Two Solutions of the Quantum Imaging X–ray CT System based on GaAs Radiation Detectors

[1]J. Přibil, [2]B. Zaťko, [1]I. Frollo, [2]F. Dubecký

[1]Institute of Measurement Science, SAS, Dúbravská cesta 9, Bratislava, Slovakia
[2]Institute of Electrical Engineering, SAS, Dúbravská cesta 9, Bratislava, Slovakia
Email: umerprib@savba.sk

Abstract. *The work presents two generations of developed portable quantum X–CT mini–systems which utilizes monolithic semi–insulating GaAs radiation detectors. This contribution describes present status of the assembling of new portable X–ray CT mini system. Performed measurement of the performance of the SI GaAs detectors and the integral spectra of ASIC DX64 readout chips are also mentioned.*

Keywords: X–ray imaging, Single photon counting detection, Image reconstruction

1. Introduction

The X–ray computer tomography (X–CT) is a non–destructive testing method able to evaluate the inner structure of investigated objects [1], [2]. The cross–sectional imaging is achieved by the mathematical reconstruction of projections of a tested object. Such a projection is an intensity image of transmitted X–ray photons through the evaluated object. Small CT imaging instruments for the evaluation of small animals have been developed preferably for operation in the positron emission mode (PET). Almost all commercial X–CT systems use photodiodes as detectors that are covered by a scintillator [3].

This paper makes a comparison of two developed portable quantum X–CT mini–systems (XCTMS) which utilizes monolithic semi–insulating (SI) GaAs detectors. The solution of these two X–CT devices was also different in the approach of sample and X–ray source/detector arrangement. Both devices are using the same principle of image reconstruction from projections [1], but modifications of the basic reconstruction algorithm to eliminate some imperfections following from physical properties of used X–ray detector and utilized scanning technique must be applied [4].

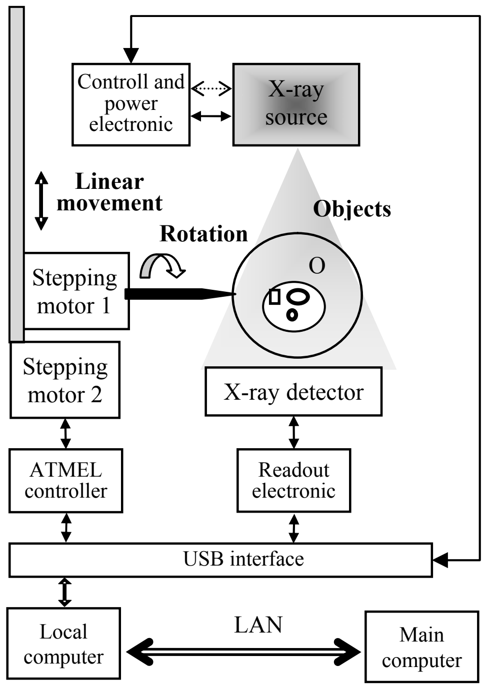

Fig. 1. Block diagram of the 1st X–CT device.

2. Subject and Methods

In the first generation of realized X–CT device was used the construction solution, where the sample is rotated and can be linear moved in the *x*-axis for changing the reconstruction geometry (zoom-in/zoom out), the X–ray source and detector are stationary [4] (see Fig.1). This device use the active X–rays source with energy of photons up to 80 keV, and the digital X–ray scanner consisting of 17 monolithic 24 strip line detectors named “SAMO” based on bulk SI GaAs [5].

In the second generation of XCTMS the different construction approach was applied. An evaluated object is located between the X–ray source and the detection unit. One of the stepper motors ensures a full rotation of the X–ray source & detection unit coupled system around the object (see Fig. 2a). The other stepper allows for its linear positioning along the *z* direction. As a fan–beam configuration (diverging beam) is used, the micro–adjustable slit ensures that the width of the X–ray beam is little wider than detector double array width and irradiates only active area of the pixel detectors.

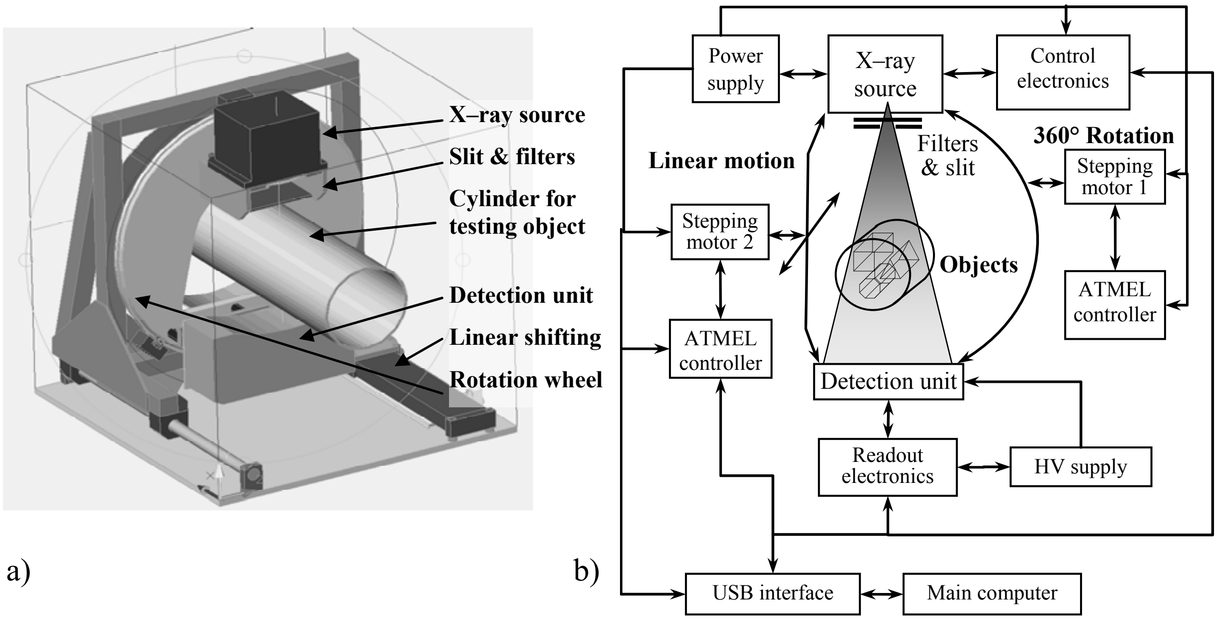

Fig. 2. The developed new portable XCTMS: 3-D visualization (a), control block diagram (b).

The mechanical construction of the XCTMS has following structure: the X–ray source, connected with the filter and the slit holder, is positioned in the top part of an aluminium wheel, which is driven by the stepper motor. The cylindrical holder is used to fix the tested objects. This XCTMS device is portable and consists of the following parts (see block diagram in Fig. 2b): the X–ray source, the detection unit, two stepper motors, which control the rotation and the linear movement of the X–ray source coupled with the detection unit around the object evaluated, and a local high–performance PC with a touch–screen monitor allowing for comfortable control of all system elements.

The X–ray source (Source–Ray Inc.: Model SB–80–500) with a tungsten anode operates in an accelerating voltage range of 35–80 kV at a maximum current of 500 μA with a maximum focal spot size smaller than 46 μm at a maximum power of 40 W [6]. X–rays generated by the source pass through two filters, selectable from 2×8 positions in two rotatable carousels, followed by a micro–adjustable slit, which restricts the width of the cone (into which X–ray photons are emitted) into a narrow, almost one–dimensional beam.

The detection unit consists of 16 input mini–modules, each with 2×64 monolithic SI GaAs pixel detectors with a pitch of 250 μm arranged along two lines on the chip and assembled into an arc. The detection double array incorporates 2×1024 pixels over a total length of 261.5 mm. A small gap, corresponding to 1.5 pixels, is maintained between each two neighbouring modules to prevent the outer pixels from damage. The total length of the double array on the chip is 16.25 mm. The operational bias of the SI GaAs detectors is ranged between 150 and 300 V. The pixel detectors are dc–coupled to the inputs of two ASICs–type DX64 readout chips [7], by wire bonding via pitch adapters, which adjust the pitch of the pixel detectors to the input pads of the ASICs. The readout chips have two discrimination levels and 20–bit counters for each channel; hence one energy window is available within one evaluation scan. The devices are glued and wire–bonded onto an input PCB (printed circuit board) with dimensions of about 16 mm × 120 mm. The PCBs are fixed onto Peltier coolers, which stabilize the working temperature of the detectors and the input electronic circuitry at about 15° C using a thick Cu holder.

We have used the filtered back projection (FBP) for image reconstruction from projections reconstruction because of sufficient speed to accuracy ratio [1]. Nevertheless the FBP needs many projections (several hundreds or more) to obtain a correct image because of many effects coming into X–ray sinogram such as fluorescence, X–ray scattering, beam hardening, phase effects, etc. Perspective approach uses an iterative scheme of tomographic reconstruction. Its advantage is that we can get a good image even from noisy data and low number of projections [1]. In the case of first generation of the X–CT device, the parallel beam or fan beam with equidistal detectors geometry can be used. For the new XCTMS with rotating X–ray source and detection unit system, the fan beam with equiangular detectors geometry will be used.

3. Experiments and Results

Before implementation of image reconstruction algorithm to the developed portable XCTMS, used approach was tested on the experimental equipment realized in two year ago [7]. For giving good X–ray images some imperfections must be eliminated. The imperfections follow from physical properties of used devices and applied scanning technique. Used type of SI GaAs detector generates the frequency noise, which also depends on the temperature. The high frequency component of this noise brings a “background” texture of reconstructed object. For that reason, the low–pas (LP) filtration on the slices of projection data matrix can be performed. On another hand, the filtration produces the blur edge effect. Therefore, the parameters of designed LP filter must be set as a compromise between two mentioned antagonistic requirements. The tested objects were placed in the maximum distance from the X–ray source and near upon the scanner. Consequently, emitted beams can be considered as parallel and the image reconstruction method based on parallel beam can be used (that be characterized by a lower computing complexity than the fan beam method). Finally, for comparison, the fan beam reconstruction method was also applied – see Fig. 3.

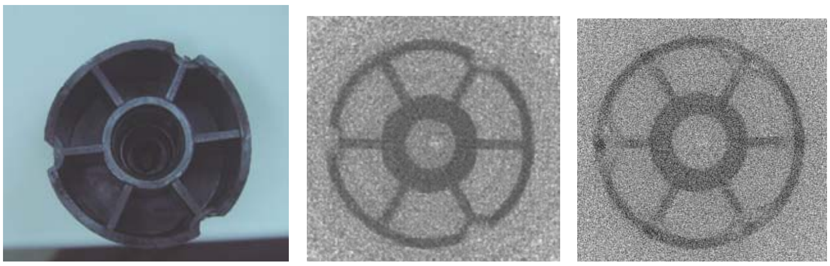

Fig. 3. Image reconstruction on the testing object: photography of plastic tube with six capsules, diameter 40 mm (left), finally reconstructed image by the parallel beam method – 100 projections per 3.6 deg (middle), reconstructed image by fan beam method (right).

The second generation of XCTMS is now almost finished. The measurement of the performance of the SI GaAs detectors and the integral spectra using ASIC DX64 readout chips were also performed. In our experiments we used eight detectors with four different diameters of the Schottky contact. The measured reverse I–V characteristics of all detectors at RT are depicted in Fig. 4a). Measured integral spectra (dependence between the total count of the channels and adjusted threshold) of SI GaAs detectors are demonstrated in Fig. 4b). Right edge of each spectrum represents impulses generated by 59.5 keV γ–photons.

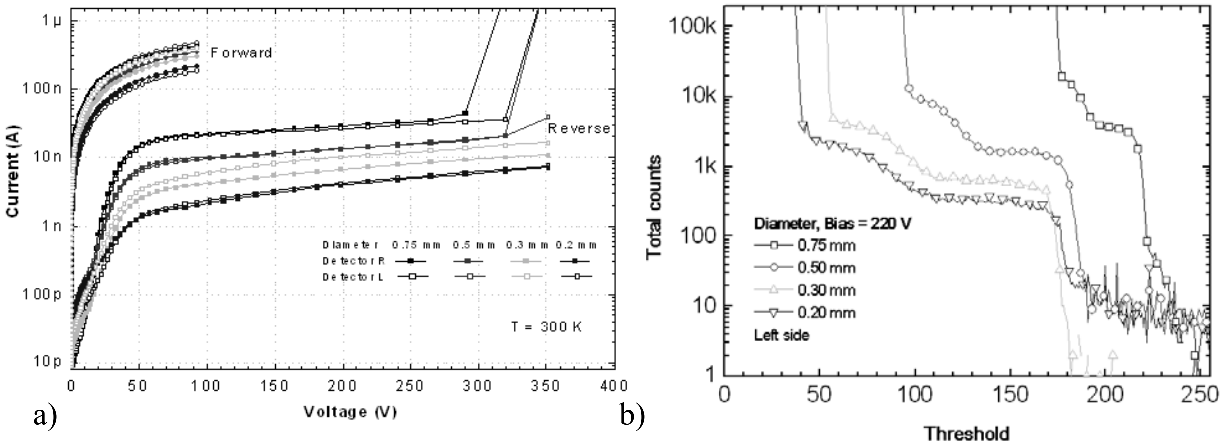

Fig. 4. Measurement of used SI GaAs detectors and ASIC DX64 readout chips: current–voltage characteristics of fabricated detectors (a), integral spectra of ^{241}Am: detector set 1 (b).

4. Conclusions

Two portable quantum X–CT mini–systems based on monolithic GaAs radiation imaging detectors have been realized. The modulation transfer function (MTF) of the first generation X–CT device was not tested up to now, because we have not an applicable phantom object. The detection homogeneity and the performance of the GaAs monolithic detectors connected to 24 channel readout chain were measured and tested; obtained results are introduced in [8].

The current assembling system is able to operate as an X–ray scanner or X–CT equipment with fixed objects up to a diameter of 180 mm and 250 mm in length. The detection part consists of a double array of 2×1024 SI GaAs detectors with a pitch of 250 μm. Two discrimination levels of the readout chip enable the energy selection of incident photons. A fine tunable slit mounted behind the X–ray source output guarantees a minimal dose for living objects. The expected spatial resolution of the device is 125 μm.

Acknowledgements

This work was partially supported by the Agency for Promotion of Research and Development under contracts no. APVV–0459–06 and APVV-99-P06305.

References

[1] Kak A. C.,Slaney M., Principles of Comp. Tomogr. Imaging. IEEE Press, 1999.

[2] Jakůbek J., *Nucl. Instr. and Meth.* A 576, 223, 2007.

[3] Wu H. et al., Book of Abstracts, IEEE NSS–MIC–RTSD. Dresden, 2008, p. 545.

[4] Přibil J. et al., Experiments with Application of Image Reconstruction Method Based on Perspective Imaging Techniques in X-ray CT Mini System. In proceedings of the *15th* International Conference IWSSIP'08, 2008, 33-36.

[5] Dubecký F. et al. Digital X-ray portable scanner based on monolithitic semi-insulating GaAs detectors. *Nucl. Instr. and Meth. in Phys. Res.* A 546: 118-124, 2005.

[6] The Model SB-80-500 SourceBlock Inst./Oper. Manual. Source-Ray, Inc. ©2002.

[7] Gryboś P. et al., Conference Record, IEEE Nucl. Sci. Sympos., 2006, N17-5, 693-696.

[8] Zaťko B. et al. Performance study of monolithic line radiation detector based on SI GaAs using X-ray source. *Nucl. Instr. and Meth. in Phys. Res.* A 551: 78–82, 2005.