

Modulation transfer function of amorphous selenium digital x-ray detectors

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ABSTRACT

We evaluate the modulation transfer function (MTF) of amorphous selenium (a-Se) digital x-ray detectors. This study includes the effects of generation and reabsorption of characteristic x-rays, which can significantly degrade the detector MTF. Monte Carlo (MC) methods are used for simulation of spatial dose distribution, and the detector MTF is computed by Henkel Transform. We consider mammography and chest radiography x-ray energies and detector thicknesses in this study. Incident photon energies of 12 keV, 13 keV, 50 keV and 100 keV are simulated for 150 μm , 300 μm , and 1 mm thick a-Se x-ray detectors. Significant MTF degradation is observed at incident photon energies higher than the a-Se K-edge, due to generation and reabsorption of characteristic x-rays.

Keywords: Amorphous selenium, modulation transfer function, direct detection, characteristic x-rays

1 INTRODUCTION

X-ray imaging is commonly used by physicians to view the internal organs and structures of human body and diagnosis of bone fractures and suspicious lesions for cancer. Digital radiography can provide many advantages over traditional film-based radiography, such as dose reduction and convenience of image processing. Amorphous Selenium (a-Se) is an excellent photoconductive material, with an effective atomic number for high x-ray absorption, low dark current, and can be uniformly deposited on large areas, making it the only commercially available x-ray photoconductive material for direct conversion digital x-ray detectors. For this study, a-Se detector is considered for medical imaging modalities in mammography and chest radiography.

One of the important metrics for evaluating an x-ray detector is the modulation transfer function (MTF). This metric is a function of spatial frequency and takes into account effects such as the reabsorption of characteristic x-rays. [?] The MTF allows us to better determine the maximum resolution of the detector, thus it is of great importance. We look at the MTF for a-Se and we show the effect of incident photon energy and thickness on the detector MTF.

2 METHODS

This section describes in detail the simulation methods of our study.

2.1 Modulation transfer function

This subsection includes more detailed equations for MTF calculations. The definition of the MTF include include the x-ray detector MTF (reabsorption of characteristic x-rays) and the aperture effect due to the pixel size. [?]

$$\text{MTF}_{\text{pre}}(k) = \text{MTF}_x(k) \times |\text{sinc}(\pi a_{\text{del}} k)| \quad (1)$$

The detector MTF can be computed by Henkel transform, and the point spread function (PSF). For this study, the PSF is constructed from simulation results. [?]

$$\text{MTF}_x = H[p(r)] = 2\pi \int_0^\infty p(r) J_0(2\pi kr) r dr \quad (2)$$

The aperture effect has a sinc squared dependence on the pixel width, and is the reciprocal of the volume under the squared MTF, give by [?]

$$a_e = \left[2\pi \int_0^\infty \text{MTF}^2(k) k dk \right]^{-1} \quad (3)$$

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The calculation of the PSF from simulation results will be covered in the following subsections.

2.2 Monte Carlo code

The latest version of the Photon Electron Shower (PENELOPE) Monte Carlo code [?] was used to simulate the photon and electron interactions within a-Se photoconductor. PENELOPE allows for simulation of detailed transport of photon and electrons, and mean free path as a function of the particle's incident energy is shown in Figure 1. Our simulation model takes into account all possible photon and electron interaction mechanisms in the diagnostic energy range. The incident photon can interact inside the a-Se detector by Rayleigh scattering, Compton scattering, photoelectric absorption and pair production, where only Compton and photoelectric absorption lead to creation of secondary electrons. This secondary electron can interact in the detector material by elastic scattering, inelastic scattering and Bremsstrahlung. Only inelastic collisions lead to energy loss and dose deposition that is required for MTF calculations.

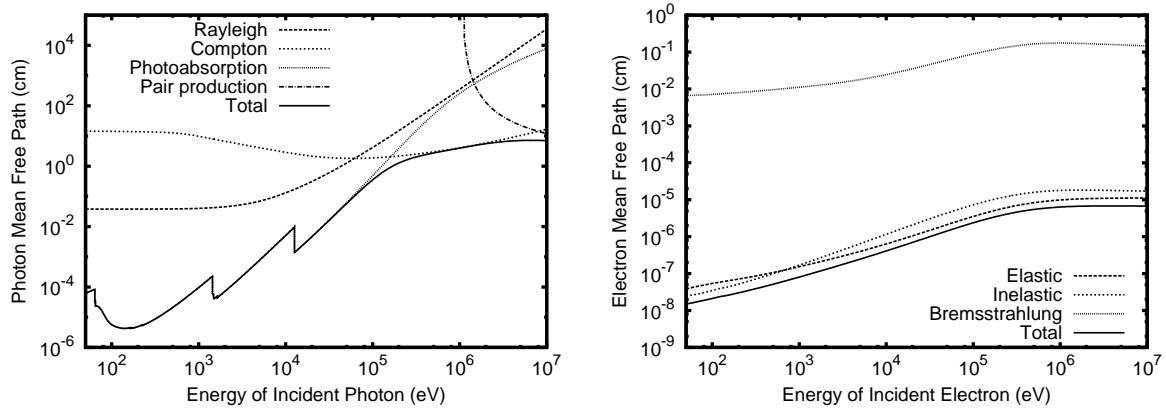


Figure 1. (a) Mean free path of photons in a-Se as a function of incident photon energy. (b) Mean free path of electrons in a-Se as a function of electron energy

2.3 Detector geometry

The detector is modeled by a single layer of a-Se. The detector model as shown in Figure 2 consist of an mono-energetic photon beam of x-ray incident perpendicularly on the center of a cylindrical detector of 10 cm in diameter. The a-Se detector is further subdivided radially with an equal spacing of $0.5 \mu\text{m}$ each. Figure 2 illustrate the modeled detector geometry.

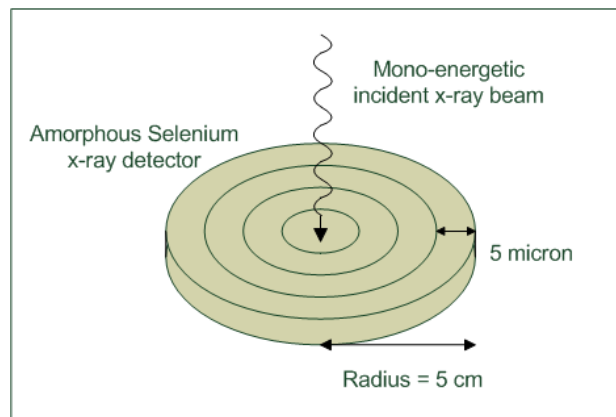


Figure 2. Detector geometry in cylindrical coordinates modeled by Monte Carlo simulation.

For calculation purposes, the density used for a-Se is 4.5 g/cm^3 . MC simulations were used to generate the dose distribution profile $d(r)$, which is the energy deposition inside the detector material with respective radial distribution.

The PSF is constructed from this dose profile using the relation below. Where the dose is normalized to the unit area.

$$p(r) = \frac{d(r)}{2\pi \int d(r) r dr} \quad (4)$$

3 RESULTS

This section shows the simulation results of detector MTF for mammography and chest radiography applications, not including the aperture dependence. Figure 3(a) shows the MTF for 150 μm thick a-Se detector for mammography application, with incident photon energy of 12, 13, 50 and 100 keV. The MTF is highest for the 12 keV case because of low incident energy lead to minimal lateral energy spreading and it is below the a-Se K-edge of 12.6 keV. For energies above this K-edge, for example 13 keV, a sharp drop of MTF is observed. This is due to the reabsorption of characteristic x-rays produced above the 12.6 keV K-edge. As incident energy increases, the more energy is deposited locally by electrons and the MTF is considerably improved. However, the MTF degrades eventually at energies above 100 keV.

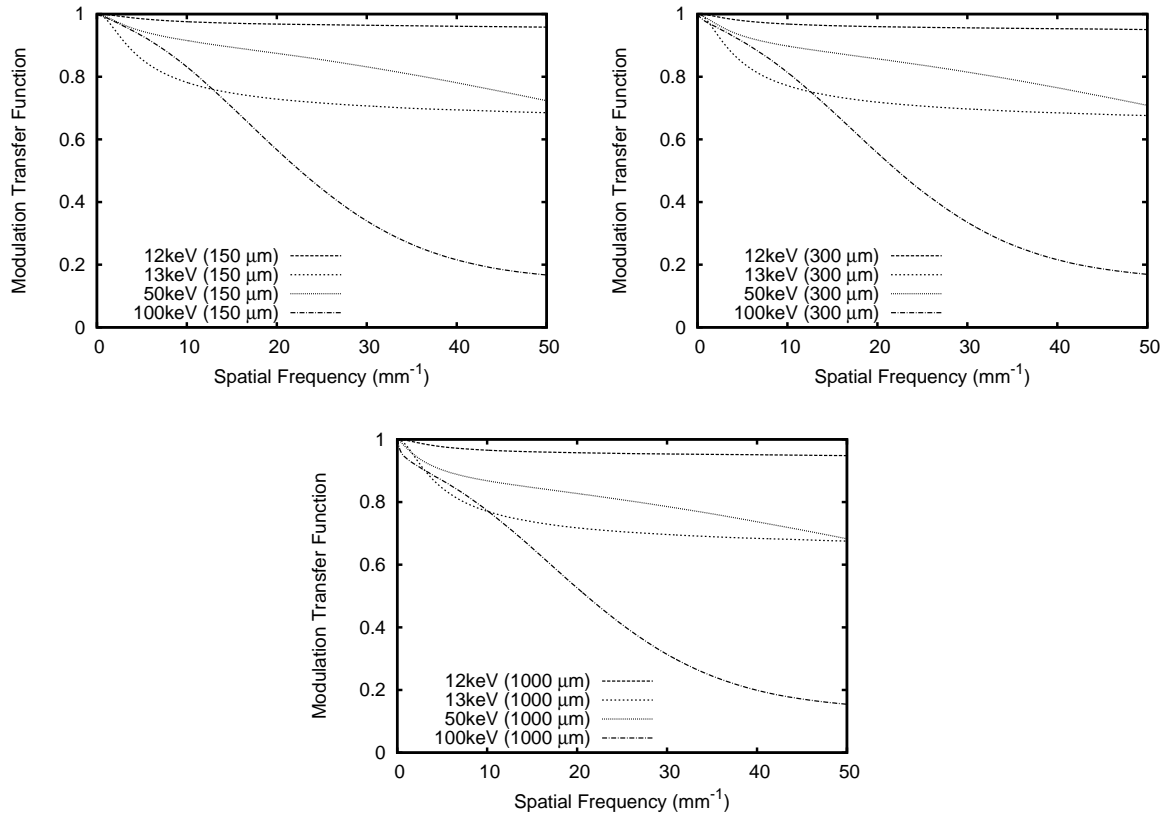


Figure 3. (a) MTF for 150 μm thick a-Se detector for mammography. (b) MTF for 300 μm a-Se detector. (c) MTF for 1000 μm a-Se detector for chest radiography.

Figure 3(b) and (c) shows similar trend of MTF for 300 μm thick a-Se detector and 1 mm thick detector commercially used for chest radiography applications. Similar MTF degradation are observed due to reabsorption of characteristic x-ray photons above the K-edge of a-Se.

4 CONCLUSIONS AND FUTURE WORK

We have shown the MTF in a-Se digital x-ray detectors, and demonstrated that the reabsorption of characteristic x-rays are significant in degradation of MTF. The detector MTF is simulated as a function of incident photon energy and detector thickness, and this shows a good indication of the resolution achievable by a-Se detectors for mammography and chest radiography applications. For future work, the aperture effect can be included in the simulation model, and further improve accuracy of calculation.

ACKNOWLEDGMENTS

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