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Measurement of Electron Mobility in a Planar CZTS Detector Using Charge-Sensitive Preamplifier

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1. Introduction

Charge transport properties, especially carrier mobility, are key parameters governing timing response and charge collection performance in semiconductor radiation detectors. To evaluate the transport property, Hecht fitting is typically performed using the photopeak of 59.5 keV gamma rays of ^{241}Am, owing to their relatively low penetration depth. However, a more precise evaluation of individual charge carriers (either electrons or holes) requires an energy source that generates carriers much closer to the surface than those produced by 59.5 keV gamma rays.

In this study, an alpha-emitting radionuclide was employed to generate charge carriers at the irradiated surface. Two readout schemes, a current preamplifier and a charge-sensitive preamplifier (CSP), were compared for electron transit-time measurement in a planar $Cd_{0.9}Zn_{0.1}Te_{0.98}Se_{0.02}$ (CZTS) detector under alpha irradiation. For the present CZTS sample, the current preamplifier output did not provide a clear transit-time marker, whereas the CSP rise time enabled reliable extraction of electron transit time and electron mobility.

2. Methods and Materials

2.1 CZTS Detector

CZTS semiconductor materials with a 2-inch diameter were grown using the Bridgman method [1]. The resulting ingot was cut into wafers perpendicular to the growth direction. Planar specimens were then extracted and processed using dicing, polishing, and chemical etching as written in [2]. The physical dimension of the processed sample size was 4×4×2mm^3. The electrical resistivity of the CZTS detector was measured by two-probe current–voltage measurement system (Kiethley 4200A-SCS), and the value was 2.34×10^{10} Ω cm.

2.2 Transit-time measurement concept

The planar CZTS detector was operated at room temperature with negative bias applied to the cathode, and the cathode surface was irradiated with a ^{241}Am alpha source. In this configuration, alpha interactions occur near the cathode side, and the generated electrons drift across the detector bulk toward the opposite anode electrode.

Detector signals were measured using either a current preamplifier or a charge-sensitive preamplifier (CSP), and the outputs were directly digitized by an oscilloscope. Electron transit time was estimated from the waveform shape. The electron mobility was then calculated from the detector thickness (d), applied bias voltage (V), and transit time (τ_r) is given as follows:

$$\mu_e = \frac{d^2}{V\,\tau_r} \qquad (1)$$

where d=2 mm for the present detector and the applied bias voltage was 300 V.

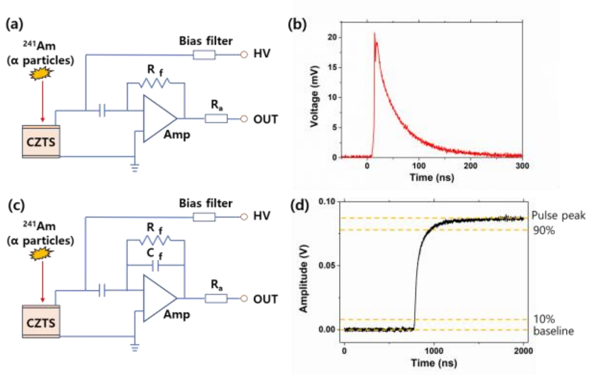

Fig. 1. (a,c) Schematic diagrams of transient signal measurements using a current preamplifier and a charge-sensitive preamplifier (CSP), respectively; (b,d) representative output waveforms measured from the CZTS detector using each readout configuration.

3. Results and Discussion

3.1 Limitation of current preamplifier output for transit-time extraction

The output waveform from the current preamplifier showed an exponentially decaying transient shape, rather than a waveform with a clearly identifiable plateau or sharp transition corresponding to the end of electron drift. As a result, it was difficult to define the electron transit time directly and reproducibly from the current preamplifier signal alone. This behavior is attributed to internal electric-field distortion caused by deep trapping, which has also been reported in previous studies on CZT/CZTS-related detectors [3]. Due to this distorted field condition, accurate mobility extraction was difficult when relying only on the current preamplifier output waveform.

3.2 Electron mobility measurement using CSP rise time

To overcome the above limitation, the rise time of the charge-sensitive preamplifier output was used as a proxy for the electron transit time. Because the CSP integrates the detector current, the rising portion of the CSP pulse reflects the charge collection process and provides a more robust timing observable than the exponentially decaying current preamplifier output.

Using the measured CSP rise time (10% to 90%), the electron transit time was determined as 124±1 ns and substituted into the mobility equation. The electron mobility measured in this work, 940±10 $cm^2/V\cdot s$, is consistent with literature values for CZTS, e.g., 830 $cm^2/V\cdot s$ in [3] and 964 $cm^2/V\cdot s$ in [4], and therefore lies within in the typically reported range of ～800–1000 $cm^2/V\cdot s$ for CZTS. The result demonstrates that CSP-based rise-time analysis can provide a practical and effective method for evaluating electron mobility in planar CZTS detectors when direct transit-time identification from current preamplifier waveforms is difficult due to internal electric-field distortion.

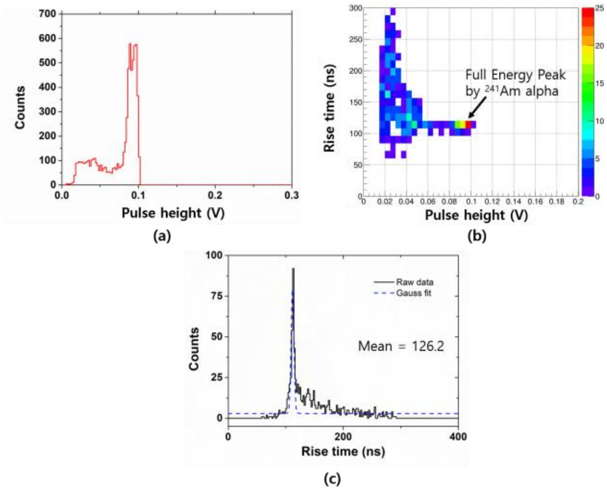

Fig. 2. (a) Pulse height spectrum measured using the charge-sensitive preamplifier (CSP), (b) two-dimensional distribution of measured rise time versus pulse height, and (c) histogram of the rise-time distribution used for electron transit-time analysis.

4. Conclusions

In this work, electron mobility in a planar CZTS detector was evaluated by cathode-side ^{241}Am alpha irradiation and transit-time analysis under applied bias voltage. The current preamplifier output exhibited an exponentially decaying waveform, which made direct transit-time determination difficult. By contrast, the rise time of the charge-sensitive preamplifier output provided a clear and reproducible measure of electron transit time.

Using this approach, the electron mobility of the CZTS detector was measured as 924 $cm^2/V\cdot s$. These results indicate that CSP rise-time analysis is a useful method for charge transport characterization of CZTS detectors, particularly when transient current waveforms do not show a distinct plateau. Furthermore, this approach can be extended to other semiconductor radiation detectors, such as CdTe, CZT, and TlBr, for practical carrier transport characterization based on transit-time analysis.

Acknowledgments

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