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Characterization of Si pixel detectors of different thickness

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Abstract

Tests on silicon pixel detector in the mammographic energy range have shown good imaging performances so, in order to improve the efficiency in this energy range, we have designed thicker detectors of the p^+/n type. The detectors have been fabricated by ITC-IRST (Trento, Italy) in high resistivity silicon substrates (300 and 525 μm thick). A TCAD simulation work has been carried out to optimize the electric field distribution and to enhance the breakdown voltage. Very low leakage current and high breakdown voltage characteristics have been measured on detectors in preliminary on-wafer tests. After that, detectors have been bump-bonded to a dedicated VLSI electronic chips, realizing an assembly. Choosing the best set-up condition and using a standard mammographic tube, we have acquired a large area image ($8 \times 8\,cm^2$) of the RMI 156 phantom, recommended for mammographic quality checks. In order to cover the whole surface, we have acquired different images translating the phantom over the assembly. We present some selected results for these assemblies both for the electrical characteristics and for the imaging performances.

Keywords: Silicon pixel detectors; Digital mammography; Single photon counting electronics

1. Introduction

The digital imaging system we are developing for mammographic applications is based on a silicon pixel detector connected by bump bonding to a VLSI chip. The detector is a matrix of 64×64 square pixels with a 170 μm pitch for a total detection area of $1.2\,cm^2$. The read-out circuit, called Photon Counting Chip, has been developed by the CERN Microelectronics group in the framework of the MEDIPIX collaboration [1,2]. The silicon detector was produced by ITC—IRST (Trento, Italy) and bump-bounded by VTT Microelectronics (Finland).

For this study we have used a standard mammographic tube (Instrumentarium Imaging Products Diamond), equipped with a Molibdenum target.

2. Detector tests

A preliminary work based on simulations was done in order to study the behaviour of the electric

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potential inside the detectors. We have found that inserting on the junction side a multiple guard ring termination structure, consisting of 12 p^+-implanted floating rings, in between the main guard ring and the scribe line, the space charge region spreads laterally much further than in the case of the single main guard ring, as a result of punch-through conduction between the rings [3]. We have decided to produce and test 300 and 525 μm thick pixel detectors. To check the properties of these wafers we have tested some single diodes whose area is $3.14 \times 10^{-2}\,cm^2$. The current densities are lower than $0.5\,nA/cm^2$ for the 300 μm and $1.2\,nA/cm^2$ for the 525 μm at full depletion of 30 and 95 V, respectively.

After the bump-bonding, the electrical properties for two of the 525 μm thick assemblies have been measured applying a voltage on the ohmic side up to a value of 200 V. The leakage current values are very low and the corresponding value of the current density is of the order of $9\,nA/cm^2$ at 200 V. These assemblies do not exhibit breakdown problem.

To verify the better detection efficiency[1] of the 525 μm thick assembly respect to the 300 μm one, we have used a flat field image acquired with ^{109}Cd. The values for the obtained efficiencies (Table 1), have been compared with the results obtained using the values contained in a Photon Cross Section Database (XCOM). The photoelectric interaction, the Compton scattering, weighted over the different emissions of the ^{109}Cd source, have been taken into account. Besides the efficiency for the 300 μm thickness has been compared also with the result of a Monte Carlo simulation [4], in which the photoelectric interaction, the Compton and Rayleigh scattering have been considered and a threshold of $3000\,e^-$, comparable to that of our electronics, has been used. The agreement between the simulated value of $17.4 \pm 0.4\%$ and the corresponding experimental one (Table 1) is satisfactory.

Table 1
Experimental and theoretical efficiency for the 300 and 525 μm thick assemblies

Thickness (μm)	Detection efficiency (%)	XCOM efficiency (%)
300	17.4 ± 1	18
525	28 ± 1.7	29

3. Imaging tests

The detector used for imaging test is 525 μm thick. Previous experimental tests showed that the amount of Compton scattering depends on the irradiation area and on the distance between the phantom and the X-ray detector. We observed that an irradiated area comparable to the area of our detector improves the image quality [5]. In order to obtain a complete image, the phantom was exposed to X-rays and moved using motors controlled by personal computer. The irradiation area was comparable to the detector area. We acquired 64 different images. The tube settings were 25 kV and 80 mAs for each image. Each image has been equalized by weighting with a high statistics flat field image obtained in the same beam condition with a 4 cm thick lucite cylinder. The layout of the RMI 156 phantom is shown in Fig. 1, while the composite image of the phantom is shown in Fig. 2. We obtained a uniform large area image. In the image we can see five nylon fibers, three microcalcification groups and four tumor-like masses.

The size of the smaller microcalcification group (detail 9) that we are able to see is 0.32 mm as consequence of the pitch dimension of our detector.

The experimental contrast[2] of tumor-like masses varies between $7.7 \pm 0.1\%$ (detail 12) and $2.0 \pm 0.2\%$ (detail 15). For the detail 12 the

[1] $\eta = N/A_0 \Omega t$, where: η is the efficiency, N the sum of the counts over the whole matrix, A the activity of the source, Ω the solid angle and t the time of the acquisition.

[2] The contrast is defined as $C = (N_b - N_d)/N_b$, where N_b and N_d are the mean number of counts/pixel registered on the background area and on the detail area, respectively.

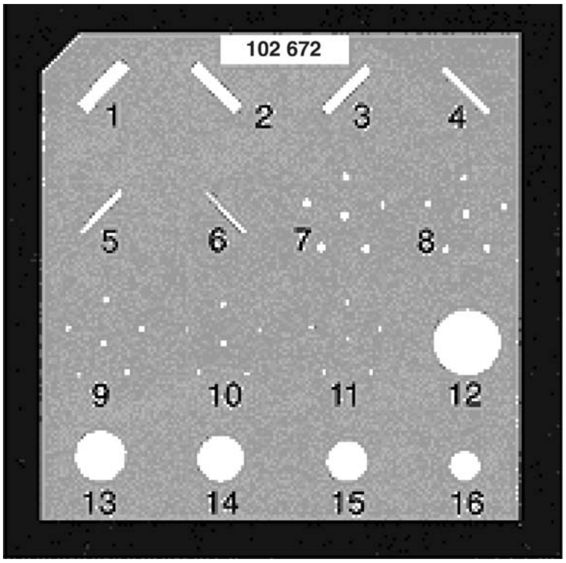

Fig. 1. Layout of the RMI156 phantom.

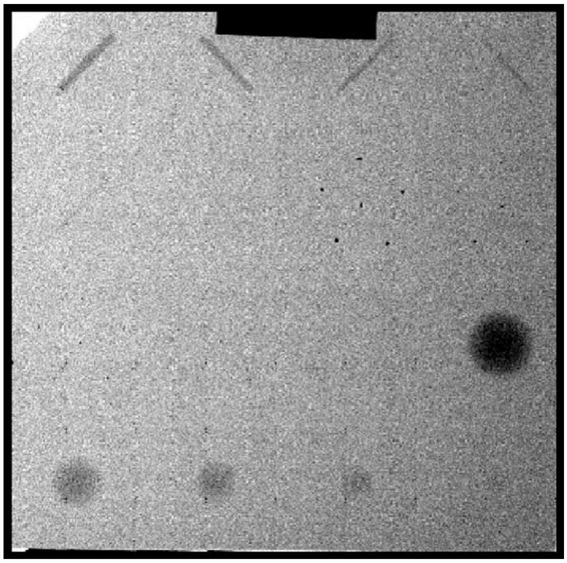

Fig. 2. Composite image of the phantom, obtained from several images of smaller field of view.

SNR[3] is 6.1 ± 0.1 and for the detail 15 the SNR is only 1.6 ± 0.2.

4. Conclusions

The performances of our system are good with respect to the indication of the American College of Radiology (ACR), that requests the detection of details 1–4, 7–9 and 12–14.

The experimental performances obtained with the 525 μm thick assembly are good and these results have encouraged us to increase further the thickness of the silicon detector.

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References

[1] M.G. Bisogni, et al., Proc. SPIE 3445 (1998) 298.
[2] http://medipix.web.cern.ch/MEDIPIX
[3] M. Novelli, et al., Nucl. Instr. and Meth. A 509 (2003) 283.
[4] W. Bencivelli, et al., Nucl. Instr. and Meth. A 310 (1991) 210.
[5] S.R. Amendolia, et al., IEEE Trans. Nucl. Sci. 49 (5) (2002) 2361.

[3]The SNR is defined as $\mathrm{SNR} = \sqrt{2}|N_b - N_d| / \sqrt{\sigma_b^2 + \sigma_d^2}$, where σ_b and σ_d are the variances of the mean number of counts/pixel registered on the background area and on the detail area, respectively.