Abstract — A silicon strip detector in edge-on configuration with a single photon counting (SPC) read-out electronics was developed for the MATISSE (MAmmographic and Tomographic Imaging with Silicon detectors and Synchrotron radiation [SR] at Elettra) project. MATISSE is an experiment of the interdisciplinary sector of the INFN (Istituto Nazionale di Fisica Nucleare), aiming at a pre-clinical phase of tomo-mammographic examinations at SYRMEP (Synchrotron Radiation for Medical Physics) beamline of Elettra, the Trieste SR facility. With a high intensity SR source it is possible to obtain practically monochromatic laminar beams, in the energy range 8-35 keV.

The MATISSE detector is side illuminated, thus allowing direct, high efficiency, conversion of X-rays. The read out electronics operates in SPC mode, maximizing the signal-to-noise ratio of the images. Thanks to the characteristics of the radiation source and to the high efficiency of the detector, the dose delivered in a tomographic examination results comparable to the one delivered in planar conventional mammography.

Detector prototypes have been assembled and tested with promising results. New tests and first tomographic images of phantoms and ‘in vitro’ samples have been planned in the next months at the SYRMEP beamline.

Index Terms — Digital mammography, Synchrotron radiation, Computed tomography, Single photon counting.

I. INTRODUCTION

The aim of the MATISSE project is the development of a detector optimized for breast tomography with synchrotron radiation. The SYRMEP beamline is operating at synchrotron light source Elettra in Trieste in the field of medical imaging[1]. After experimentation on test objects and in vitro tissues, the beamline has been upgraded in order to allow clinical mammographic examinations, i.e. with patients.

At the experimental station, the laminar beam has a section of 21 cm x 0.4 cm. The image is acquired by scanning the breast in front of the stationary beam. An innovative patient support has been developed in order to move the patient, laying in prone position, with micrometric precision and accurate speed selection. The rotational movement has also been implemented in order to allow the acquisition of tomographic images.

The application of Computed Tomography (CT)[2] to breast imaging, combined with the use of synchrotron radiation, allows the discrimination of small size and low contrast details, keeping the dose delivered to the sample comparable to the one delivered in a planar conventional mammography[7], thanks to the possibility of selecting the optimal energy for each sample. The use of a monochromatic beam avoids the presence of beam hardening artifacts in the process of reconstruction of tomographic images, and a reconstruction of the attenuation coefficients of tissue is also possible. Since the beam is laminar with negligible divergence, the production of the tomographic images can be performed without introducing approximations in the reconstruction algorithm.

II. THE DETECTION SYSTEM

The detection system is based on a silicon microstrip detector with read-out electronics operated in single photon counting mode[5].

A. Silicon sensors

The silicon detector has been designed in order to maximize the absorption efficiency for photons in the mammographic energy range (17-32 keV)[6]. The detector is oriented with the strips parallel to the incoming beam (‘edge-on’ configuration). Therefore the incoming photons are fully absorbed in the 2 cm long p+ implants. The pixel size is defined by the detector’s thickness (300 micron) times the strip pitch (100 micron). The vertical resolution of the image can be improved by moving the sample of steps smaller than the vertical pixel size[7].

The undepleted region present on the illuminated side of the detector, between the scribe-line and the strips implants, causes an efficiency loss since the charge produced by photons in this region is not collected by the strips. In order to minimize this region, the MATISSE sensors have the guard ring only on three sides and the distance between the end of the wafers and the strips implants is reduced with respect to standard sensors (240 µm instead of 440 µm) without compromising the noise characteristic of the sensors (leakage current of the order of 0.1 nA per channel). The whole design guarantees an efficiency more than 70% at all energies of interest[6].

The detector matches the laminar beam shape and allows an almost complete scatter rejection, that ensures an high contrast resolution of the images.

B. Front-end electronics

The single photon counting read out electronics maximizes the contrast resolution of the images, as the only source of noise is given by the intrinsic Poisson-like statistics on the number of
photons. This is of particular relevance in tomographic imaging since the statistics of each voxel is acquired over several steps of rotation and less than 1000 X-rays are detected at each projection.

High gain and low noise are the characteristics needed in order to discriminate the X-rays signal (the charge created by a photon is of the order of 1 fC). A good efficiency response at high counting rates is needed in order to limit the time duration of the examination to a few seconds. These requirements are met by the va64_tap and ls64 ASICs by IDEAS ASA (Norway), shown in Fig.1. The ENC specification is of 500e- , that guarantees a SNR of 10:1, while the peaking time is of 75 ns [8]. The va64_tap has 64 parallel analog input with parallel digital open drain outputs. Each channel consists of a charge preamplifier and of an optional gain stage, followed by a shaper AC coupled to a comparator with selectable threshold. The ASIC has a global threshold setting for the chip and a fine tuning individual channel threshold by means of a 4 bit DAC.

The ls64 works as parallel level shifter and is directly bonded to the va64_tap. The counting and the interfacing functions have been implemented by means of an Altera APEX20K FPGA. A parallel counter with loadable shift register has been implemented for each counter. The acquisition is controlled by a VME I/O register interfaced with a PC. The acquisition program is written in C with GTK graphical interface and controls also the motion of the sample.

III. FIRST RESULTS

Different prototypes of the detection system have been assembled and tested [9].

A. The 64 channel prototype

The first prototype assembled consists of a multiplayer printed circuit board with a single ASIC (64 channels) and a relative sensors with 64 channels connected by means of wire bonding, as the Fig.2 shows.

In order to test the rate response of such prototype, pulses of various frequencies have been injected through the calibration capacitor directly connected to the va64_tap analog input. A very good linear response without efficiency loss was observed up to 3.5 MHz rate (Fig.3). This high rate should allow to perform an examination in a few seconds without observing contrast loss. Images of mammographic test object have been acquired at the SYRMEP beam line at Elettra. In order to test the performances of the prototype a Gammex RM180 phantom was used as test object. It consists of plexiglas discs with different thickness, whose theoretical contrast can be calculated by means of the attenuation coefficient of Plexiglas. The Fig.4(a) and Fig.4(b) show the images of a column of discs acquired at 28 keV and 32 keV respectively. The values of the energies were chosen because they are suitable for CT examination. The Fig.4(c) shows the plot of the measured contrasts respect to the theoretical ones. As you can see, the measured values are very close to the theoretical ones. Moreover contrast lower than 1% are still visible with a statistic of about 104 photons/pixel.

B. The 384 channel prototype

Finally, a new printed circuit board containing 6 ASICs (384 channels) was designed and connected to a silicon sensors giving a sensitive area of 3.84 cm (Fig.5). This configuration is a good candidate to became a module for the final detector (that should have a sensitive length of about 20 cm in order to match the synchrotron beam). In fact it could be possible repeat the scheme of such prototype up to reach the desired dimension. Some preliminary tests were performed with this detector. In particular the Gammex RM180 phantom was still used as test
Theoretical Contrast (%) | Measured Contrast (%)
---|---
28 keV | 0
32 keV | 0.5

Fig. 4. Images of column of discs of a Gammex RM180 test object acquired at 4(a) 28keV and 4(b) 32keV and 4(c) a comparison between measured and theoretical contrasts.

Fig. 5. Board assembled with 384 channels detector.

Theoretical contrast (%) vs Measured contrast (%)

IV. CONCLUSION

The first prototype of the MATISSE detector has been tested with good results in terms of SNR and rate response. Planar images of mammographic tests object have been acquired and the measured contrast values result comparable with the theoretical ones.

Since the detector for clinical examination requires a width of at least 20 cm, a new prototype with a sensitive area of 3,84 cm has been designed and assembled. The preliminary tests with such detector have been performed giving promising results although further optimization is needed in order to achieve the desired specifications for the detector in terms of speed and noise.

REFERENCES