# Quantitative Analysis of Energy Spectrum Distortion for CdZnTe Detector

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## 1. Introduction

Cadmium Zinc Telluride (CZT) has combined relatively high atomic number ($Cd^{48}$, $Zn^{30}$, and $Te^{52}$) with enough bandgap energy (1.52 eV) to permit room temperature operation[1]. Hence, a semiconductor detector made of CZT has been employed in scientific and technological fields, most notably in medical imaging and high energy astrophysics[2]. However, due to the low transport properties of carriers, electron-hole pairs generated in CZT sensor by irradiated radiations cannot be completely collected[3]. Eventually, this problem leads to a significant distortion of the spectrum.

The distortion of radiation energy spectrum could be described with a model of charge drift in the semiconductor material and charge induction on the electrodes (cathode and anode). Therefore, the analysis of the suitable model for ion-pair (electron and hole) drift is very important thing to simulate the radiation response of CZT detector.

In this study, the simple model dependent on the interaction positions of incident radiations and mobility-lifetime ($\mu\tau$) of ion-pairs was studied to predict the charge collection efficiency on electrodes. Evident difference of energy spectrum caused by reflecting charge collection efficiency was evaluated for a CZT detector ($5\times5\times5$ $mm^3$) widely used in spectroscopy, using the Monte Carlo codes (Geant4[4] and MCNPX[5]).

## 2. Materials and Methods

The electron-hole pairs are generated from the energy loss of induced radiation in CZT sensor. The output pulse is proportional to the collected charge on the electrodes, and, that is, mainly dependent on the mobility-lifetime, $\mu_e\tau_e$ and $\mu_h\tau_h$, for electrons and holes, respectively. The charge collection efficiency is represented as the ratio of the number of charge carriers induced at the electrodes to the total number of carriers created by the radiation interaction. If the effect of detrapping is neglected, the charge collection efficiency for planar detector is given by the Hecht equation[6]:

$$\eta(z) = \frac{\lambda_e}{d}\left[1 - e^{-(d-z)/\lambda_e}\right] + \frac{\lambda_h}{d}\left[1 - e^{-z/\lambda_h}\right]$$

Where, d is the detector thickness, and $\lambda_e = \mu_e\tau_e E$ and $\lambda_h = \mu_h\tau_h E$ are the mean free paths of electrons and holes, respectively, in the case of radiation induced from the cathode surface. E is the strength of the electric field in CZT sensor.

In the study, the CZT detector manufactured by the "eV PRODUCTS" was selected to analyze the difference in energy spectrum of incident radiation. 59.5 keV gamma ray was assumed to be perpendicularly incident on the detector from $^{241}Am$, and was located at 1 m away from the CZT sensor. To compare the distortion of energy spectrum, Hecht equation was employed to Geant4 simulation, whereas, MCNPX simulation was performed without charge collection efficiency. All parameters for calculation of charge collection efficiency are shown in Table 1.

**Table 1. Parameters for Hecht Equation**

| | |
|---|---|
| Detector Size | $5\times5\times5$ [$mm^3$] |
| Detector Density, ρ | 6.1 [$g/cm^3$] |
| Electron-Hole Creation Energy, w | 4.6 [eV] |
| Mobility-Lifetime (Electron, $\mu_e\tau_e$) | $1.69\times10^{-3}$ [$cm^2/V$] |
| Mobility-Lifetime (Hole, $\mu_h\tau_h$) | $3.76\times10^{-5}$ [$cm^2/V$] |
| Biasing Potential, E | 500 [V] |

## 3. Results and Discussions

The number of ion-pairs generated as a function of CZT depth was calculated by MCNPX, as shown in Figure 1. The spatial distribution of produced ion-pairs in CZT sensor was also shown in the figure. It can be seen that the number of generated electron-hole pairs is exponentially decreased along with the penetration depth of radiation. Especially, it is found that most of ion-pairs are generated within 0.3 mm depth from the cathode surface.

The total charge collection efficiency as a function of position within the detector was illustrated by using the Hecht equation as shown in Figure 2. It was recognized that the maximum charge collection efficiency was about 87% at 0.1 mm from the incident surface. It was also shown that most of collected charge was caused by the electron. Since the mean free path of electrons ($\lambda_e$) is much longer than the holes about 40 times, they can be reached easily to the positive electrode (anode).

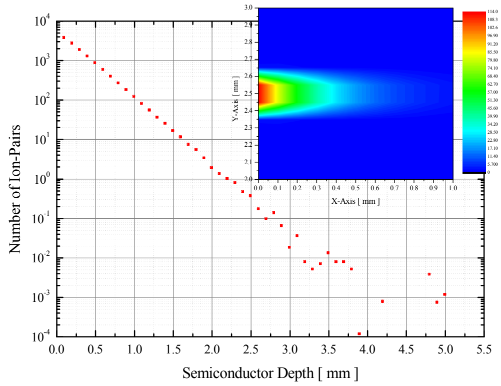


**Fig. 1. Number of Electron-Hole Pairs Generated as a Function of CZT Depth**

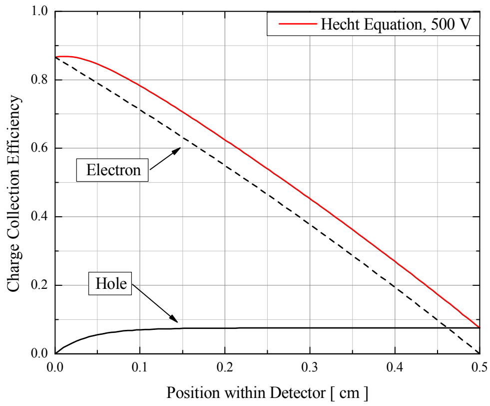


**Fig. 2. Charge Collection Efficiency (η) as a Function of Position within a Semiconductor Detector with a Constant Electric Field**

The energy spectrum of 59.5 keV gamma rays was calculated by Geant4 and MCNPX, as shown in Figure 3. Due to the reflecting charge collection efficiency in Geant4 simulation, full energy peak of incident radiation has a discrepancy about 7 keV. It was also recognized that tail effect at the low energy ranges could be simulated from the Hecht equation.

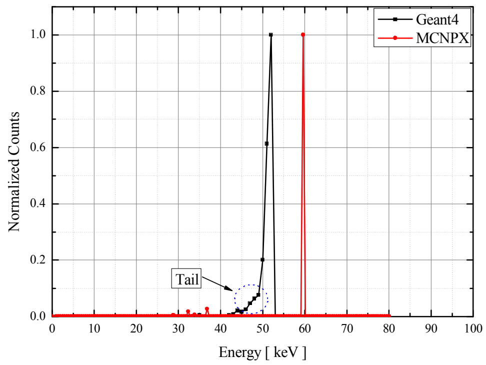


**Fig. 3. The Energy Spectrum of Incident Gamma-Ray (59.5 keV) Calculated from Geant4 and MCNPX**

## 4. Conclusions

When a CZT detector was used in the spectroscopy, a spectrum distortion was caused from poor charge collection and relatively small mobility-lifetime of holes. With the aim of interpreting these problems, the Hecht equation was researched, and was employed to simulate energy spectrum of radiation source.

It can be found that calculation result from the Monte Carlo codes has a significant discrepancy of full energy peak position. Also, tailing effect at low energy range can be simulated through the reflecting the charge collection efficiency.

Therefore, this study has been supplied that a quantitative difference of energy spectrum distortion for CZT detector ($5 \times 5 \times 5$ mm$^3$) is about 7 keV. Also, the contents in the study can be applied to simulate the electron-hole motion in CZT sensor and to analyze the measured spectrum from the semiconductor detector.

## Acknowledgement

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