Investigation of the Response Function of the Schottky CdTe detector with Guard-ring Cathode Through Monte Carlo Calculation and Measurement

Akram Mohammadi¹⁾, Mamoru Baba¹⁾, Hiroko Ohuchi²⁾

1) Cyclotron and Radioisotope Center, Tohoku University

2) Graduate School of Pharmaceutical Sciences, Tohoku University

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We investigated the response function of a Schottky CdTe detector with a guard-ring cathode through Monte Carlo calculation using the MCNP code and measurement in order to apply the detector for the analysis of X- and γ -ray spectra in medical radio-diagnostic units for quality assurance and quality control of the systems. The CdTe detector has high potential as an X- and γ -ray spectrometer owing to compactness due to a large photon absorption cross section and high energy resolution.

We measured the detector response function for various operating conditions, i.e., bias voltage and shaping time using an ^{241}Am source to find the optimum operating condition, and then measured the detector responses and full energy absorption efficiency for ^{241}Am , ^{152}Eu , ^{133}Ba and finally compared with the calculation. The experimental response functions are well reproduced by the MCNP code except for the part of the low energy tail due to charge trapping effect.

Key words: Schottky CdTe detector, detector response function, Monte Carlo calculation, detector performance, full energy absorption efficiency

1. Introduction

The assessment of the radio diagnostic systems performance requires knowledge on the incident X- and γ -ray spectra. For this purpose, an X- or γ -ray detector with high energy resolution is of prime importance. Compactness of the detector is also necessary because of a limited space available in some X-ray units. The Hp-Ge detectors which are widely used as high energy resolution X- or γ -ray spectrometer are quite large and hard to arrange in the limited space of some radio diagnostic X-ray units such as X-ray CT and Mammography.

CdTe detectors are much more compact than Hp-Ge detectors and offer sufficient photon detection efficiency and to a great advantage they can be used at room temperature^{1),2)}. Therefore they can be good candidates as X-ray spectroscopic systems. However, energy resolution of the CdTe detectors may be influenced by the charge carrier trapping effect³⁾. This effect reduces photo-peak efficiency

and causes a low energy tail structure in γ -ray peak area, and hence deteriorates energy resolution. Moreover, instability in long-term continues operation of the diode detector is observed due to a polarization effect in the semiconductor device. Nevertheless the Schottky CdTe diode detector with a guard-ring cathode has high energy resolution and good stability when it operates at sufficiently high bias voltage⁴⁾.

In order to evaluate the performance of the Schottky CdTe detector as a medical X-ray spectrometer, detailed information is required on the detector response function to investigate the detector spectroscopic properties. For this purpose the Monte Carlo simulation is a powerful technique and in this regard the MCNP4C code has been successfully used for detector response calculation by Gallardo et al. in order to determine primary X-ray spectra in radio diagnostic systems^{5),6)}.

In this work, we investigated the response function and

For Correspondence: Akram Mohammadi
Cyclotron and Radioisotope Center, Tohoku University
Aoba-6-3, Aramaki, Aoba-ku, Sendai, Miyagi, 980-8578, Japan

TEL: 022-795-7806 FAX: 022-795-7809
e-mail: akram@cyric.tohoku.ac.jp

efficiency of a Schottky CdTe diode detector in the energy range which is important in the medical diagnostic field after evaluating the detector performance at various operating conditions and the detector stability.

2. Materials and methods

2.1 Experimental method

The experimental equipment includes a Schottky CdTe detector, a spectroscopy amplifier, a multi channel analyzer (MCA) and some radioactive sources. The detector employed in this study was a Schottky CdTe detector using a guard-ring cathode (provided by Clear Pulse Company and thereafter referred as a Schottky CdTe detector). It is a planar detector with the crystal size of 6×6 mm² and 0.3 mm thick. The cathode electrode is made of platinum and separated into two parts; central cathode which is the active area for γ -ray detection, and a guard-ring cathode surrounding the central cathode. The width of the guard ring is 0.950 mm, gap between electrodes is 0.050 mm and the active area is 4×4 mm². The anode surface is made of indium and in full contact. The detector has two windows made of aluminum and Kapton with the same thickness of 0.05mm. The guard ring electrode is connected to the ground directly and the indium electrode is connected to positive voltage. The signal from the detector is fed to a charge sensitive preamplifier and spectroscopy amplifier with selectable shaping time from 0.5 μ sec to 10 μ sec.

In this study, the spectra of ²⁴¹Am source was measured at various bias voltage and shaping time for search of the optimum operating condition. Then the spectra of ¹³³Ba and ¹⁵²Eu sources were measured in the optimum operating condition and finally the detector stability was studied for a long-term operation. In all experiments, the sources were located in close contact with the detector without any collimator, because the activity of the sources was low and the pile-up effect did not occur in the detector.

2.2 Simulation Method

The MCNP4C code is suitable for modeling the detector response because it contains the F8 tally which is named pulse height tally and provides the energy distribution of pulses created in a detector in addition to the capability to take into account the geometry in detail. The detector resolution has been taken into account in the simulation by use of a Gaussian energy broadening (GEB) function which

corresponds to the detector FWHM (full width at half maximum) observed for the ²⁴¹Am source. In the calculation, however, we could not take into account the carrier trapping effect of the detector because of the code limitation. The dead layer was not considered too because of thin thickness. The radioactive sources were modeled as a point or surface source with their energy distribution given in reference⁷. The minimum discrepancy between calculation and measurement were found for the case of the surface source model. This will be due to the fact that the sources were contacted to detector closely in which the source dimension cannot be neglected compared to the dimensions of the experimental setup.

The number of photons starting from the source was increased up to 10^8 to achieve good statistical accuracy. The energy bin was specified equal to that in the measurement. In addition, the full energy absorption efficiency of the detector was also calculated for monoenergetic sources and compared with the measured ones for 60 and 81 keV γ -rays.

3. Results and discussion

3.1 The detector performances at various operating conditions and the detector stability

The measured spectra of ²⁴¹Am at bias voltage of 50, 100 and 200 V and shaping time of 0.5 μ sec, 2 μ sec and 5 μ sec are given in Fig. 1(a) and (b), respectively. The effects of the bias voltage and the shaping time are shown on the shape of the 60 keV line in these figures. Figure 1(a) indicates that the bias voltage of 50 and 100 V are not high enough in order

Fig.1. Spectra of ²⁴¹Am obtained with the Schottky CdTe detector with a guard ring cathode (a) at fixed shaping time of 2 μ s and various bias voltage and (b) at fixed bias voltage of 200 V and various shaping time.

to achieve complete charge collection for 60 keV γ -ray in the present 0.3 mm thick CdTe detector, as shown by larger tail structures due to the charge carrier trapping than at maximum voltage of 200 V. Then the bias voltage was set at 200 V.

For finding appropriate shaping time, the spectra of ^{241}Am was measured for all shaping times of 0.5, 1, 2, 3, 5 and 10 μsec and the results are given in Fig. 1(b). Optimum shaping time is chosen based on high counting rates and high energy resolution^(1), 8). The shaping time must be long enough to collect more charge carrier and it must be short enough to achieve the high counting rates. Too short shaping time leads to poor energy resolution because of incomplete charge collection. Hence the optimum shaping time should be set at midrange value, which is a compromise between maximum count rate and maximum spectral resolution. From Fig.1 (b) the quality of spectra in 60 keV optimized for 2 μsec shaping time in which the lowest FWHM was obtained to be 1.53 keV.

To confirm the detector stability, we kept the detector on during 24 hours, applying 200 V bias voltage with 2 μsec shaping time and measured ^{241}Am spectra for every five minutes. During 24 hours operation, the shift of 59.54 keV γ -ray was less than 0.33 %, and the change of integrated counts between 53.6 keV and 62 keV was less than 0.1%. The results indicate that our detector has good long-term stability.

3.2 Measurement and calculation of the detector response function

The response of the detector was measured at the optimum operating condition, 200 V and 2 μsec shaping time, for ^{241}Am , ^{133}Ba and ^{152}Eu sources. In Fig. 2, Fig. 3 and Fig. 4, we show the experimental results in comparison with calculation. From these results, the energy resolution is

Fig.2. Comparison of the measured γ -ray spectra of ^{241}Am with simulated spectra.

estimated to be 1.53 keV, 1.6 keV and 2.07 keV (FWHM) for 59.54 keV, 81 keV and 121.78 keV, respectively. In these figures, tailing is insignificant because our detector is thin (0.3 mm) and additionally it has a Schottky contact whose barrier is high enough to prevent injection of holes into CdTe crystal. In thick detectors, the tailing will be more serious because higher-energy photons penetrate more deeply and the drift distance of holes is longer. In the case of our thin detector, the drift distance of holes would be defined by the thickness of depletion layer (less than 0.3mm), then the tailing will not be more severe when γ -ray energy increases. As a trade off, the efficiency of our detector is limited to low values for high energy photons.

The full energy absorption efficiency of the detector was

Fig.3. Comparison of the measured γ -ray spectra of ^{133}Ba with simulated spectra.

Fig.4. Comparison of the measured γ -ray spectra of ^{152}Eu with simulated spectra.

Fig.5. Comparison of calculated and measured full energy absorption efficiency of the Schottky CdTe detector with a guard-ring cathode.

also been calculated using the MCNP4C code and compared with the measurement for 59.54 keV and 81 keV lines of ^{241}Am and ^{133}Ba sources, respectively. Figure 5 shows the calculated and measured efficiency of the detector. The dips at 26.5 and 31.5 keV are attributed to the escape of the K-fluorescent X-ray of Cadmium and Tellurium, respectively. The relative error between calculated efficiency and measured for 59.54 keV and 81 keV are 3.2% and 7%, respectively.

The general agreement between the calculation and the measurement confirms the validity of the calculation. It means the detector response function can be obtained successfully by the MCNP4C code because of insignificant carrier trapping in our detector.

4. Conclusion

In this study, at first we presented the response function of the Schottky CdTe detector with a guard-ring cathode for various bias voltage and the shaping time. Then the measured response function and the full energy absorption efficiency were compared with those calculated by the MCNP4C code.

From the detector response for ^{241}Am source in various operating condition, we found that higher full energy absorption efficiency and lowest tailing are achieved at the highest bias voltage of 200 V, and the optimum shaping time 2 μ sec as a compromise between energy resolution and pile up effect.

In this study, the detector response function and peak efficiency proved to be simulated generally well by the MCNP code except for the tail component due to charge trapping although the effect is not serious in the present thin

(0.3 mm) detector.

The detector will be applied to the characterization of medical X-ray fields with the calculated response and efficiency.

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