Phosphor Screen Optics in Indirect-Conversion X-ray Imaging Detectors

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Objectives

• Investigating important optical properties of Gd₂O₃:S: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, the point-spread function, Modulation Transfer Function, and Swank factor.

Introduction

• Granular Gd₂O₃ phosphor screen is still widely used as the key x-ray converter in the configuration of indirect-conversion digital radiography detectors.
• Easy handling (flexible), lower cost, good spectral match to the readout photodiode.
• The optics between scintillators and photodiode arrays should be carefully designed.
• Because it can be a crucial source causing a secondary quantum sink that reduces the detectable quantum efficiency at high spatial frequencies.
• Ideal performance of indirect-conversion detectors: DQE = αa × L

Methods

• Gd₂O₃ phosphor screen model
• Optical photon transport simulation
• Monte Carlo simulation code: DETECT2000 (Laval University, Quebec, Canada)
• To estimate the screen detector performance, we defined two parameters;
  • light collection efficiency, Swank factor
  • PSF and MTF at the optical photon detector plane
• Light collection efficiency
  • The collection efficiency for the optical photons generated at a depth z in the screen is defined as
  \[ \eta(z) = \frac{\text{total # of optical photons generated at depth } z}{\text{total # of optical photons absorbed in bulk of at surface}} \]

Results

• Light collection efficiency
• Point-spread function
• Modulation transfer function
• Swank factor

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 indexes between the phosphor screen and the photodiode causes a significant loss in the detector signal.
• The thickness of the optical coupler largely affects signal blurring.
• Also, light collection efficiency effects to statistic noise (Swank factor) in the detector.
• 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.
• Therefore, optical coupling between phosphor screen and photodiode in the indirect-conversion X-ray imaging detector is major design parameter.