Analytic Modeling of Energy-Absorption Response Functions for Photoconductor-Based X-Ray Detectors

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1. Introduction

In x-ray imaging detectors, the signal generated in a detector element is proportional to the number of secondary carriers (such as optical photons or electron-hole pairs) generated in the x-ray convertor. Furthermore, the location and statistics of secondary carriers are directly related to the absorbed x-ray energy. Even under monochromatic exposure conditions, there will be a distribution of absorbed energies due to the statistical nature of x-ray interactions.

At diagnostic energies (10-120 keV), escape of fluorescent x rays following a photoelectric absorption and Compton-scattered x rays are primary sources of absorbed energy dispersion [1]. This increases both variability in deposited x-ray energy and image noise in both energy-integrating and photon-counting x-ray detectors. Accurate measurement of incident photon energy is particularly important in photon-counting techniques such as K-edge imaging. Therefore, it is necessary to model and understand the effects of x-ray interaction physics on the absorbed energy distribution (AED) which describes the expected distribution of absorbed energy as a function of incident photon energy. This energy dispersion determines the energy resolution of spectroscopic systems and affects image quality in radiographic systems through the Swank factor and detective quantum efficiency [2,3,4,5].

We believe understanding the AED will give insight to the fundamental performance limitations of both conventional and novel photon-counting x-ray imaging detectors.

2. Methods and Materials

Analytic expressions relating the AED to underlying x-ray interaction physics have been introduced previously at the IEEE NSS-MIC-RTSD 2012 meeting [6]. This AED is determined by calculating both the probability and energy deposited for each interaction type (e.g., photoelectric, photoelectric with fluorescence, Compton) for semi-infinite slab and pixel geometries. Energy contributions from neighboring elements in digital detectors are an important cause of additional energy dispersion as shown in Figure 1.

In addition to energy deposition considerations described in the previous model, transport considerations can have a large impact on the AED. We have extended the analytic model to include transport properties of liberated secondary quanta for more practical and accurate modeling, including depth-dependent charge transport properties such as charge collection and sharing between neighboring elements. These effects are particularly important in pixel imaging detectors.

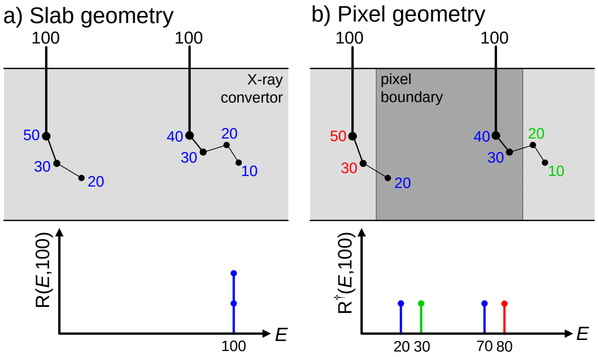

Fig. 1. Schematic illustration showing the effect of multiple scatter on the response function for slab (a) and pixel (b) geometries. Numbers in converter correspond to photon energy deposited with each interaction.

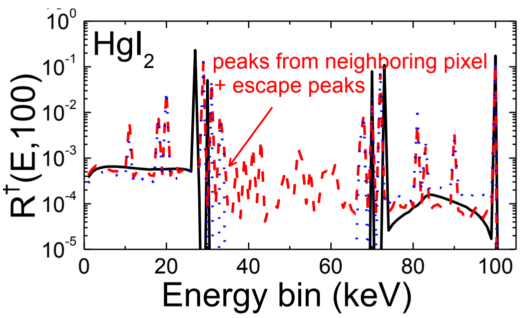

Fig. 2. Comparison of analytic absorbed-energy response function (black solid line) and Monte Carlo simulations, with (red dashed line) and without (blue dotted line) multiple scattering.

Photoconductor-based detectors are playing an important role in the development of photon-counting and spectroscopic systems. We have extended the AED description to include secondary quanta transport properties associated with detector materials and geometries in these systems. We assumed Poisson conversion gain to account for the random nature of charge liberation for a given x-ray deposition (assumed to be deterministic conversion in the previous model).

The effect of depth-dependent and incomplete charge collection [7] and charge sharing [8,9] on the AED was characterized by calculating the mean probability distributions representing the absorbed energy relocation as a function of absorbed energy. For the charge-sharing model, we calculated the fractions contributing to neighboring elements along the interaction depth.

3. Result and Summary

While x-ray AED results, including Poisson conversion gains and obtained for particular materials and configurations, have been validated by Monte Carlo calculations (see Fig. 2), the strength of analytic models is that it allows one to determine the two-dimensional response functions of arbitrary photoconductor materials without the computational demands of Monte Carlo simulations. Since small pixel size is a mandatory requirement to achieve high resolution imaging system, understanding the effects of x-ray interaction and charge transport properties on image quality is critical.

We believe this model will be useful for correcting spectral distortion artifacts commonly observed in photon-counting applications and evaluating the imaging performance of novel x-ray convertor materials, and are in the progress of using Monte Carlo simulations and experiments using a CdTe pixel detector to validate the transport properties of the analytic approach.

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