ESRF	**Experiment title:** **Differential phase contrast x-ray microscopy**	**Experiment number:** MI-354
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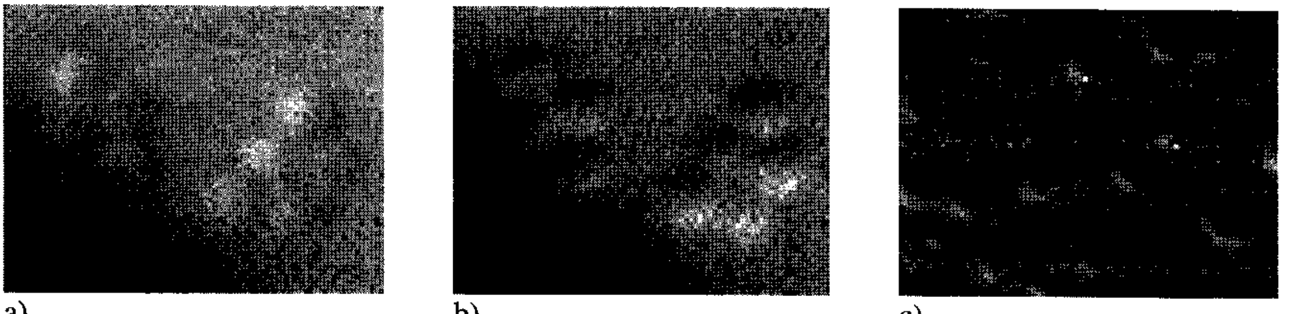
Report:

A new form of phase contrast x-ray imaging was demonstrated on ID21 at the ESRF in November 1999. In this case, the single photodiode used as the transmitted x-ray detector in the scanning transmission x-ray microscope (STXM) was replaced by an 80×80-element CCD detector, and a full CCD frame was recorded for every pixel in the STXM raster scan. The use of such a multi-element device provided a fully configurable detector geometry for the STXM, and allowed a very flexible choice of imaging modes, including some that were hitherto impossible in the STXM. The usual incoherent brightfield signal is formed from the sum of each CCD frame, while anti-symmetric detector combinations yield a differential phase contrast (DPC) signal [1]. Of the DPC signals, one of the most interesting is the first-moment signal, as this configuration results in a system with a linear response to phase gradients in the specimen transmittance [2]. The great advantage of such a system is that the different image signals can all be acquired simultaneously, from a single scan of the sample, while the choice of the detector configuration most appropriate for the sample under investigation can be amended retrospectively if desired.

The detector used was a CCD39-02 (EEV Ltd, UK), with a 2 mm square active area, back-face thinned for direct x-ray detection. It was supplied with suitable readout electronics to allow full CCD frames to be read out in under 10ms, through a 12-bit ADC, and this whole sub-system was controlled by software running on a PC. This software also allowed the CCD data collection to be synchronised with the raster scan of an STXM, returning a real-time image signal to the STXM control system, while the 3-D dataset is handled locally by the PC control system. The philosophy behind this approach was to allow the configured detector system to be installed easily and with minimal modification to a working STXM, in a sense to provide a "drop-in" replacement for the existing single-element detector. One possible disadvantage of a configured detector imaging system is that each 2-D image raster by the STXM now generates a large 3-D dataset; if a full CCD frame is stored for each point in a 128×128 raster, then the data volume for this single scan is around 200MB, although the rapid increase in the capacity of modern mass storage devices means that this no longer presents significant data-handling problems, even for a PC-based system.

The initial tests were carried out at an x-ray energy of 3.3 keV. The images in Figures 1a) and 1b) show 1μm diameter polystyrene latex spheres imaged in DPC mode. At 3.3 keV no absorption contrast could be seen above the noise level of the image. The DPC signals show the two components of the phase gradient, parallel to the horizontal and vertical directions in the image field. Figure 1c) shows a DPC image of small copper islands, typically less than 1μm in size, that are essentially flat with steep sides. The appearance of the DPC image allows this structure to be identified quite readily since the steep edges produce the highest gradients in the transmittance, and hence the highest contrast features. In this sample, there is a significant absorption component as well, but is clear that the effect of the absorption changes on the image contrast is reduced by the use of an anti-symmetric detector response, since the "land" areas of the islands are of uniform intensity in Figure 1c) (similar to that of the surrounding support film),.



a) b) c)

Figure 1: 3 differential phase contrast x-ray images, taken with x-ray energy 3.3keV. In each case the field size is 6μm × 4.5μm, and the samples are supported on a 100 nm thick Si_3N_4 membrane. Figures 1a) and 1b) show two orthogonal components of the first moment detector signal from 1μm diameter polystyrene spheres. Figure 1c) shows the vertical component of the first moment signal from a random array of copper islands.

In conclusion, therefore, the use of a configured detector system for the STXM has made available a range of new imaging odes, and in particular allows the simultaneous acquisition of both absorption and phase contrast images.

1. GR Morrison, JN Chapman, Optik, **64**, 1 (1983)
2. EM Waddell, JN Chapman, Optik, **54**, 83 (1979)