or in two, three or even four crystals through a Compton scattering process [8, 16]. In this situation, some fraction of γ-rays lose their full energy as Compton events in two or more detectors. These coincidence events are recorded in list coincidence mode and they can be recovered into the photo peak by adding the gain matched coincidence signals of all the four detectors. The photo peak total efficiency in this add-back mode will, therefore, increase by a add-back factor F [7, 15],

$$F = 1 + \varepsilon_{\text{add-back}} \Big/ \sum_{i=1}^{4} \varepsilon_i\,, \qquad (4)$$

where ε_i and $\varepsilon_{\text{add-back}}$ are the photo peak efficiencies in individual crystals and the add-back mode efficiency obtained by summing the two-fold, three-fold and four-fold events.

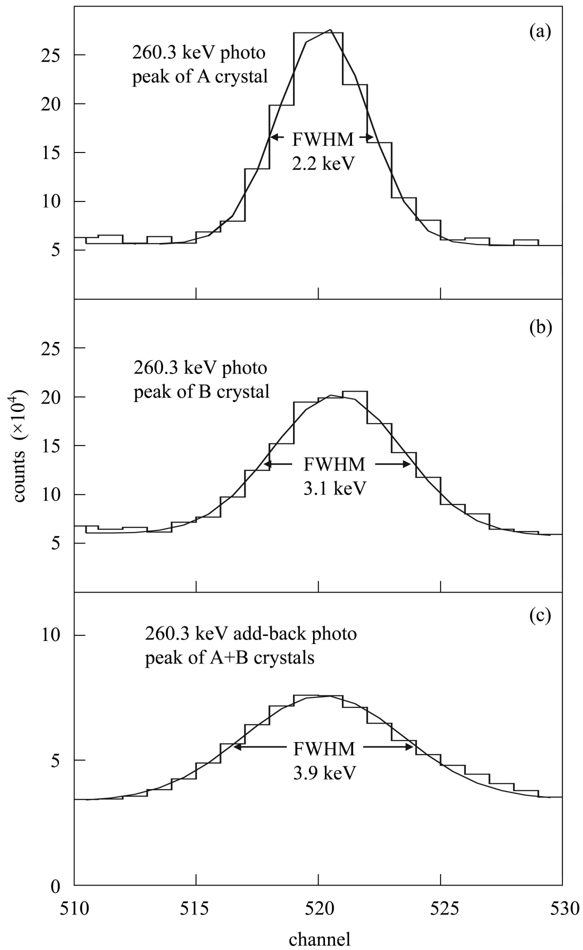

Fig. 2. A typical resolution of the 260.3 keV photo peak from ^{176}Ir decay obtained in single mode and add-back mode.

In the process of addition of two-fold events, it is possible that one of the crystals detects a photo peak and the other detects a Compton event. The addition of such an event results in a Compton event in the higher-energy region. If the two crystals record Compton events of the same photo peak, the photo peak signal will be recovered. When two crystals record Compton events of the different photo peaks, a new Compton event arises in the energy spectra. However if both the crystals record photo peaks, the addition gives rise to a sum peak. In order to illustrate the above character, Fig. 3 shows the reference spectrum characteristic of a single Clover crystal A in the upper panel and the two-fold add-back spectrum of crystals A and B in the lower panel. As it is clear in this figure, the recovered photo peaks (135.0, 260.3, 346.9 keV etc.) and the sum peaks (123.0, 195.0, 206.4 keV etc.) are presented in Fig. 3(b). The Compton-background moves to the high energy region. It is worthwhile to note that the reference spectrum was obtained from crystal A when crystal

B was fired simultaneously and the add-back spectrum was processed with the summation of the simultaneous signals of crystals A and B. Considering two-fold summing effects of A and B crystals, one can obtain a high photo peak efficiency and the efficiency will be improved with the increasing of γ-ray energy. For instance, the efficiencies increase by about 20% at 260 keV, 30% at 346.9 keV, 49% at 437.0 keV etc. Certainly, in the future it is necessary to study the three-fold and four-fold add-back characteristics in detail using good experimental data to assure that all four Clover crystals work well.

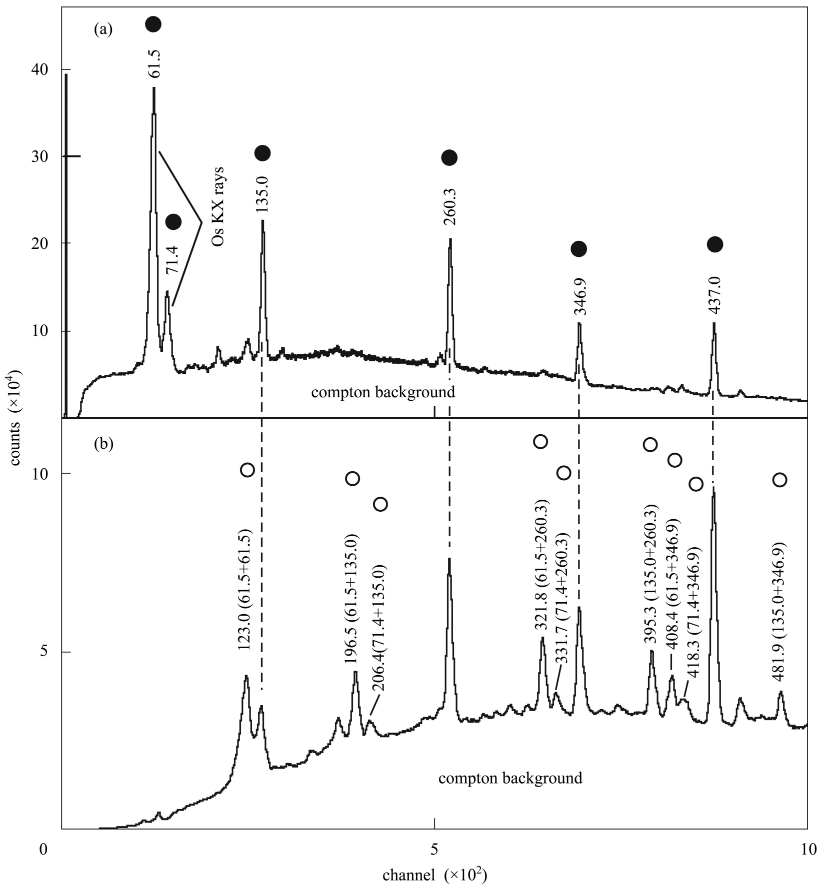

Fig. 3. Summing effects of photo peaks in a Clover detector. (a) Single spectrum of A crystal, (b) add-back spectrum of A and B. Solid and open circles correspond to photo peaks and sum peaks, respectively.

5 Conclusions

The qualitative analysis of the energy resolution and the summing characteristics for a Clover detector were investigated using heavy-ion evaporation reactions. Though the resolution will worsen slightly in the add-back mode, the high efficiency due to the recovered photo peaks is attractive in γ spectroscopic experiments.

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