Comparative Beta-ray Spectroscopic Performance of Identically Grown CdZnTe and CdZnTeSe Crystals

Younghak Kim[a], Mee Jang[a], Jiwon Seo[b], Jung-Yeol Yeom[c], Beomjun Park[d,*]
[a]*Environmental Radioactivity Assessment Team, Nuclear Emergency & Environmental Protection Division, Korea Atomic Energy Research Institute, Daejeon 34057, Korea*
[b]*Korea Institute of Fusion Energy (KFE), Daejeon 34133, Korea*
[c]*School of Biomedical Engineering, Korea University, Seoul 02841, Korea*
[d]*Nuclear Research Institute for Future Technology and Policy, Seoul National University, Seoul 08826, Korea*
[*]*Corresponding author: pbj0116@snu.ac.kr*

***Keywords :** CdZnTeSe, Beta-ray spectroscopy, Semiconductor detector, Charge collection efficiency

1. Introduction

Beta-emitting radionuclides are closely associated with nuclear power plants, decommissioning processes, and environmental monitoring. In particular, high-energy beta emitters such as ^{90}Sr require reliable spectroscopic techniques to assess contamination levels and radiological risk. Conventional beta detectors, including liquid scintillation counters and gas-flow proportional counters, often suffer from limited energy resolution, bulky system configuration, or operational complexity. Semiconductor detectors based on CdTe compounds offer compact geometry, high stopping power, and the possibility of energy discrimination.

Recently, CdZnTeSe (CZTS) has emerged as a promising alternative to conventional CdZnTe (CZT), owing to its reduced defect density and improved charge transport properties [1–3]. While the superior gamma-spectroscopic performance of CZTS has been reported, its beta-ray spectroscopic characteristics, particularly under identical crystal growth conditions, have not been systematically compared.

In this study, planar CZT and CZTS crystals grown under identical Bridgman conditions were fabricated and evaluated. Their gamma-response was first analyzed to establish material quality and energy calibration, followed by beta-ray spectroscopic measurements. Finally, experimental results were quantitatively compared with Monte Carlo simulations to evaluate the influence of charge transport properties.

2. Methods and Results

2.1 Gamma-response evaluation of identically grown CZT and CZTS crystals

Figure 1 shows the pulse height spectra of low- and high-energy gamma-ray sources obtained from the grown CZT (a–c) and CZTS (d–f) detectors. Low-energy gamma lines at 59.5 keV and 81 keV were clearly observed in both materials. However, CZTS exhibited more distinct photopeaks and improved spectral definition compared to CZT.

The improved performance of CZTS is attributed to the reduction of Te inclusions, suppressed sub-grain boundaries, and enhanced carrier transport properties induced by selenium incorporation [3, 4]. Although both detectors were configured in planar geometry without single-carrier sensing structures, CZTS demonstrated superior peak clarity, indicating improved intrinsic material quality.

At higher gamma energies (e.g., 662 keV), both detectors exhibited degraded peak definition due to limited detector thickness and increased hole contribution. Nevertheless, the overall spectral response confirmed that CZTS possesses improved charge transport characteristics prior to beta-ray evaluation.

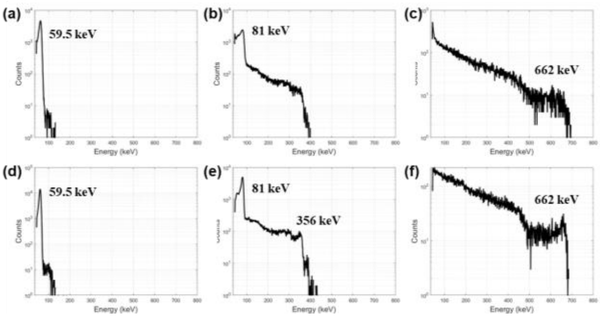

Fig. 1. Gamma-ray pulse height spectra of planar (a–c) CZT and (d–f) CZTS crystals grown under identical conditions. Low-energy responses at 59.5(^{241}Am) and 81 keV(^{133}Ba) and high-energy responses up to 662 keV(^{137}Cs) are compared to evaluate intrinsic material quality and charge transport characteristics. Physical dimensions of CZT and CZTS were 5.5×5.0×2.3 and 5.1×5.9×2.9 mm^3, respectively.

2.2 Pulse height spectra of beta-emitting radioisotopes

Figure 2 presents the pulse height spectra of beta-emitting radioisotopes obtained with CZT (a–c) and CZTS (d–f). Distinct spectral shapes corresponding to different beta sources were observed, reflecting their respective maximum energies and penetration depths.

For CZT, significant count loss and reduction of the maximum spectral energy (E_{max}) were observed across the energy range, particularly for high-energy beta emitters such as ^{90}Sr. This behavior indicates charge carrier trapping and recombination effects, which become more pronounced as interaction depth increases.

Since high-energy beta particles penetrate deeper into the detector, hole transport properties strongly influence charge collection efficiency in planar configurations.

In contrast, CZTS exhibited improved spectral retention and reduced high-energy signal loss. The enhanced performance is consistent with improved hole mobility-lifetime products reported for selenium-doped CdTe-based compounds [5]. These results demonstrate that material-level transport improvements directly translate into better beta-ray spectroscopic performance.

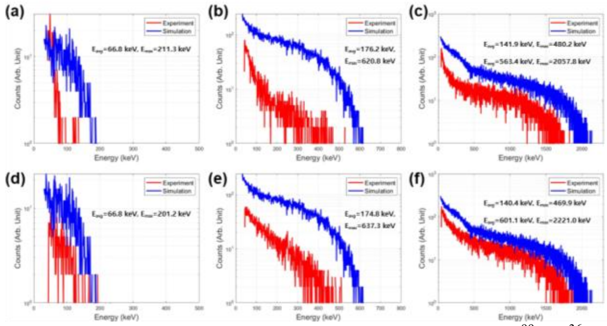

Fig. 2. Pulse height spectra of beta-emitting radioisotopes (^{99}Tc, ^{36}Cl, ^{90}Sr) obtained with (a–c) CZT and (d–f) CZTS detectors. The spectral retention and maximum energy behavior demonstrate the influence of carrier transport properties, particularly at higher beta energies.

2.3 Quantitative evaluation through experiment-to-simulation ratio

To quantitatively evaluate spectral performance, the ratio between experimental and simulated spectra based on the results of ^{90}Sr was calculated as shown in Figure 3. The simulated spectra were generated using Monte Carlo modeling (Geant4) incorporating detector geometries such as detector holder, sample size, surrounding materials and radiological information.

Across the entire energy range, CZTS exhibited consistently higher experimental-to-simulation ratios compared to CZT. The difference became more pronounced at higher energies, where charge carrier loss effects are dominant. This trend confirms that CZTS retains a larger fraction of deposited charge, resulting in improved charge collection efficiency.

The quantitative ratio analysis supports the interpretation that selenium incorporation enhances transport properties, reduces trapping-related signal loss, and improves spectral fidelity in beta-ray measurements.

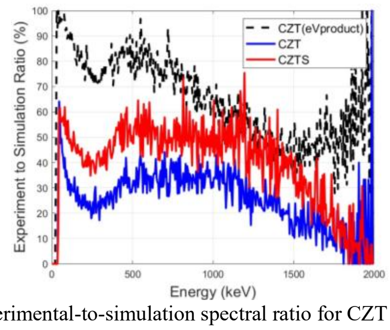

Fig. 3. Experimental-to-simulation spectral ratio for CZT and CZTS detectors across the measured energy range. Higher ratios in CZTS indicate improved charge collection efficiency and reduced signal loss compared to CZT.

3. Conclusions

In this study, planar CZT and CZTS detectors grown under identical conditions were systematically compared for gamma- and beta-ray spectroscopy. Gamma-response measurements demonstrated improved peak definition in CZTS, indicating enhanced material quality. Beta-ray pulse height spectra revealed reduced signal loss and improved high-energy retention in CZTS compared to CZT. Quantitative comparison using experimental-to-simulation ratios confirmed that CZTS maintains superior charge collection efficiency across the entire energy range. These findings demonstrate that selenium incorporation effectively enhances charge transport properties in CdTe-based semiconductors and improves beta-ray spectroscopic performance. Further performance enhancement is expected through the application of single-carrier sensing configurations such as pixelation or coplanar grid structures.

Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF), funded by the Korean government (MSIT) (RS-2025-00513114). It was also supported by the Nuclear Safety Research Program through the Korea Foundation of Nuclear Safety (KoFONS), using financial resources granted by the Nuclear Safety and Security Commission (NSSC) of the Republic of Korea (RS-2023-00231329).

REFERENCES

[1] Y. Kim, J. Ko, J. Byun, J. Seo, H. M. Park, B. Park, Characterization of high Zn content $Cd_{0.87}Zn_{0.13}Te_{0.98}Se_{0.02}$ grown using Bridgman technique, *Applied Radiation and Isotopes* 211 (2024) 111383.

[2] B. Park, J. Ko, J. Byun, B. Park, M. -J. Lee, J. Kim, Feasibility study of CdZnTe and CdZnTeSe based high energy X-ray detector using linear accelerator, *Nuclear Engineering and Technology* 55.8 (2023) 2797-2801.

[3] B. Park, Y. Kim, J. Seo, J. Byun, V. Dedic, J. Franc, A. E. Bolotnikov, R. B. James, K. Kim, Bandgap engineering of $Cd_{1-x}Zn_xTe_{1-y}Se_y$ ($0<x<0.27$, $0<y<0.026$), *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 1036 (2022) 166836.

[4] U. N. Roy, G. S. Camarda, Y. Cui, R. Gul, G. Yang, J. Zazvorka, V. Dedic, J. Franc, R. B. James, Evaluation of CdZnTeSe as a high-quality gamma-ray spectroscopic material with better compositional homogeneity and reduced defects, *Scientific reports* 9.1 (2019) 7303.

[5] K. Kim, Y. Kim, J. Franc, P. Fochuk, A. E. Bolotnikov, R. B. James, Enhanced hole mobility-lifetime product in selenium-added CdTe compounds, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 1053 (2023) 168363.