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Analysis of Physical Factors Influencing on Charge Collection Efficiency in CdZnTe Detector

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1. Introduction

A Cadmium Zinc Telluride (CdZnTe) detector has many properties that make it well suited for use as X-ray, gamma-ray and charged particle detectors [1]. Its wide band-gap energy allows it to be operated at room temperature. And its large atomic number offers high photon absorption cross-sections [2]. However, the charge carriers generated in the CdZnTe detector are inefficiently collected on electrodes due to their low transport properties. Consequently, the charge collection efficiency causes a significant distortion of the energy spectrum. Simultaneously, attention is also paid to the tailing caused by charge carriers trapping. The tailing is usually derived from the mean free path ($\lambda=\mu\tau E$) which can be calculated from the mobility-lifetime ($\mu_e\tau_e$ for electrons, and $\mu_h\tau_h$ for holes). And the mobility-lifetime can be calculated with the Hecht equation [3].

As shown in Table I [4], the data on the charge transport properties, which were published by various authors, are quite different from each other.

For that reason, the mobility-lifetime data of available published papers were employed to quantitatively evaluate the effect on the charge collection efficiency in the CdZnTe detector (5×5×5 mm^3) which was widely used in spectroscopy. Also, various bias voltages were applied to evaluate the change of charge collection efficiency.

2. Materials and Methods

When an incident gamma-ray forward the cathode surface is absorbed in CdZnTe sensor, a large number of electron-hole pairs are generated proportionally to the deposited energy. The electrons and holes are separated by the applied electric field, and drift to their respective electrodes. Also, the charge carriers depend on mobility-lifetime products, i.e., $\mu_e\tau_e$ for electron and $\mu_h\tau_h$ for hole, respectively. Then, the charge collection efficiency is computed as the ratio of the induced energy at the electrodes to the deposited energy by the incident radiation. In case of a uniform electric field and negligible de-trapping, the charge collection efficiency is determined as a function of interaction depth using the following well-known Hecht equation:

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

$$\lambda_e = \mu_e \tau_e E$$
$$\lambda_h = \mu_h \tau_h E$$

where, d is the thickness of the detector, z the distance from the cathode to the interaction point, μ the carrier mobility, τ the carrier lifetime, E the applied electric field, λ_e and λ_h are the mean free paths of electrons and holes, respectively.

To evaluate the characteristic of the charge collection efficiency using the Hecht equation, the data of the mobility-lifetimes were obtained from the published papers as shown in Table I.

Table I. The Data of the Mobility-Lifetime for Electrons and Holes in Published Papers

Author	$\mu_e\tau_e$ [cm^2/V]	$\mu_h\tau_h$ [cm^2/V]
J. A. Heanue (1996)	3.0×10^{-3}	1.6×10^{-5}
Khusainov (1999)	2.0×10^{-3} ~ 3.0×10^{-3}	1.5×10^{-4} ~ 2.0×10^{-4}
Y. Eisen (1999)	8.0×10^{-4} ~ 8.0×10^{-3}	3.0×10^{-6} ~ 3.0×10^{-5}
J. Franc (1999)	8.0×10^{-4} ~ 9.0×10^{-3}	3.0×10^{-6} ~ 6.0×10^{-5}
R. Arlt (1999)	2.5×10^{-3}	Less than $(1.6~2.0)\times10^{-4}$
Rasolonjstovo (2000)	3.0×10^{-3}	2.0×10^{-5}
M. C. Veale (2007) [5]	1.25×10^{-3}	-

In this study, the data from Table 1 were selected with the values of 9.0×10^{-4} ~ 9.0×10^{-3} [cm^2/V] for electrons and 4.0×10^{-5} ~ 1.3×10^{-4} [cm^2/V] for holes. Then, the charge collection efficiency was calculated. Furthermore, various bias voltages were utilized in order to analyze the effect on the charge collection efficiency.

3. Results and Discussions

Various mobility-lifetimes for electrons were used to calculate the charge collection efficiency as shown in Fig. 1. When the mobility-lifetime for electrons rises, the charge collection efficiency was significantly increased near the cathode surface. The maximum difference between calculated results was about 24 %. Therefore, it was found that the mobility-lifetime for electrons was sensitive to the peak channel for the spectrum.

As shown in Fig. 2, the more the mobility-lifetime for holes increases, the less the difference between the maximum charge collection efficiencies is.

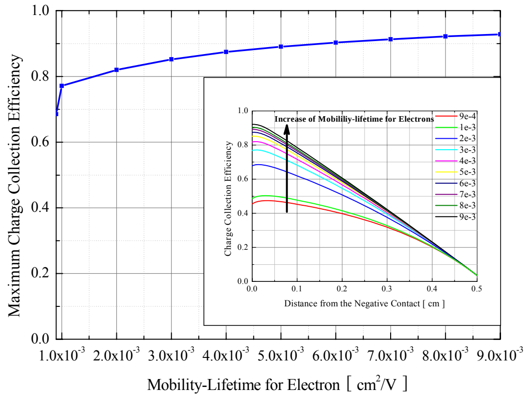

Fig. 1. Maximum Charge Collection Efficiency vs. Electron Mobility-Lifetime (Charge Collection Efficiency versus Various Electron Mobility-Lifetime with a Bias Voltage of 300 V and $\mu_h\tau_h$ of 6.0×10^{-5} cm^2/V)

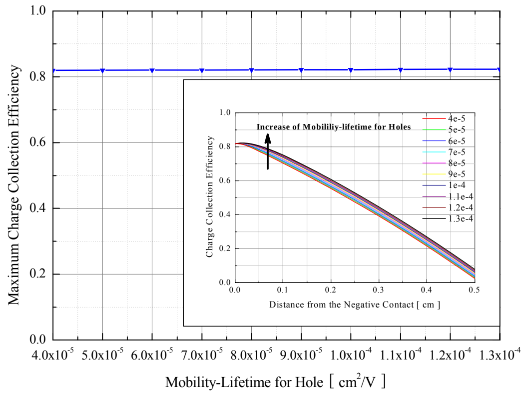

Fig. 2. Maximum Charge Collection Efficiency vs. Hole Mobility-Lifetime (Charge Collection Efficiency versus Various Hole Mobility-Lifetime at a Bias Voltage of 300 V and $\mu_e\tau_e$ of 4.0×10^{-3} cm^2/V)

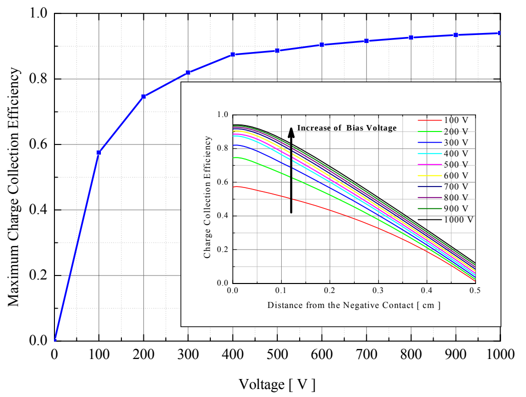

Fig. 3. Maximum Charge Collection Efficiency vs. Bias Voltage in which $\mu_e\tau_e$ and $\mu_h\tau_h$ are 4.0×10^{-3} cm^2/V and 6.0×10^{-5} cm^2/V, Respectively

However, when the incident radiation interacts with the CdZnTe detector far from the cathode surface, it can be expected that the mobility-lifetime for holes mainly affects the mount of tailing effect due to the change in the charge collection efficiency.

The maximum difference between calculated results was about 38 % as shown in Fig. 3. Hence, the charge collection efficiency was largely affected by the bias voltage in comparison with the mobility-lifetime as mentioned above. Moreover, it was expected that the bias voltage affected strongly the spectral shape as shown in Fig. 3 (small figure).

4. Conclusions

When a CdZnTe detector is used, the charge collection efficiency is inefficiently collected due to low mobility-lifetime. To analyze this affect, the mobility-lifetimes for electrons and holes were used from the published papers, and the widely-used Hecht equation was employed to calculate the charge collection efficiency.

It was found that the quantitative maximum difference between the calculated maximum charge collection efficiencies was about 24% for electrons and 35% for bias voltages. Also, the energy spectra could be obtained and analyzed.

As a result, this study is expected to provide useful data of physical factors (the mobility-lifetimes for electrons and holes) influencing on the charge collection efficiency.

Acknowledgement

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