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High Spatial Resolution, Energy Resolved Imaging with the pnCCD Color X-ray Camera

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The color X-ray camera (CXC) is a device capable of energy-resolved X-ray imaging at high readout rates [1,2]. A high-resolution pnCCD detector with an image area of 12,7 x 12,7 mm^2, 264x264 pixels and 48 µm pixel size is integrated into a vacuum-sealed housing. The split frame, frame store operation along with a full column parallel readout allows for high readout speed of up to 1000 fps. At this rate, the statistical RMS noise per pixel is below 4 e$^-$ ENC. The detector has a fully depleted volume of 450 µm thickness and shows very high quantum efficiency approaching 100 % in the 1 keV-10 keV energy range and amounting to 35 % for 20 keV photons. To keep the leakage current at negligible levels even at slower readout rates, the pnCCD is thermoelectrically cooled. The TEC warm side is coupled to a water-cooled copper heat exchanger. The camera housing is evacuated to a pressure below 1 mbar by a fore pump in regular intervals to avoid condensation on the chip. Thus, for applications outside the vacuum the device can be used as a standalone instrument. In this case the entrance window consists of 50 µm thick Beryllium with a lower energy threshold around 3 keV. Since the camera head is compatible with high-vacuum environment, it is possible to directly attach the housing to a UHV-measurement chamber. In this case a windowless operation is also possible, pushing the lower detection limit to about 200 eV.

Special polycapillary optics has been developed by IfG [3]. Where needed, these X-ray lenses allow, similar to an optical object lens, the spatially resolving CCD detector to take X-ray images of the specimen. They consist of thin channels on a glass support. The channels guide the X-ray photons generated within a small area (angle) of the sample onto a respective small area on the detector, such acting as an angular filter for the emitted radiation (Figure 1). Basically two types of optics exist: the parallel channel optics delivering an unmagnified picture and the conical optics, which is used for achieving magnification imaging. Magnification ratios of 6:1 are achieved with such conical structures. Examples of imaging obtained with these two types of optics are given. If the detector is used in single photon counting mode, e.g. the energy and impact position of every single photon are known, the combination of charge splitting and center of gravity reconstruction allow for retrieving the impact position of single photons with a precision far below the pixel size. Without any optics, the detector intrinsic theoretical limit for 5 keV photons under standard operating conditions gives a RMS precision of the position reconstruction of few micrometers. Depending on the diameter of the capillary, the projected area “seen” on the detector may correspond to less than a pixel. In this case, by applying a center of gravity calculation method for the final charge distribution, it is possible to experimentally achieve spatial resolution well below the pixel size.

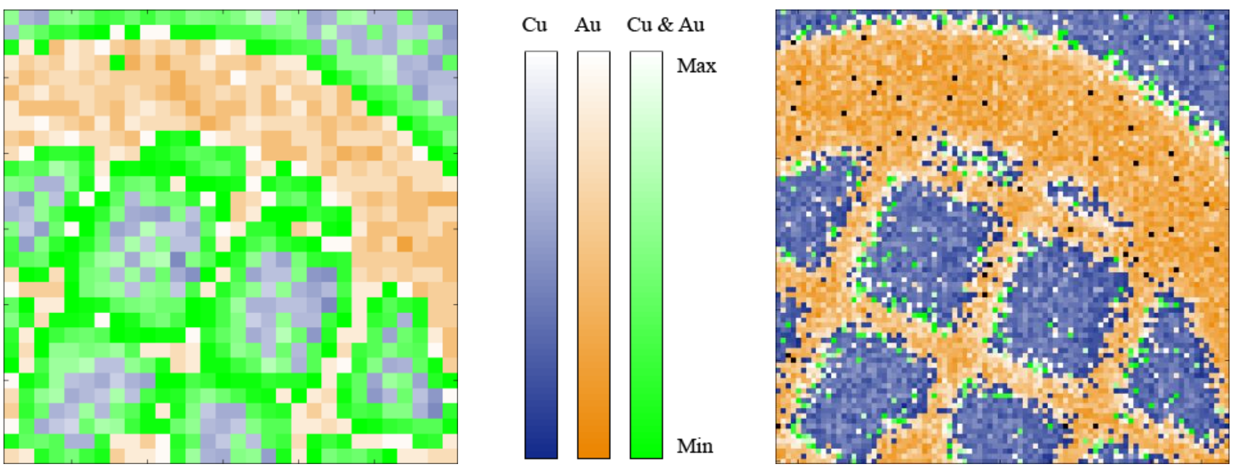
Figure 1 shows first results of the application of such a method. In this experiment, gold meshes were irradiated uniformly by an X-ray tube and the fluorescence photons were collected by a 1:1 optics and imaged onto the detector. The channel diameter of the single capillaries was 17 µm and the pixel size 48 µm square. By applying a simple event reconstruction (top left picture of Figure 1) without any centroid method, the gold bars of 26 µm diameter cannot be resolved. By applying a specialized centroiding method and by assigning single events to subpixels on the detector (right and bottom pictures of Figure 1), a progressive enhancement of the resolution is achieved demonstrating the sub-pixel resolution capability. Magnifying optics up to 10:1 magnification and polycapillary channel sizes in the order of 10 µm are currently actually under development. This, in combination with smaller capillary sizes, would allow theoretical limits for measured spatial resolution of the sample down to less than 10 micrometers.

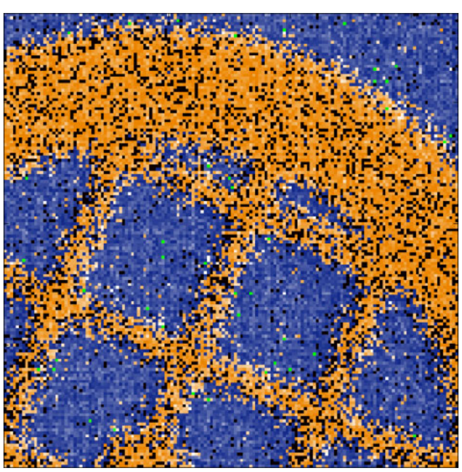
Present developments which aim at better algorithms to reach the theoretical detector resolution are on going. In the paper the relevant design and performance features of this new X-ray imager will be outlined as well as measurement results of its enhanced capabilities will be presented.

[1] I. Ordavo *et al*, Nucl. Instr. and Meth. A, **654** (2011), p. 250
[2] O. Scharf *et al*, Anal. Chem, **83** (2011), p. 483.
[3] A. Bjeoumikhov *et al,* X-ray spectrometry, **32** (2003), p. 172

No sub-pixels used
Effective pixel size 48 µm

3 x 3 sub-pixels used
Effective pixel size 16 µm





5 x 5 sub-pixels used
Effective pixel size
9.6 µm

Figure 1. Pictures showing results of measurements to achieve subpixel resolution by a specialized center of gravity reconstruction algorithm. All three plots show the same image section and are calculated from the same raw data.

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