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Image quality of a pixellated GaAs X-ray detector

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Abstract

X-ray detection requires materials with large atomic numbers Z in order to absorb the radiation efficiently. In case of X-ray imaging, fluorescence is a limiting factor for the spatial resolution and contrast at energies above the k_{α} threshold. Since both the energy and yield of the fluorescence of a given material increase with the atomic number, there is an optimum value of Z. GaAs, which can now be epitaxially grown as self-supported thick layers to fulfil the requirements for imaging (good homogeneity of the electronic properties) corresponds to this optimum. Image performances obtained with this material are evaluated in terms of line spread function and modulation transfer function, and a comparison with CsI is made. We evaluate the image contrast obtained for a given object contrast with GaAs and CsI detectors, in the photon energy range of medical applications. Finally, we discuss the minimum object size, which can be detected by these detectors in of mammography conditions. This demonstrates that an object of a given size can be detected using a GaAs detector with a dose at least 100 times lower than using a CsI detector.

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Keywords: GaAs; X-ray detector; Image quality

1. Introduction

Spatial resolution is the main parameter, which characterizes the quality of an image. It is related to the minimum distance between two objects that an imaging system can distinguish for a given contrast, and thus gives the minimum size of the object, which can be detected. Consequently, when using solid state detectors, the image quality depends strongly on the nature of the material because fluorescence, producing a halo around the impact point where the photon is absorbed, depends on its atomic number Z. Among materials that can be used to detect X-ray photons at room temperature, GaAs optimizes the absorption and fluorescence (which both increase with Z) among other materials such as CsI, which are used for numerical X-ray imaging [1]. Large-area self-supported thick epitaxial GaAs, which is now produced [2], fulfil the requirements for medical X-ray imaging due to the homogeneity of its electronic properties over large area, while meeting also industrial requirements (low cost, standard processing technology) [3,4]. Since there still remains a challenge to fabricate a demonstrator, i.e. make an image with a pixel detector, we evaluate the image quality by modelling the effect of fluorescence on the spatial resolution. This illustrates the improvements, which are expected by the introduction of numerical imaging GaAs detectors, compared to actual detectors based on scintillator materials (CsI). We consider only the fluorescence effect, i.e. neglect any other noise, to get the ultimate performances, which should be reached.

2. Evaluation of image quality

To evaluate the spatial resolution, we use the classical way, the line spread function (LSF) and the corresponding modulation transfer function (MTF) [5]. The LSF is the image of a slit determined experimentally, whose width is smaller than the pixel size. Here, we modelize the image of such a slit (of width $c = 10\,\mu m$) by moving it parallel to pixel row (see Fig. 1).

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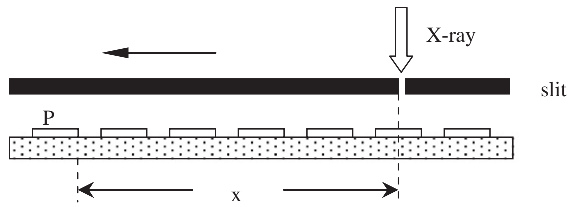

Fig. 1. Schematic representation for LSF determination.

We calculate the signal on a specific row P of pixels, whose edge is x mm away from the slit. Because the width of slit is much smaller than the pixel size L, we assume that the incident photons passing through this slit are at the same distance (x) from the edge of pixel P. For a given dose ϕ, the total number of photons of energy E passing through the slit is $cL\phi$. When the slit is not on pixel P, the signal S (number of introduced electron–hole pairs) on pixel P produced by the fluorescence photons is

$$S = cL\phi k_\alpha w_\mathrm{k}(1 - \mathrm{e}^{-\alpha_E d})(\mathrm{e}^{-\alpha x} - \mathrm{e}^{-\alpha(L+x)})/\varepsilon \quad (1)$$

where k_α is the energy of the fluorescence photons, w_k the yield of fluorescence, α the corresponding absorption coefficient, α_E the absorption coefficient of the incident photons, d the thickness of detector and ε the energy needed to produce an electron–hole pair.

When the slit is on pixel P ($x = 0$), S becomes

$$S = cL\phi(1 - \mathrm{e}^{\alpha_E d})(E - k_\alpha w_k \mathrm{e}^{-\alpha L})/\varepsilon. \quad (2)$$

The dependence of the signal S on the distance x gives the LSF. The corresponding MTF is the fast Fourier transform of the LSF. The maximum spatial frequency that can be reached is the Nyquist frequency, equal to $1/(2 \times \text{pitch})$.

3. Results and discussion

The detector considered here is made of pixels of 50 μm and has a thickness of 200 μm. The slit has a width of 10 μm, allowing 100% X-ray transmission and 0% out, corresponding to a contrast (see Ref. [1]) of the object equal to 1. The LSFs and MTFs at 40 keV for GaAs and CsI detectors are given in Figs. 2(a) and 3, respectively. Fig. 2(b) gives the image corresponding to the LSFs of Fig. 2(a).

As illustrated in Fig. 2, the fluorescence photons in CsI propagate laterally across several rows of pixels. As shown in Fig. 2(b), the charges induced by fluorescence photons, emitted in a given pixel, are collected in a large number of neighbouring pixels, thus deteriorating the spatial resolution. The signal induced by fluorescence photons in the GaAs detector goes to zero faster than in the CsI one. Consequently, a GaAs detector exhibits the best MTF, as illustrated in Fig. 3. The MTFs presented here have been calculated assuming all the fluorescence photons are absorbed in the detector, while in practice only a fraction is absorbed (taking this into account would improve the MTF). The spatial frequency (l p/mm) is 1.8 for CsI for a modulation transfer value of 0.3. In case of GaAs, the

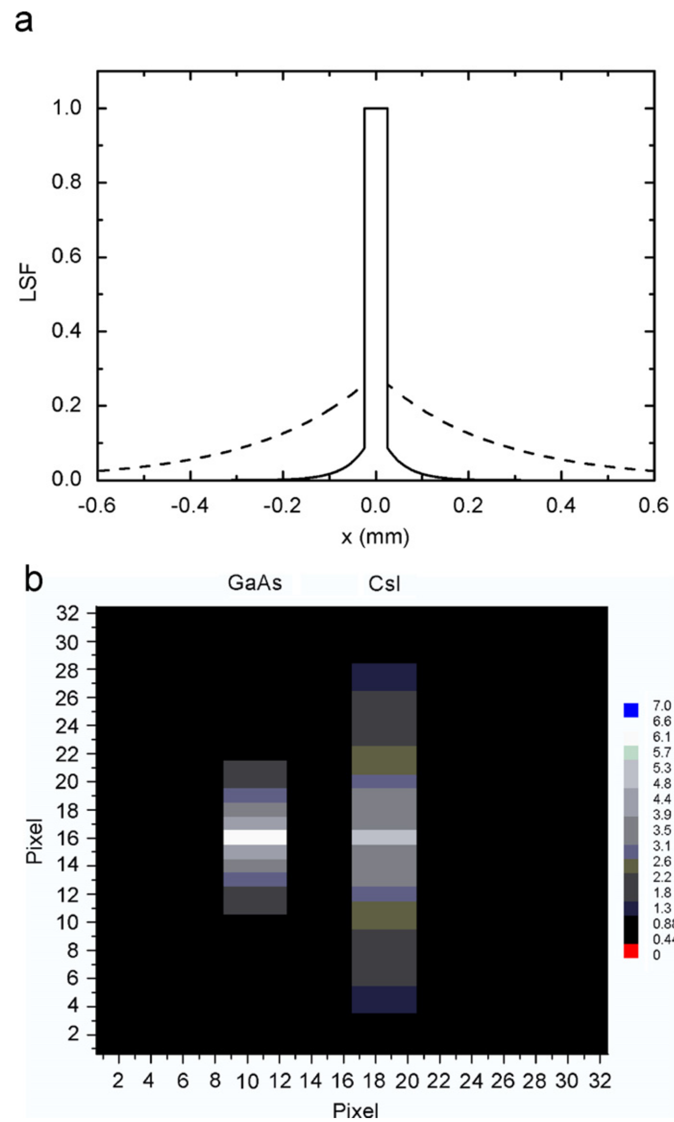

Fig. 2. Calculated LSFs (a) and images (b) of 50 μm pixel GaAs (▬) and CsI (▬▬), 200 μm thick, detectors at 40 keV for a dose of $10^8\,\mathrm{cm}^{-2}$.

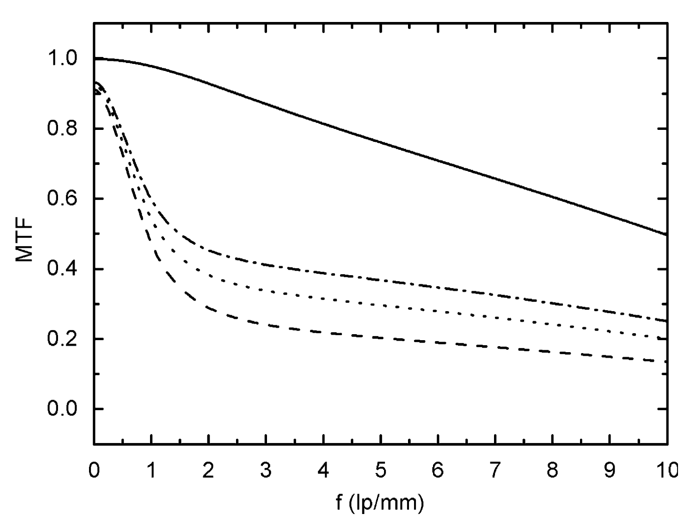

Fig. 3. MTFs of 50 μm pixel, 200 μm thick, detectors for a dose of $10^8\,\mathrm{cm}^{-2}$. GaAs (▬) and CsI (▬▬): 40 keV; CsI (•••••): 50 keV; CsI (▪•▪): 60 keV.