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Five Dimensional X-ray Imaging with the Color X-ray Camera

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Scanning electron microscope based X-ray EDS analysis and micro focused X-ray fluorescence (μXRF) analysis typically rely on a focused beam to create X-ray images. The beam is addressed to an array of points on a sample, and a full X-ray spectrum is recorded at each point. An X-ray spectrum is a one dimensional data structure where the intensity (usually measured in arbitrary units known as "counts") is a function of energy. Recording these one dimensional data structures at each point in an array creates a three dimensional data structure known as an X-ray spectrum image (XSI). As a technique, X-ray imaging has proved useful in a wide variety of fields, and it was particularly improved by the invention of the silicon drift detector, which reduced the time required to acquire an XSI by a factor of ten or more [1].

Five dimensional X-ray imaging is based on the idea of recording a full XSI at each point in a two dimensional array on a sample. This new imaging mode is made possible through the use of an imaging spectrometer, such as the pnCCD based Color X-ray Camera (CXC) [2]. An imaging spectrometer records the (X_{camera}, Y_{camera}) position where each X-ray event hits the detector as well as the energy of the X-ray event. In this way, a three dimensional XSI can be recorded from a single analysis without scanning the X-ray beam or the stage. With a two dimensional array of XSIs, each intensity is a function of (X_{sample}, Y_{sample}, X_{camera}, Y_{camera}, energy), as shown in Figure 1. Through a combination of high count rates (>500 000 cps with a 1000 Hz frame rate) and excellent energy resolution (typically lower than 145 eV at Mn Kα), the CXC enables efficient five dimensional X-ray imaging with a single instrument, using either a focused or a collimated X-ray beam.

Figure 2 shows the major results of imaging a semiconductor sample using the five dimensional X-ray imaging technique. A PMZT structure (Mn doped Pb on zirconate titanate, $1.3\,\mu\mathrm{m}$ thick) was applied to a single crystal wafer of [100] silicon, with layers of single crystal Pt [111] and polycrystalline TiO_2. The initial data set was generated by addressing a collimated X-ray beam (beam diameter approximately 4 mm at the sample surface) to an array of 220 x 150 equally spaced points (point spacing = $100\,\mu\mathrm{m}$) on the sample and saving a full XSI (X_{camera}, Y_{camera}, energy) at each point. From the five dimensional data set, the fluorescence spectrum and diffraction pattern signals at each analysis point (X_{sample}, Y_{sample}) can be separated and derived according to the method described in [3]. Images in the top row of Figure 2 are elemental X-ray images representing the intensity distributions of Pt and Pb. The counts in the Pb Lα and Pt Lα peaks are summed and plotted as an image, revealing a number of structures and surface compositional changes across the sample. Similarly, the counts from the first two diffraction peaks are summed and shown as the second row of images in Figure 2. Note that, although the beam is several millimeters in diameter, the method is able to reveal structures significantly smaller than the beam. This presentation will focus on the method of five dimensional X-ray imaging as well as the practical applications of the technique to complex, multilayered or otherwise heterogeneous structures.

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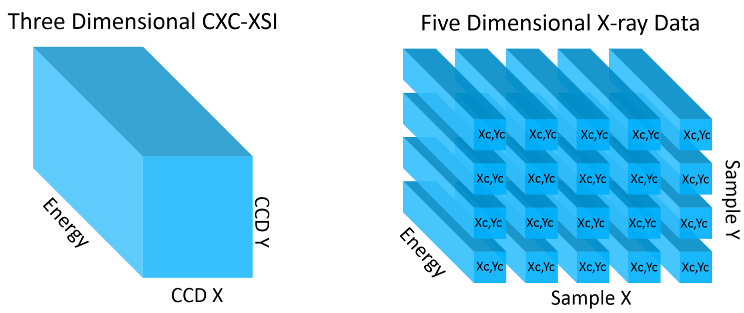

Figure 1: A comparison of the dimensions of an XSI generated from the CXC (left) and the five dimensional X-ray image (right). Each XSI in the five dimensional X-ray image comes from a single analysis point on the sample, as recorded by the CXC.

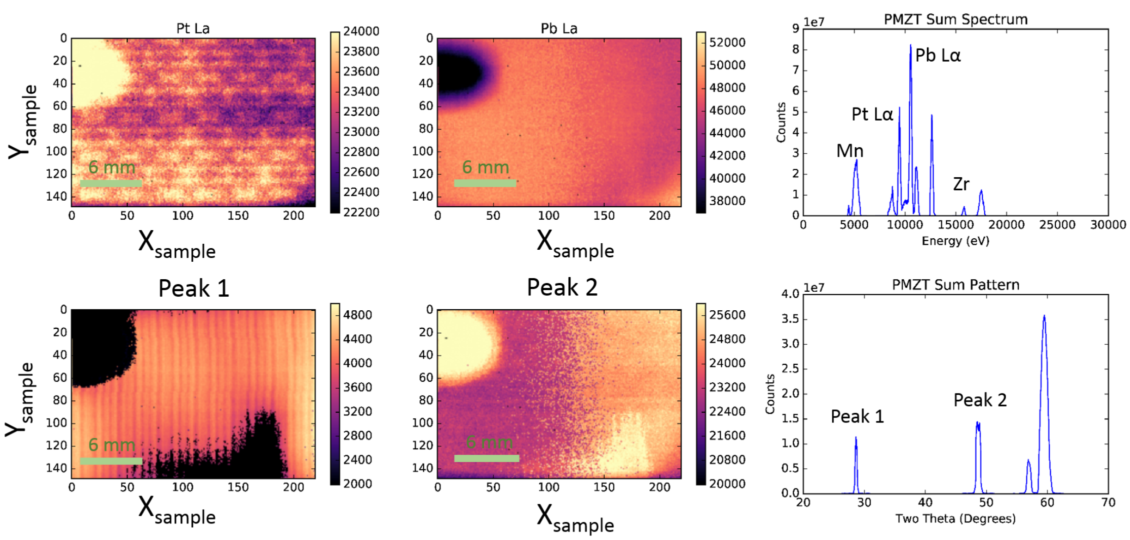

Figure 2: Derived fluorescence (top) and diffraction (bottom) from a five dimensional X-ray image. The derived images all have dimensions of (X_{sample}, Y_{sample}) because the XSIs from each analysis point have been processed to show intensity distributions of fluorescence lines or diffraction peaks.

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