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A New Spectroscopic Imager for X-rays from 0.5 keV to 150 keV Combining a Fully Depleted pnCCD Coupled to a Columnar CsI(Tl) Scintillator with Fano Limited Energy Resolution and Deep Subpixel Spatial Resolution

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Highly energy and position resolving detectors over a wide energy range are required for space telescopes in high energy astrophysics missions and for diffraction and fluorescence experiments in material science. By combining a low noise fully depleted pnCCD detector with a columnar CsI(Tl) scintillator an energy dispersive spatially resolving detector can be realized with high quantum efficiency in the range from below 0.5 keV to above 150 keV. The detector is exposed to the photon source such that the X-rays first traverse the 450 µm sensitive pnCCD. If they are stopped through the photoelectric effect in the Silicon detector, Fano limited energy resolution is achieved. This is true for all X-rays from a few hundred eV up to approximately 15 keV. Above this energy the conversion probability in the CsI(Tl) is becoming higher. Due to the high atomic number Z of Cs and I (55 and 53) hard X-rays are stopped efficiently for photon energies up to 150 keV for a 0.7 mm thick CsI scintillator. The light from the scintillator is recorded with the same back-illuminated pnCCD. For X-rays from a ^{57}Co source at energies of 122 keV we achieve an energy resolution of 0.7% (FWHM=850 eV) for the conversion in the Silicon directly while the energy resolution for the conversion in the CsI(Tl) is 9% (11 keV). We have performed “knife edge” measurements at 122 KeV and achieved a position precision at that energy of 27 µm. Monte-Carlo simulations were showing similar, fully compatible results. In case the X-rays are converted directly in the Silicon the position precision is better than 10 µm. This is close to the physical limits of spatial resolution in such a system which is given by the length of the tracks of the secondaries in the ionizing process in Silicon and CsI The CsI columns act as a light guide limiting the lateral expansion of the scintillation light.

The pnCCD system as a spectroscopic detector for simultaneous hard and soft X-ray imaging consists of a pnCCD chip with a pixel size of 75x75 µm^2 and a 0.7 mm thick columnar CsI(Tl) scintillator, coupled to the pnCCD back side, which is optimized for a maximal transmission of scintillation light from CsI(Tl). The schematic set-up is shown in Fig.1. The read out is performed column parallel wise, reaching frame rates of more than 1000 frames per sec. The detector stack is irradiated from the pnCCD side (see Fig. 1a). It has a high quantum efficiency for X-rays in the range from 0.5 keV to above 100 keV.

In previous publications (see references [1,2]) we have reported about the energy resolution of unstructured and columnar CsI scintillators coupled to a position and energy resolving detector system. In the present paper we focus on the spatial resolution of such a system using the “knife edge” technique to extract the modulation transfer function and finally the spatial resolution.

For the „knife edge“ measurements a ^{57}Co source has been positioned in a distance of 120 mm from the pnCCD. The “knife edge” is a 4 mm thick Tungsten block with a distance of 0.5 mm to the pnCCD – CsI surface. The manufacturing accuracy of the tungsten edge is +/- 5 µm. Fig. 1b, shows the measured indirect spectrum, The hit map generated by events in the CsI is shown in Fig. 2a. The mean measured modulation transfer function (MTF) of the spectroscopic imager in this setup is plotted in Fig. 2b (black curve).

In summary we have developed a high resolution soft and hard X-ray imager exhibiting Fano limited energy resolution over a wide energy range. We have demonstrated a spatial resolution reaching the intrinsic physical limits with a combined Silicon – columnar CsI(Tl) detector unit. The raw data deliver a position precision of

27 µm at 122 keV. If we correct for the non-ideal experimental conditions the position precision improves to 20.3 µm (λ = 0.27) in perfect agreement with MC simulations (blue curve).

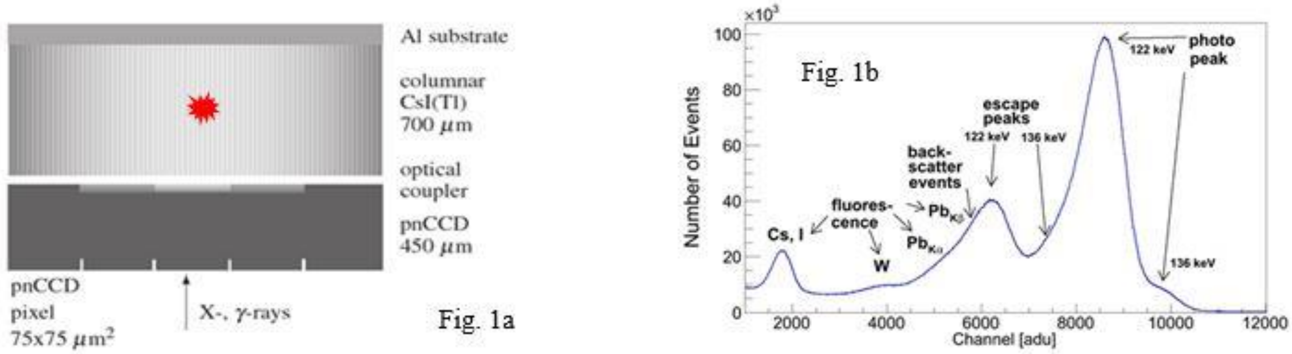

Figure 1. Fig. 1a. Detector stack configuration, consisting of the columnar CsI(Tl) scintillator, which is grown onto an aluminum substrate and coupled to the backside of the pnCCD with an optical coupler. The star assigns a possible position, where the gamma-ray interacts with the CsI(Tl). The area illuminated by the scintillation light are shown in lighter gray. Fig. 1b. Spectrum generated by X-rays of 122 keV, which had an inelastic interaction inside the columnar CsI(Tl) scintillator. The scintillation light was recorded through the homogeneous entrance window of the pnCCD.

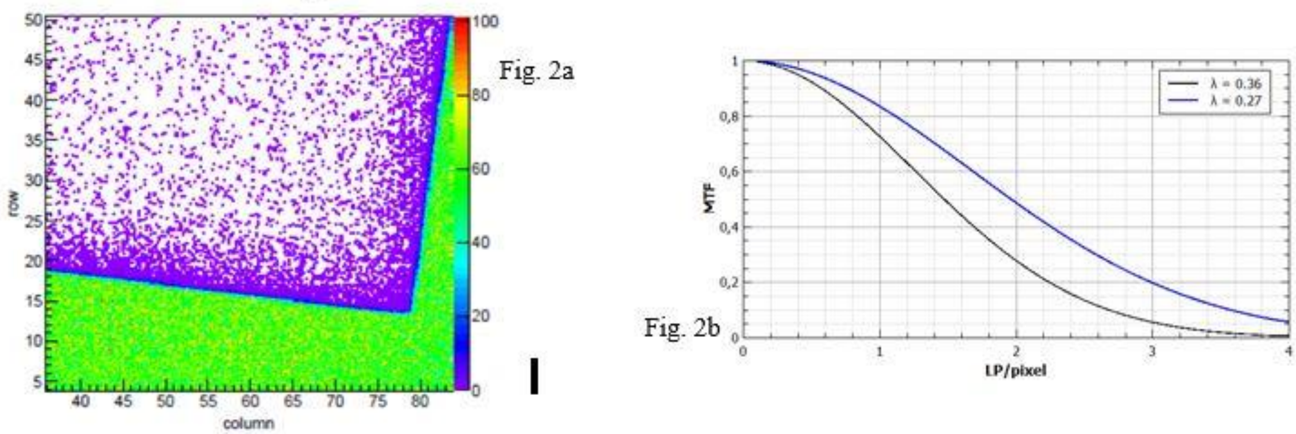

Figure 2. Fig. 2a. Events of the spectrum shown in Fig. 1b generate the hit map shown in this figure (binning 15x15µm2 rows and columns are in pixel units). The edges of the Tungsten block are clearly visible. Fig. 2b. Modulation Transfer Function (MTF) as a function of the spatial frequency (here: number of line pairs per pixel). The black curve shows the measured MTF extracted from the knife edge data displayed in Fig. 3. By subtracting all geometric effects (source expansion, knife edge precision, detector source distance and the interaction depth in the CsI(Tl) scintillator, etc.) calculated by GEANT4 MC simulations and the manufacturing error of the edge we obtain the MTF under ideal experimental conditions. In this case λ is 0.27 corresponding to 20.3 µm (blue curve). This is in very good agreement with the simulated spread of the deposited energy of the secondary interactions of photo electrons and fluorescence photons.

References

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[2] D. M. Schlosser et. al, Jour. Instr., vol. 12, Apr. 2017.

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