Available online at www.sciencedirect.com
SCIENCE DIRECT®

ELSEVIER

Nuclear Instruments and Methods in Physics Research B 213 (2004) 603–606

NIM B
Beam Interactions with Materials & Atoms

www.elsevier.com/locate/nimb

Dual energy imaging in mammography: Cross-talk study in a Si array detector

G. Baldazzi [a], D. Bollini [a], M. Gambaccini [b], M. Gombia [c,*], L. Ramello [d], A. Tuffanelli [b]

[a] *Department of Physics and INFN, University of Bologna, Viale B. Pichat 6/2, 40127 Bologna, Italy*
[b] *Department of Physics and INFN, University of Ferrara, Via Paradiso 12, 44100 Ferrara, Italy*
[c] *Department of Physics, University of Bologna, Via B. Pichat 6/2, 40127 Bologna, Italy*
[d] *Department of Advanced Science and Technology and INFN, University of the East Piemonte, Corso Borsalino 54, 15100 Alessandria, Italy*

Abstract

One of the main limitation to the extensive use of breast-cancer screening as a prevention method is the relatively high X-ray dose released to the patient. A new approach is under study in which two quasi-monochromatic beams – with mean energies of 18.0 and 36.0 keV – are produced simultaneously, starting from an X-ray tube, by means of a monochromator based on a pyrolytic graphite crystal. The two beams are superimposed in space. The removal of the energy components with low content of diagnostic information from the spectrum, leads to a reduction of the dose released to patients maintaining (or improving) the image quality. The two quasi-monochromatic beams impinge on the patient and then are detected with a solid-state array detector; the image results as the difference between the transmitted intensities of the two detected beams.

In this work, the performances of two different electronic readouts and three pixel widths of a silicon position sensitive array detector are simulated and described in order to minimize cross-talk effects between adjacent pixels. The use of a detector with spectrometric capabilities is necessary to separate, by means of thresholds, the high energy photons from the low energy ones.

PACS: 87.62; 87.59.H; 87.59.E; 29.40.W
Keywords: Medical imaging equipment; Digital radiography; Mammography; Solid-state detectors

1. Introduction

The main advantages of the use of a two-energy spectrum for digital subtraction mammography stands in the reduction of the dose released to patients and in the improvement of the contrast. In fact, the high energy components of the spectrum, produced by a classic X-ray tube with the anode of

* Corresponding author. Address: Lab. of Montecuccolino, DIENCA, University of Bologna, Via dei Colli, 16, 40136 Bologna, Italy. Tel.: +39-051-209-5136; fax: +39-051-209-5047.
E-mail address: mirko.gombia@mail.ing.unibo.it (M. Gombia).

0168-583X/$ - see front matter © 2003 Elsevier B.V. All rights reserved.
doi:10.1016/S0168-583X(03)01654-9

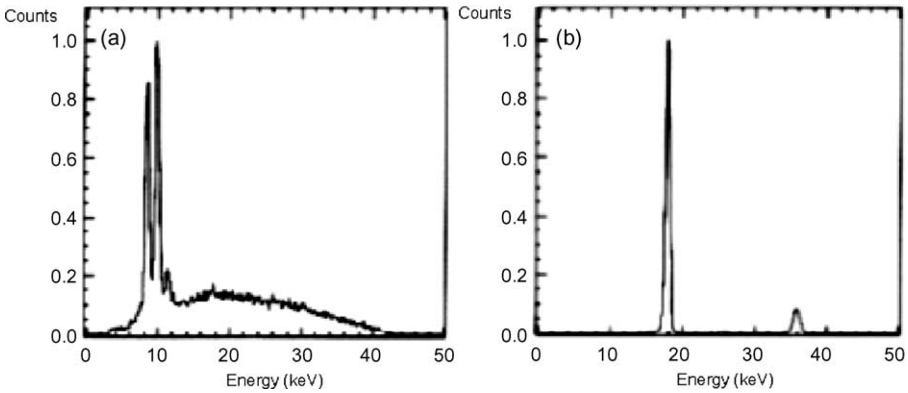

Fig. 1. Spectrum produced by a standard mammographic X-ray tube with molybdenum anode (on the left) in comparison with the spectrum produced by the dual energy monochromator (on the right).

molybdenum, do not contribute to the diagnostic image since the difference between the linear attenuation coefficient of the healthy and pathological tissue becomes smaller as energy increases. Both the spectrum currently used in mammographic investigations and the new spectrum composed by two quasi-monochromatic peaks are shown in Fig. 1.

2. Experimental setup

The apparatus for dual energy mammography is constituted by an X-ray tube with the anode of molybdenum, a variable collimating system and the experimental monochromator that is now under characterization [1,2]. The monochromator is based on a highly oriented pyrolytic graphite (0 0 2) mosaic crystal ($28 \times 60 \times 1$ mm^3 with a measured mosaic spread of 0.26°) [3]. The collimator and the crystal motions are controlled by several micrometric actuators.

The detection system is a silicon microstrip detector with spectrometric capabilities and an integrated front-end and data acquisition electronics. Now it is also under test and characterization. To optimize the detection efficiency, the X-ray photons are collimated on the front side of the strips, as shown in Fig. 2, so the pixel size is $300 \times L$ μm^2. The pixel width in the experimental prototype is $L = 100$ μm, the best value found running simulations for $L = 50$, 100, 200 μm.

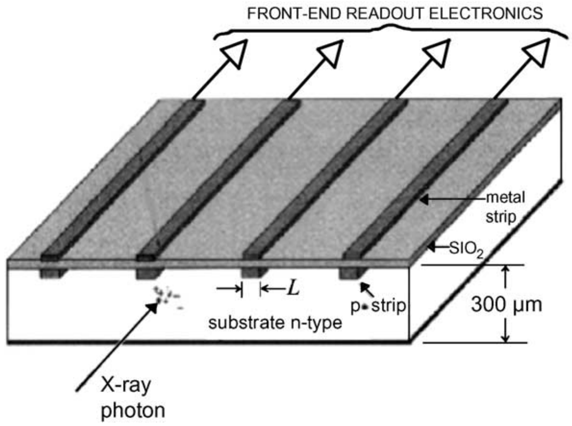

Fig. 2. Sketch of the detector. The depletion thickness is 300 μm, the strip width is L. Photons impinge on the detector from the front side as illustrated. The simulations show that the best width for the strips is 100 μm.

3. Characteristics of the simulations

In order to design the spectrometric device for the detection of the two fundamental harmonics of the dual energy technique, two kinds of electronic readouts were simulated: (1) a strip with an ADC for each energy channel – called E_1 – and (2) a digital readout with a threshold discriminator for each channel – called E_2. Using E_1, the position of a detected event is calculated as a weighted sum over the released energy in different pixels; the total energy released inside the device is the energy sum over all pixels. Using E_2, the pixel in which the released energy exceeds a fixed threshold is assumed as the interaction center and the energy therein deposited as the energy released in the device.

Simulations have also the goal to determine the optimal pixel width L to minimize the tails, mainly generated as a consequence of cross-talk effect, of the 36 keV photons in the 18 keV region.

Twelve simulations were performed varying the following parameters: (a) the beam energy – the values $E = 18$ and 36 keV were tested; (b) the pixel width – $L = 50$, 100 and 200 μm; (c) a phantom of 40 mm thickness of plexiglass, simulating soft tissues, or air in standard conditions.

The transport of both photons and electrons and fluorescence effects were taken into account. A 5 keV cut-off energy was imposed and trigger and threshold values of 12 keV were fixed. Energy resolution was of 2.11 keV FWHM, correspondent to about 11% for 18 keV photons as experimentally measured on detector prototypes. The source parallel beam is randomly generated over the front surface of the detector (Fig. 2) covering an area of 0.3 mm × 102.4 mm. The detector depth was considered of 300 mm.

For each simulation, performed with dedicated subroutines [4,5] built on the EGSnrc Monte Carlo code [6], an 800 MHz Pentium III dual processor PC generated and followed 500,000 photon histories.

4. Results

In every test with 18 keV photons, there were not counts above 22 keV, and this value is reached only as an effect of silicon detector energy resolution. So the 22 keV is the upper limit for the 18 keV peak. With the 18 keV energy beam, simulations show that results are independent from pixel L dimension and electronic readout.

Some of the results of the simulations with 36 keV photons are shown in Figs. 3 and 4, while Table 1 summarizes the cross-talk effects. With the first kind of electronic readout (E_1), the number of detected counts is independent from pixel dimension L. In this case we would choose the smallest available pixel dimension in order to maximize the spatial resolution. The digital readout (E_2) shows a worse performance generating greater tail in low energy region. However, the effect of tails decreases reducing pixel dimensions: in particular, the number of counts for $L = 50$ μm is two times higher than for $L = 100$ μm and about four times higher than for $L = 200$ μm. These results are true both in presence and in absence of scattering media.

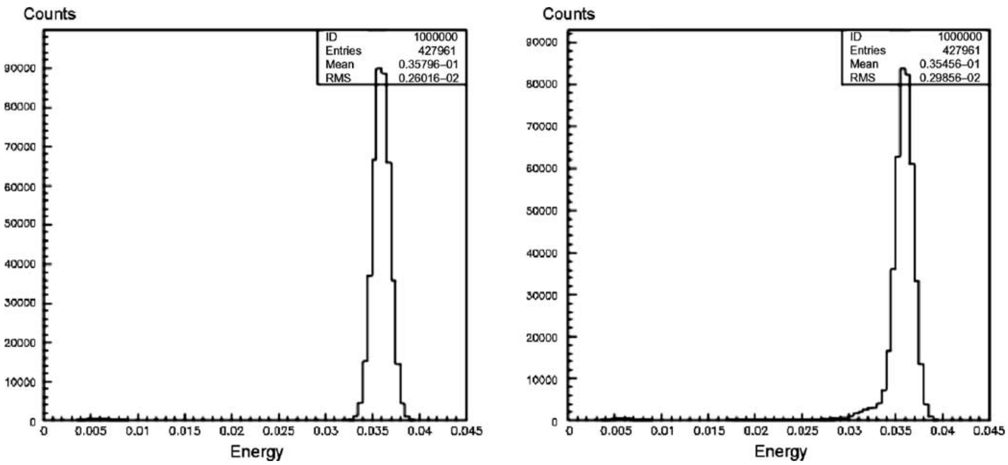

Fig. 3. Simulated spectra of the 36 keV beam. The strip width is 100 μm. The spectrum on the left is referred to an ADC for each channel (E_1), the one on the right to a digital readout with a threshold discriminator for each channel (E_2).

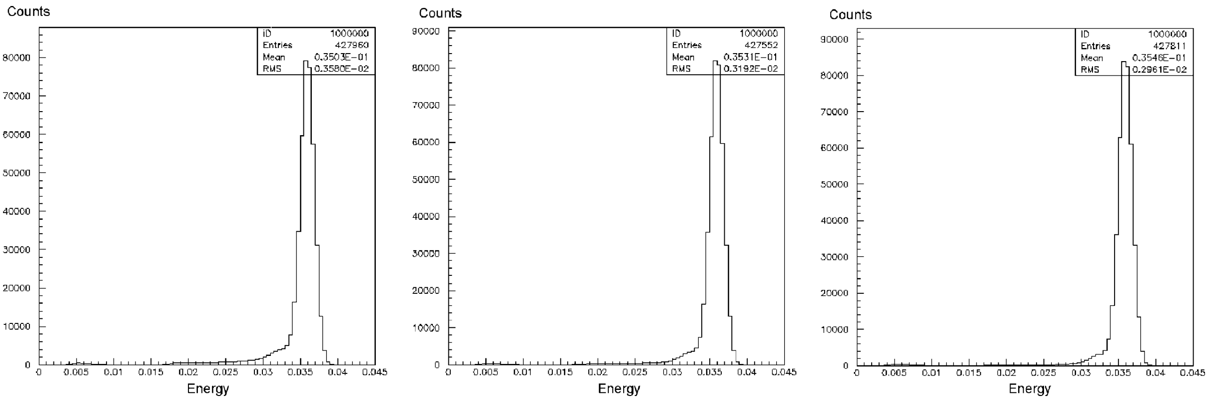

Fig. 4. Simulated spectra of a 36 keV beam with (E_2); pixel dimensions of 50 μm (on the left), 100 μm (on the middle) and 200 μm (on the right).

Table 1
Photons of 36 keV detected in the low energy region for different pixel dimensions L, for electronic readout E_1 or E_2 and with or without the scattering media

Phantom/L (μm)	Energy detected under 22 keV	
	E_1	E_2
Air/50	175	7150
Air/100	164	3657
Air/200	160	1905
Plexiglas/50	75	2372
Plexiglas/100	62	1263
Plexiglas/200	75	663

5. Conclusions

Simulations were in agreement of the linear pixellated geometry with pixel dimensions of 0.3×0.1 mm^2 and pixel depth of 30 mm in a so called SYRMEP geometry [7].

A strip with an ADC for each channel is better than a digital readout with a threshold discriminator for each channel from the point of view of the 18 keV tail.

The detector, was developed initially at the University of Eastern Piemonte in Italy [8] and modified following the results of the present study, is now under test.

Acknowledgements

This work has been supported by MURST – COFIN 2000, Italy in the frame of a collaboration research program of Italian Universities and by National Institute of Nuclear Physics (INFN).

References

[1] G. Baldazzi, D. Bollini, E. Celesti, M. Gambaccini, M. Gombia, C. Labanti, A. Taibi, A. Tuffanelli, in: IEEE NSS-MIC Conference Record, San Diego, CA, USA, 4–10 November 2001.

[2] A. Tuffanelli, A. Taibi, G. Baldazzi, D. Bollini, M. Gombia, L. Ramello, M. Gambaccini, in: SPIE, Medical Imaging Conference 2002, MI4682-33.

[3] A. Tuffanelli et al., SPIE Proc. 3773 (1999) 192.

[4] M. Gombia, A.B. Brill, D. Bollini, A. Del Guerra, in: IEEE NSS-MIC Conference Record, San Diego, CA, USA, 4–10 November 2001.

[5] D. Bollini, R. Campanini, M. Gombia, N. Lanconelli, A. Riccardi, Int. J. Mod. Phys. C – Comput. Phys. 13 (4) (2002) 465.

[6] I. Kawrakow, Med. Phys. 27 (4) (2000).

[7] F. Arfelli et al., in: SPIE Conference on Medical Applications of Penetrating Radiation, SPIE, Vol. 3770, 1999, p. 2.

[8] P. Grybos et al., Nucl. Instr. and Meth. A 454 (2000) 214.