X-Ray Projection Microscopy with a CCD Detector

Application Note

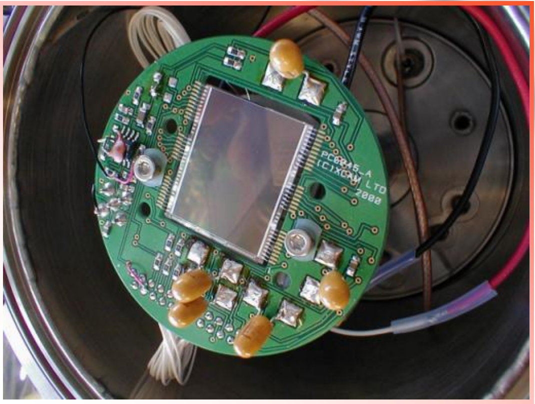

Figure 1 A prototype custom CCD and headboard developed by Xcam Ltd for this work

Researchers at the Commonwealth Scientific and Insustrial Research Organisation (CSIRO) in Australia have developed new X-ray projection microscopy techniques that use phase-contrast information to increase the resolution and information content of images. This work has been funded by XRT Limited, and is currently being commercialised by them. This technique utilises a scanning electron microscope (SEM), as a microfocus X-ray source, together with an optimised sample/detector geometry to optimise the system for 'phase-contrast' imaging. X-ray microscopy has advantages over optical techniques, offering a much greater depth of field, higher resolution, and the ability to image relatively thick, optically opaque and scattering samples.

X-ray projection microscopy

- An X-ray microsource, with a spot size < 1 μm, is used to illuminate a sample, forming an X-ray projection image of the sample at the charge coupled device (CCD) detector.
- The ability of a CCD to directly detect X-rays with high spatial resolution, high X-ray quantum efficiency in the 1-8 keV range and ability to resolve the incident X-ray energies by pulse height analysis, make the CCD a perfectly suited detector for this application (Figure 1).

Phase-contrast imaging

- Phase-contrast imaging allows greatly improved image information in the high-spatial frequency domain and also allows the imaging of objects that are weakly-absorbing.
- Phase shifts in the X-ray wavefront occur as the X-rays interact with the sample, producing Fresnel diffraction fringes in the recorded image.
- Mathematical phase-retrieval algorithms can then be used on the acquired 'phase-contrast' image to indirectly measure or reconstruct the phase shifts imposed on the X-rays by the sample.

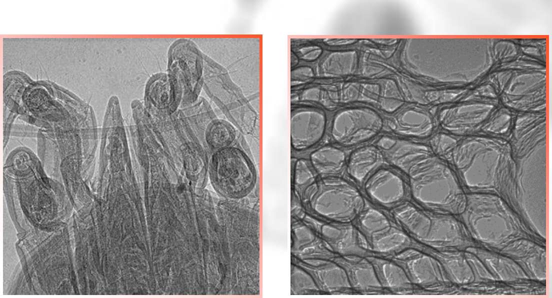

Figure 2 Images taken using the Xcam system, of part of a mite (left) and the microstructure of a section of wood (right)

System resolution and the CCD detector

- The imaging resolution of an X-ray projection microscopy system is primarily limited by the size of the X-ray source, but an additional limitation to the imaging resolution of the system is the detector resolution.
- Using a CCD as the detector, the detector resolution is simply the CCD pixel size. Typical image configurations use full frame operation with a 1000 × 1000 pixel CCD with 13 × 13 μm pixels.
- The ultimate practical limitation to the resolution is the minimum feature size that can be distinguished from the noise in the system e.g. the noise given by photon statistics if photon-counting. Typical exposures are 1-2 minutes, and several images are summed to get a total exposure time of around 10-15 minutes for a high quality, high resolution X-ray microscopy image (Figure 2).

Multi-spectral imaging and multi-energy phase retrieval

- The linear relationship between the size of the charge signal generated in the depletion layer of a CCD, and the incident X-ray photon energy can be used to measure the energy of incident photons to within ~200 eV. This allows relatively monochromatic images formed by X-rays of different energies to be accumulated.
- Once the CCD detector is correctly calibrated, images formed at different energies can be reconstructed, and obtained simultaneously. This method of multi-spectral imaging avoids any alignment problems that would occur if such images were acquired separately.
- Phase retrieval algorithms can then be used to extract the density distribution of the sample from the multi-spectral image. Within the detectable X-ray energy range of the CCD a number of different X-ray sources can be used, including silver, tantalum, gold and titanium (Figure 3).

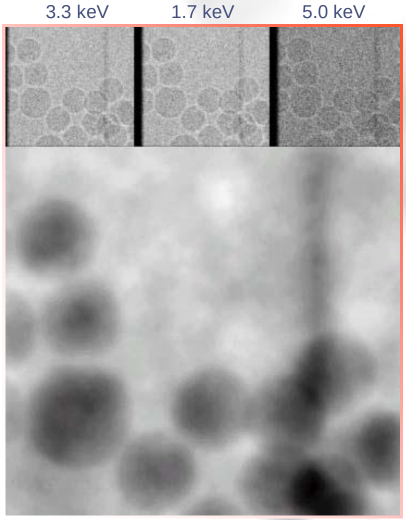

Figure 3 Three images (top) of 9 μm latex spheres acquired simultaneously using multi-spectral imaging at 3.3 keV (Au-M), 1.7 keV (Ta-M) and 5.0 keV (Ti-M) and (lower) a projected density distribution obtained by phase retrieval from the three images

Microtomography using phase-contrast imaging

- The Xcam system can also be used for ‘microtomography’. This technique enables a full three-dimensional representation of an object to be constructed from a series of X-ray images taken with the object at different angles.
- The sample is rotated in fixed interval steps between each image. The final image resolution is limited by the number of sample images obtained and by the data collection time.
- The images are reconstructed from phase-contrast data, and, as a result, show phase-contrast related features such as bright fringes at the external edges of objects (Figure 4).

Figure 4 Microtomography of a fly’s leg joint. The collected tomographic dataset image (left) and a longitudinal section through the reconstructed three-dimensional volume (right)

Future developments

Further improvements to the imaging capability of the system described are possible, including the use of deep-depletion CCDs for imaging thicker samples with higher energy X-rays; open electrode CCDs for imaging low contrast samples; and improved spatial resolution. Further information about the CCD and associated electronics used to take the presented images can be obtained from Xcam.

A more detailed version of this application note can be downloaded from the Xcam website, http://www.xcam.co.uk/notes/index.html

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