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Impacts of optical-coupling properties in indirect-conversion detectors

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1. Introduction

For the optical model of the phosphor screen, it was regarded as a weak absorbing medium in which scattering is caused by refraction at boundaries between the phosphor grains and organic binders.

The Monte Carlo method is an efficient tool to understand the phosphor screen physics and sometimes it can replace the experimental measurements[1-2].

In this study, we have investigated the optical properties of Gd_2O_2S:Tb granular phosphor screens for the use in indirect-conversion detectors by using the Monte Carlo method. We considered the effects of the optical coupler and the passivation layer of photodiode on the overall detector performance. For various design parameters of a phosphor screen, we investigated the depth-dependent interactions in terms of the light collection efficiency and the point-spread function (PSF).

2. Methods

2.1 Optical phantom transport simulation

DETECT2000 (Laval University, Quebec, Canada) is Monte Carlo code for simulating optical photon transports. We adapted it to granular phosphor screens by adjusting optical properties of the screen such as absorption mean free path μ_A, scattering mean free path μ_S, and refractive index n_{scn}. To estimate the screen detector performance, we defined two parameters; the light collection efficiency η and PSF at the optical photon detection plane.

Using the circular symmetric property of the distribution, we counted the number of detected photons within each annular strip, which has the same width (5 μm) in radial direction *r*, and normalized each counted number by the area of the corresponding annular strip. Then, we obtained PSF(*r*) by normalizing the area-normalized counts with that of the center circle.

In the simulations, total number of optical photons generated at various depth potions was modeled as a point source and at least 5×10^6 photons were generated in an isotropic direction.

2.2 Detector models

As shown in Fig. 1, we modeled a phosphor screen detector which has refractive index of 2.4 as cylindrical thin-slab geometries with infinite lateral dimension. Mean free paths of absorption and scattering were taken to be 1 and 4×10^{-3} cm, respectively[2]. The side surface of a phosphor screen was defined as a metal surface with a reflection coefficient of *zero*, which implies that the optical photon escaping through the side surface never comes back and its simulation is terminated. The top surface was defined as a polished surface with variable reflection coefficients R_{back} to account for reflectance of materials used as a backplane reflector such as TiO_2[3]. The exit surface was treated as a ground surface and the escaped optical photons were tallied at a virtual detection plane located apart from the bottom surface to consider the real escaped photons. Surface treatments and boundary conditions used in the simulations are summarized in Fig. 1.

A photodiode was simply modeled as a thin passivation layer plus silicon layer. The materials of the passivation layer were defined by defining a wide range of refractive index n_{ox}. The thickness of the passivation layer was assumed to 2 μm. We defined the bottom surface of the passivation layer as a detection plane. And optical properties of the optical coupler were defined by wide ranges of refractive index n_{opt} and thickness t_{opt}. Table I summarizes the Monte Carlo simulation parameters used in this study.

3. Results

3.1 Light collection efficiency

Fig. 2 summarizes the light collection efficiency for various design parameters. The dependence of light collection efficiency on refractive index of the optical coupler is shown in Fig. 2(a). Maximum collection efficiency is achieved when the refractive index of the optical coupler is close to either that of the passivation layer or that of the phosphor screen. On the other hand, the effect of the optical coupler thickness on the collection efficiency is negligible as shown in Fig. 2(b).

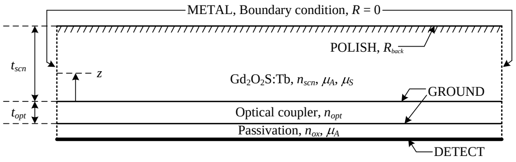

Fig. 1. Monte Carlo modeling of a granular phosphor screen.

Table I: Physical and optical parameters of the detector models used in Monte Carlo simulations.

parameters	Gd_2O_2S:Tb	Optical coupler	Passivation layer
μ_A (cm)	1	–	1×10^3
μ_S (cm)	4×10^{-3}	–	–
n	2.4	1.5 (1.0 – 3.0)	1.46 (1.2 – 3.0)
R	0.88 (0.3 – 1.0)	–	–
t (μm)	85	10 (1 – 50)	2

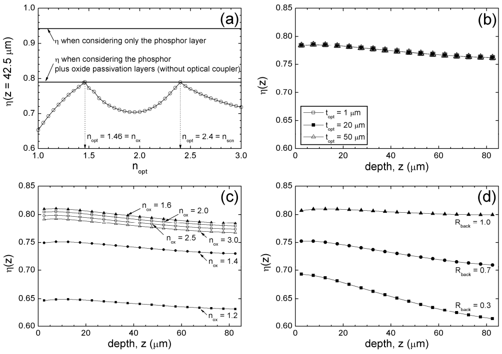

Fig. 2. Depth-dependent collection efficiency for various simulation parameters.

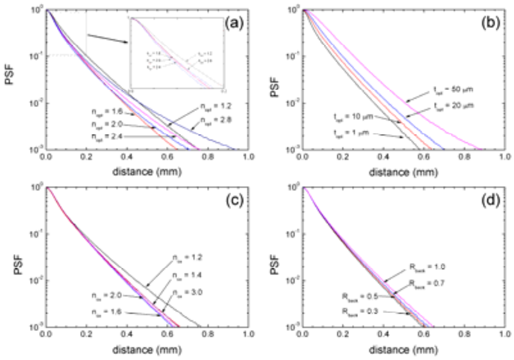

Fig. 3. PSFs for various simulation parameters.

Fig. 2(c) shows the light collection efficiency with respect to the refractive index of the passivation layer. From the results, the lower refractive index of the passivation layer than that of the optical coupler degrades the light collection efficiency. Moreover, higher collection efficiency is achieved when the refractive index of the passivation layer is located between that of the optical coupler and that of the phosphor screen.

The effect of the reflection coefficient of the screen backing on the collection efficiency is shown in Fig. 2(d). As the reflection coefficient increases, the collection efficiency also increases.

3.2 Point spread function

Fig. 3 summarizes the PSF characteristics for various design parameters. Similar to the case of light collection efficiency, a better PSF performance is achieved when the refractive index of the optical coupler gets closer to either that of the passivation layer or that of the phosphor screen, as shown in Fig. 3(a). On the contrary, the increased thickness of the optical coupler significantly degrades the PSF performance as shown in Fig. 3(b). The dependence of the refractive index of the passivation layer on the PSF performance is almost negligible except when the refractive index is lower than that of the optical coupler, as shown in Fig. 3(c). As the reflection coefficient of the screen backing increases, the PSF blurs as shown in Fig. 3(d). However, the degradation is almost negligible.

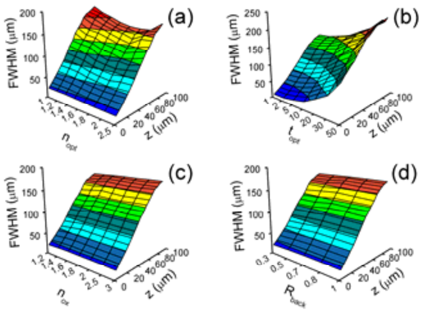

Fig. 4 FWHMs as a function of depth position of optical photon generation for various simulation parameters; (a) refractive index of optical coupler

Fig. 4 summarizes the effects of design parameters on the FWHM of PSFs. As shown in Fig. 4(a) and (b), most significant parameters to the resolution properties are the refractive index and thickness of the optical coupler. On the other hand, the refractive index of the passivation layer and reflection coefficient of the screen backing does not significantly affect the resolution properties.

4. Conclusions

The results obtained in this study suggest a guideline for a design of digital radiography detectors. From the Monte Carlo simulations, the most crucial component affecting the light collection efficiency in the indirect-conversion detector configuration was the optical coupler. Mismatched use of an optical coupler in refractive indices between the phosphor screen and the photodiode causes a significant loss in the detector signal. Moreover, the thickness of the optical coupler largely affects signal blurring. In view of the design of the readout photosensitive elements for maximizing the light collection efficiency, the passivation layer of a photodiode should have a refractive index between those of the phosphor screen and the optical coupler.

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REFERENCES

[1] P. F. Liaparinos, I. S. Kandarakis, D. A. Cavouras, H. B. Delis, and G. S. Panayiotakis, "Modeling granular phosphor screens by Monte Carlo methods," Med. Phys. Vol.33, No.12, pp.4502-4514, 2006.
[2] A. Badano, R. M. Gagne, B. D. Gallas, R. J. Jennings, J. S. Boswell, and K. J. Myers, "Lubberts effect in columnar phosphors," Med. Phys. Vol.31, No.11, pp.3122-3131, 2004.
[3] M. K. Cho, H. K. Kim, T. Graeve, S. M. Yun, C. H., Cho, H. Lim, and J.-M. Kim, "Measurements of x-ray imaging performance of granular phosphors with direct-coupled CMOS sensors," IEEE Trans. Nucl. Sci. Vol.55, No.3, pp.1338-1343, 2008.