Comparison of the Effect of Incomplete Charge Collection on DQE of Various Direct Conversion Detectors

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1. Introduction

In the direct conversion detector, the signal is transferred by the flow of charges generated when the interaction occurs in the photoconductor by incident energy. In this moment, if the charges generated are trapped by various factors while in constant time they travel to the electrodes, the loss of signal and addition of noise happen. This incomplete charge collection results in the degradation of the detector performance. So it is very important to investigate how the incomplete charge collection affects the performance of detector depending on different photoconductors to choose the best material and design the detector system.

In this study, we investigated how the performance of the detector system is degraded due to incomplete charge collection in various photoconductors in terms of detective quantum efficiency.

2. Methods and Results

2.1 Photoconductors

material	$\mu_e\tau_e$ (cm^2/V)	$\mu_h\tau_h$ (cm^2/V)	ε (V/μm)	Density (g/cm^3)	W (eV)
Se	0.65×10^{-6}	3×10^{-5}	10	4.3	45
HgI_2 (PVD)	5×10^{-5}	10^{-6}	0.5	6.3	5
HgI2 (SP)	5×10^{-5}	10^{-7}	1.0	6.3	
CdZnTe	2×10^{-4}	3×10^{-6}	0.25	5.8	5
PbI_2	7×10^{-8}	2×10^{-6}	0.5	4	5
PbO	5×10^{-7}	0	1.0	4.8	15
TlBr	0	1.5×10^{-6}	1.0	7.5	6.5

Table 1 Properties of photoconductors (μ_t, μ_h: mobility (cm^{2}V^{-1}s^{-1}), τ_e, τ_h: life times, ε: constant electric field) [1].

The various materials are considered to investigate the effect of incomplete charge collection. Table 1 shows the properties of materials [1]. In the table, μ_e and μ_h denote the mobility, τ_e and τ_h mean life time, and ε means the constant electric field. Subscripts, *e* and *h* mean electron and hole, respectively.

2.2 Incomplete charge collection

As mentioned, if incident x-ray interacts at depth z in photoconductor, electron-hole pairs are generated. These electron-hole pairs have an exponential probability distribution when they are trapped while travelling to both electrodes [2]. When it is supposed that the electric field is constant, the total depth-dependent signal can be given by equation (1) and this is agreement with Hecht relation. It means the mean gain of charge collection at depth z where the interaction occurs. Equation (2) represents the probability density describing the depth of interaction due to x-ray. Therefore the expectation of $\langle c \rangle$ and $\langle c^2 \rangle$ can be defined by equation (3). From the equation (3) we can calculate the noise factor which describes the effect of incomplete charge collection.

$$\bar{c}(z) = \frac{1}{L}\left[\mu_t \tau_t \varepsilon (1 - e^{-\frac{z}{\mu_t \tau_t \varepsilon}}) + \mu_b \tau_b \varepsilon (1 - e^{-\frac{(L-z)}{\mu_b \tau_b \varepsilon}}) \right] \quad (1)$$

$$\rho(z) = \frac{\mu e^{-\mu z}}{\eta} \quad (2)$$

$$\langle c \rangle = \int_0^L \bar{c}(z)\rho(z)dz,\ \langle c^2 \rangle = \int_0^L \bar{c}^2(z)\rho(z)dz \quad (3)$$

2.3 Cascaded model analysis

In the previous study [3], we modeled the theoretical DQE model and analyzed the performance of various photoconductors in terms of DQE (detective quantum efficiency). Expanding previous study, we applied the charge collection stage into DQE model by using cascaded model analysis.

$$\mathrm{DQE}(0) = \eta A_s A_c \quad (4)$$

$$\mathrm{DQE}(\rho) = \eta A_s A_c \mathrm{T}^2(\rho)\mathrm{sinc}^2(\pi a \rho) \quad (5)$$

DQE(0), and DQE(ρ) from the cascaded model theory can be approximated to equation (4) and equation (5), respectively. In the equations (4) and (5), η means quantum efficiency, A_s is the swank factor and A_c is the noise factor due to incomplete charge collection. A_c can be defined to $\langle c \rangle^2 / \langle c^2 \rangle$ and calculate from the equation (3). T(ρ) means the MTF due to the x-ray spreading and can be obtained by MonteCarlo simulation [3]. Although, Swank factor is important parameter, it was set to 1 for the convenience of calculation. So we can directly figure out how charge trapping phenomena affect the degradation of whole detector performance.

2.4 Results

Figure 1 shows the degradation of DQE(0) in the various photoconductors considering the incomplete charge collection as the thickness of materials increases at 20 keV. Figure 1(a) shows the case when electron travelling to bottom electrode and collected. Figure 1(b) shows the opposite. Parameters used for the calculations for of each material are summarized in Table 1. In both cases, DQE(0) performance with thickness of materials degrades dramatically in some materials, especially TlBr and CdZnTe. However, DQE in most materials are affected by the charge trapping seriously when it is compared with quantum efficiency.

Figure 2 shows the DQE performance considering the x-ray spreading and incomplete charge collection. The thickness of materials was set to 500 μm. The additive noise was ignored. As mentioned, MTFs due to the x-ray spreading were obtained by using the Monte Carlo simulations. In the case that electrons were collected to bottom electrode (Fig. 2(a)), TlBr, Se and HgI_2 show quite good performance compared to others. In other case (Fig. 2(b)), TlBr shows the worst results compared with the other case shown in the Fig. 2(a).

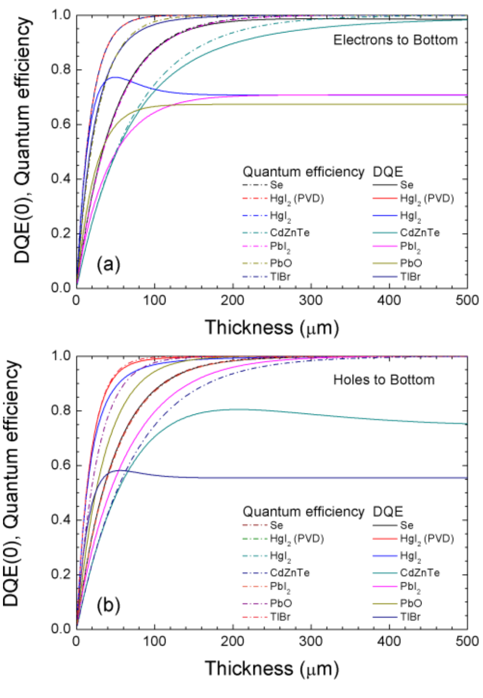

Fig. 1 degradation of DQE(0) in the various photoconductors considering the incomplete charge collection as the thickness of materials increases at 20 keV. Graph (a) shows that generated electron are collected in bottom electrode and graph (b) shows that generated holes are collected in bottom electrode

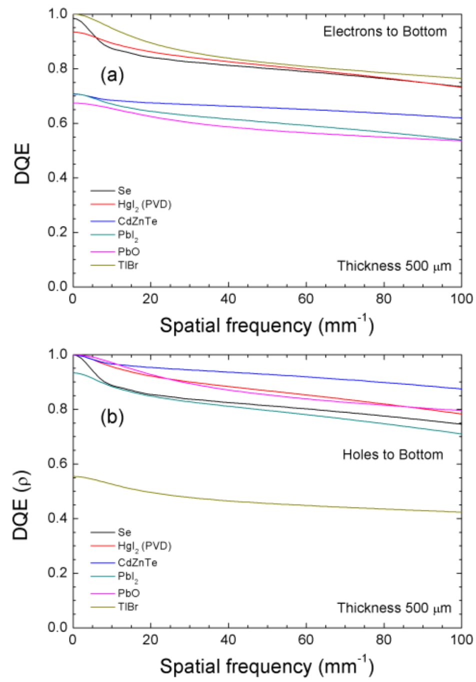

Fig. 2 Degradation of DQE due to noise factor generated by incomplete charge collection considering x-ray MTF at the thickness of 500 μm.

3. Conclusions

We investigated how incomplete charge collection affects the performance of detector system in various materials and their thickness. For the quantitative comparison, the conventional cascaded model theory was used and incomplete charge collection stage was applied. As shown in Fig. 1 and 2, DQE performance has a wide variation according to kinds of materials, thickness, and electrode side on which the charges are collected. So, the selection of a proper material and thickness are very important to design and develop the direct conversion detector system.

This study is limited to 20 keV of monochromatic x-ray. The ongoing research is to consider the various energy and beam quality, and the effect of additive noise, etc. We expect to present the best material and its thickness, etc., to design the direct conversion detector system considering proper applications.

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