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Characterization and Comparison of Detector Systems for Large Area X-ray Imaging

Jeffrey M. Davis[1,*], Julia Schmidt[2], Martin Huth[2], Sebastian Ihle[2], Daniel Steigenhöfer[2], Peter Holl[2], Gerhard Lutz[2], Udo Weber[1], Adrian Niculae[1], Heike Soltau[1], Lothar Strüder[2]

[1.] PNDetector GmbH, Otto-Hahn-Ring 6, 81739 München, Germany
[2.] PNSensor GmbH, Otto-Hahn-Ring 6, 81739 München, Germany

In the last 15 years, there has been a major shift in the type of detector used in X-ray microanalysis [1]. The silicon drift detector (SDD) is now the predominant energy dispersive X-ray spectrometer, having replaced the lithium drifted silicon detector. With high spectral resolution at input count rates over 100 000 counts/s, an SDD reduces the total time required to record a high quality X-ray image. In 2005, a multi-element SDD was also introduced, which combined multiple SDDs into a single detector [2]. These detectors combine large solid angles (for more efficient X-ray collection) with fast spectral processing through multiple pulse processors. Yet its primary drawback is that the SDD does not record the position of each X-ray event in addition to the energy. An array of SDDs could do this, but the position resolution would be poor. Otherwise, an X-ray scintillator combined with an ordinary charge coupled device (CCD) can record the location of the X-ray event, but the energy resolution is usually poor. An ideal imaging spectrometer would be one that can record both position and energy.

In 2011, PNSensor introduced an X-ray pnCCD camera, an energy dispersive X-ray spectrometer developed in collaboration with PNDetector. The pnCCD is a unique CCD that combines the excellent position resolution of the CCD with the energy resolution of an SDD. The pnCCD is able to collect X-rays at high count rates with the spectral resolution of every pixel on par with high performing SDDs, because it records both the position of the X-ray event and the energy. This spectroscopic imaging capability opens up new opportunities for X-ray imaging and analysis, especially for large samples analyzed in the µXRF.

Numerous experiments have been performed to test and quantify the spectroscopic qualities of the detector as they relate to high precision X-ray microanalysis. Functioning purely as a spectrometer, the pnCCD can count at a rate of 200 000 counts/s (or more) with a resolution of approximately 150 eV at Mn K-alpha. However, when a polycapillary optic is placed in front of the pnCCD to focus the incoming X-rays, the pnCCD can be used to produce X-ray images. This is particularly useful in µXRF where the pnCCD eliminates the requirement of scanning the sample under the X-ray beam by recording all 70 000 spectra at once. The imaging area of the pnCCD is 1.2 cm x 1.2 cm, with a pixel size of 48 µm (sub pixel resolution down to 10 µm possible). Although the electronics and data processing are different from the SDD, the end result of an experiment performed with the pnCCD is an X-ray Spectrum Image (a full X-ray spectrum stored at each pixel). As a large area imaging spectrometer, the pnCCD has proved extremely useful in diverse fields such as cultural heritage conservation and materials science, where efficient, large area imaging is necessary [4]. This work is primarily concerned with the advantages and opportunities provided by the pnCCD when used as an imaging spectrometer in a µXRF system. As shown in Figure 1, the spectral performance of the detector, while counting at a rate of over 200 000 counts/s is easily comparable to an SDD counting at a rate of approximately 20 000 counts/s. Figure 2 shows an image produced with the pnCCD. The image was collected in approximately 600 s, and it covers an area of 1.4 cm^2. To get the same data from an SDD based system, the stages in a conventional µXRF would have to move at a rate of 5 m/s and count at a rate of 115 000 counts/s.

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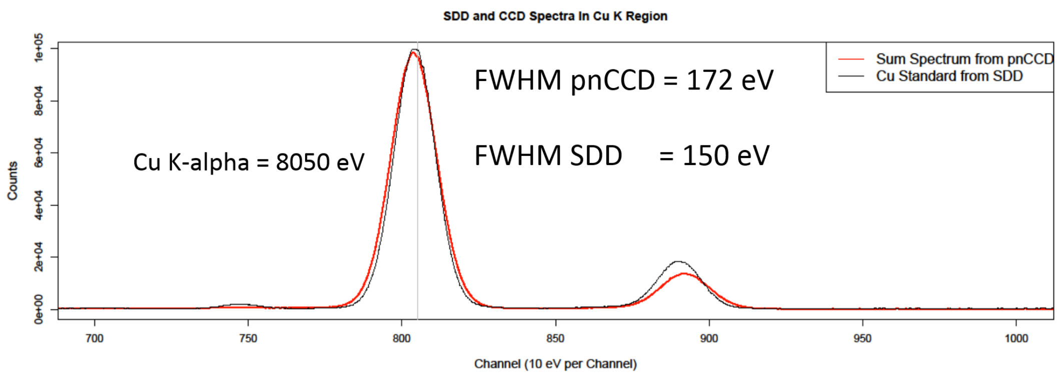

Figure 1: Spectral comparison of a spectrum from an SDD (black line) and a spectrum made with a pnCCD (red line). The pnCCD spectrum has an equivalent resolution of 152 eV at Mn K-alpha The performance of the spectrometer at a count rate of over 200 000 counts/s is very good for imaging purposes.

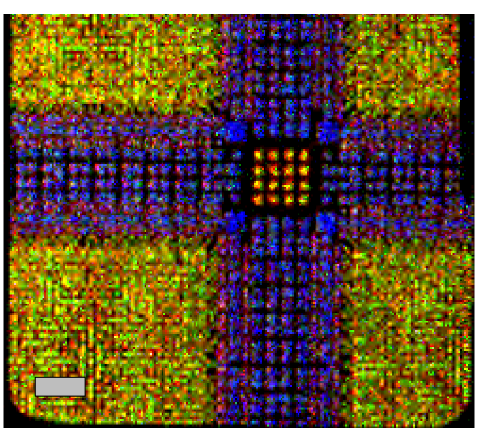

Figure 2: The X-ray image of a section of an IBM circuit board has dimensions of 1.2 cm x 1.2 cm, and it was acquired in 600 s. Yet this image was produced with the pnCCD without moving the stage, fully resolving spatial features, such as the wires in the center, which are approximately 150 µm in diameter. Here the Cu X-rays are colored in red, the Au X-rays are in blue and the Ni X-rays are in green. The scale bar represents 1.4 mm on the image.

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