Diffraction mapping of complex refractive index in nano-structures using the phase-retrieval x-ray diffractometry method

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We were able to obtain diffraction patterns from the samples including gold nano-structures (nanowires, nano-checkerboard, nano-mesh, nano-dots) and an InGaAs/AlAs/GaAs nano-roll. The data will allow us to apply the Phase-Retrieval X-Ray Diffractometry (PRXRD) method to reconstruct fine structure of these nano-samples. The data recorded from gold test nano-structures will be used to evaluate coherence requirements to carry out such experiments. The data recorded from the nanoroll structure will be used to evaluate the capacity of the beamline to ultra-high local resolution for micro-diffraction studies of such structures.

Key word: phase-retrieval, coherent diffractive imaging, nano-rolled multilayers

To visualize an object at the nanoscale, a significant amount of x-ray photons must be delivered to a very small area. A state-of-theart synchrotron source (6-8 GeV 3rd generation machine) equipped with a modern undulator typically delivers approximately 1010-1012 photons/sec/mm2 at 8-20 keV within the coherence volume. A simple calculation shows that for a cube with 100 nm^3 dimensions, the actual flux incident on the smallest feature, which is still resolvable by a reconstruction algorithm, within the sample will be at best 102-104 photons per second [1].

It is thus imperative to explore the "real-life" experimental conditions when diffraction data from nanostructured samples can be collected to allow us to obtain quantitative information (such as shape, density and local strain) about the samples. The aim of the experiment was to collect experimental diffraction data from various nano-structured samples. We will use the

Phase-Retrieval X-Ray Diffractometry (PRXRD) method [2-3] to reconstruct fine structure of these nano-samples. PRXRD is a non-destructive technique, which only requires knowledge of a sample's structure as a verification to a reconstruction. This technique has been proven effective in reconstructing local areas of samples up to 0.5 micron size, with a spatial resolution of 0.5nm-10nm, and we are aiming to lower the locality to the scale of nano-particles.

The experimental method involved aligning the optics, including additional to the beamline's Si(400) monochromators and ~10 micron slits for increased temporal and spatial coherence. The detection system was crystal-analyzer based coupled with a scintillation counter. The samples were inserted into the beam, the local structures were located, and intensity versus diffraction angle was measured over a range of approximately +/- 0.5 degrees from the Bragg peak, giving us a spatial resolution in resulting profiles of approximately 5nm. Some examples of experimentally recorded intensities are shown in Figures 1 and 2.

We were able to obtain diffraction patterns from the samples including gold nanostructures (nano-wires, nano-checkerboard, nano-mesh, nano-dots), an InGaAs/AlAs/GaAs nano-roll and silicon nano-tubes of various annealing times. Initial analysis indicates that little to no damage has occurred to these samples, except for the silicon nano-tubes which appear to have been damaged during illumination or preparation. The recorded diffraction data is shown in Figure 3.

In conclusion, we have observed and recorded experimental diffraction patterns from various nano-structures, which will allow us to perform PRXRD reconstructions with a spatial resolution of 0.5-5nm. The test gold structures have been recently studied using a rotating anode laboratory source to allow us to evaluate the coherence and brightness conditions for quantitative analysis of sub-100nm features in nanostructured materials.

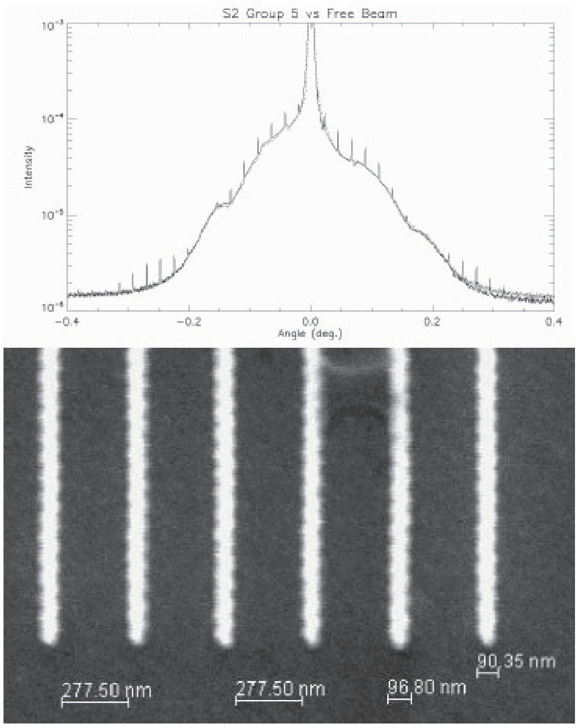

Figure 1. Diffraction pattern (top) from gold nano-wires (bottom) manufactured at the Singapore Synchrotron Light Source (SSLS).

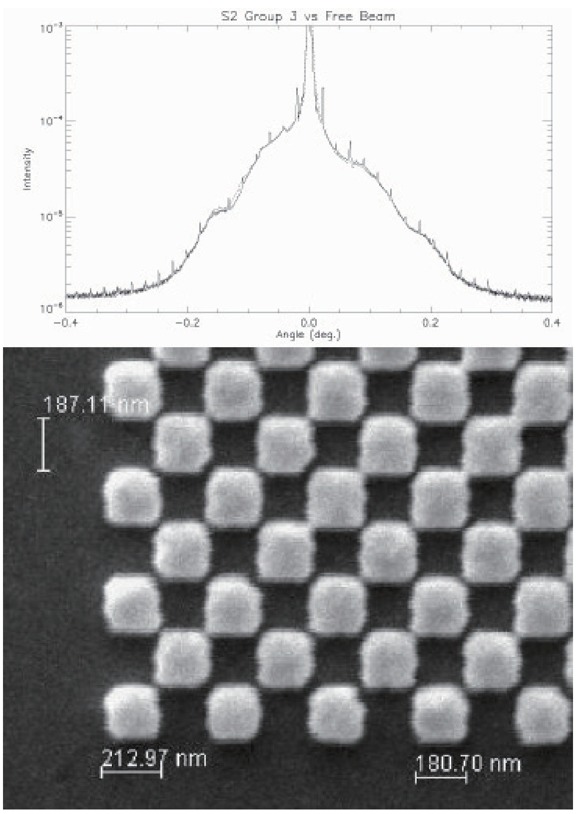

Figure 2. Diffraction pattern (top) from gold nano-checkerboard (bottom) manufactured at the Singapore Synchrotron Light Source (SSLS).

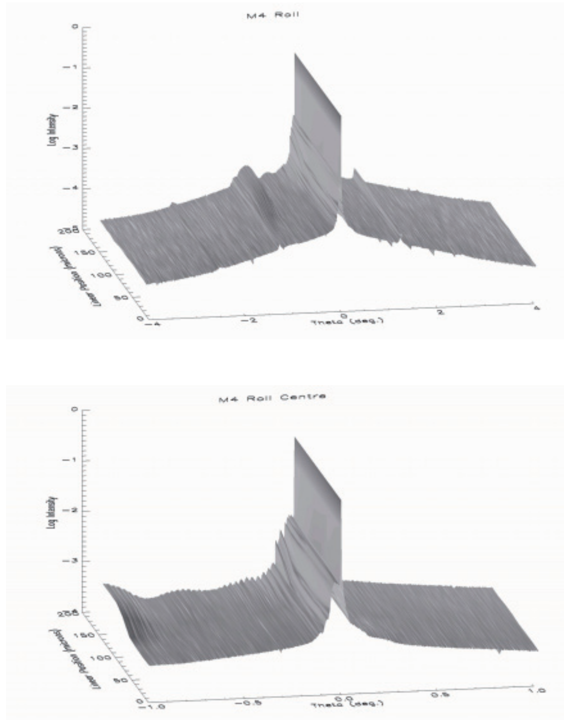

Figure 3. A series of diffraction patterns recorded from a nano-rolled sample as function of the beam position with respect to the roll location on the substrate. The top figure shows the full scans, which will allow reconstructions to be perfomed with spatial resolution of approx. 0.5nm, and the bottom figure shows the fine diffraction pattern variations as the beam was moved from the substrate, the roll and the flat multilayer areas.

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