BEAMLINE
X1A

PUBLICATIONS
M. Feser, B. Hornberger, et. al,. "Integrating Silicon Detector with Segmentation for Scanning Transmission X-ray Microscopy," *Nucl. Instrum. and Meth. in Phys. Res. A*, **565**, 841-854, (2006).

B. Hornberger, et al., "Quantitative Amplitude and Phase Contrast Imaging in a Scanning Transmission X-ray Microscope," *Ultramicroscopy*, **107**, 644-655, (2007).

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Phase Contrast Made Quantitative With New Detector and Advanced Analysis Techniques

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It's gentler on a specimen if it can bend x-rays rather than absorb them. Scientists at Stony Brook University have developed a way to use this beam-bending effect to obtain quantitative phase contrast images in scanning x-ray microscopes and microprobes, by using a special detector developed in collaboration with Brookhaven Lab and the Max Planck Semiconductor Lab.

An x-ray beam passing through a specimen can be absorbed as well as refracted. Traditionally, absorption has been used to produce contrast in x-ray microscopes, but this does not work well if the specimen is damaged by the absorbed radiation, or just does not absorb enough to produce sufficient contrast – as it happens at higher photon energies. However, consider the effect of a rough water surface in a swimming pool: although the water absorbs light barely at all, we see bright and dark patches at the bottom of the pool. This is because refraction redirects the light depending on the surface angle of the water, so that some areas receive more light than others. This redirection produces phase contrast, and this effect can also be exploited in x-ray imaging.

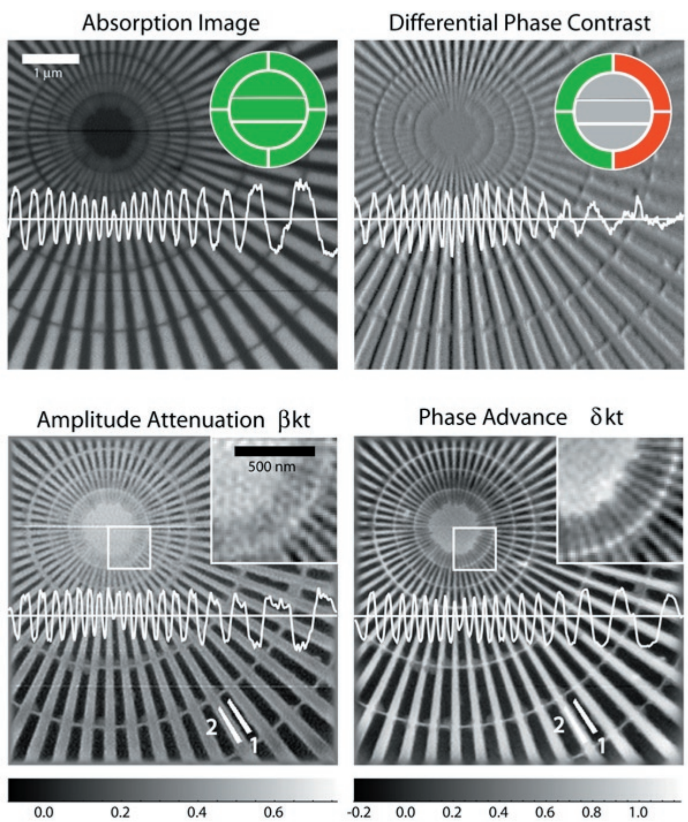
A variety of approaches to phase contrast x-ray imaging have been developed worldwide. Our goal was to make phase contrast available in a scanning microscope, because these kinds of microscopes also let you collect other useful signals (x-ray fluorescence from trace elements, for example) and are already good in minimizing damage to the specimen. An x-ray lens (Fresnel zone plate in this case) is used to focus the beam to a tiny, 35 nm resolution spot through which the specimen is scanned. The usual approach is to measure the total transmitted intensity for each image pixel, which produces an absorption image of the specimen. However, if a detector that is divided into segments is used, the difference image of opposing segments provides a measure of the beam deflection of the specimen at each scan pixel. At the same time, the signals from all segments can be added up to produce the same absorption image of a traditional single detector.

A key step was to develop a segmented detector with high efficiency and rapid readout. Such a detector has been developed by our team, which includes Michael Feser, Benjamin Hornberger, and Chris Jacobsen from Stony Brook University, and Pavel Rehak and Gianluigi De Geronimo from BNL's Instrumentation Division along with Lothar Strüder and Peter Holl from the Max Planck Semiconductor Laboratory in Munich, Germany.

Benjamin Hornberger (left) and Michael Feser displaying the segmented detector

With this detector, it is easy to display difference signals between detector segments and thus provide what are called differential phase contrast images. However, going from these images of differences in the specimen, to direct images of the phase shift of the specimen, is desirable (for example for measuring the mass of the specimen as needed in quantitative concentration calculations of trace element fluorescence) yet not straightforward. We have built upon previous work in electron microscopy to develop a Fourier filtering method, which can be used to obtain quantitative phase contrast images from the segmented detector. We represented the imaging process in the x-ray microscope mathematically, and then inverted the process to recover the specimen from the images obtained. This procedure recovers amplitude *and* phase of the specimen, while removing the blurring effects of the optical system.

The method has been demonstrated with a Germanium test pattern imaged at NSLS beamline X1A, where the recovered values of absorption and phase shift compared well with the numbers expected from tabulated material properties. Currently, the method is being implemented at Argonne National Laboratory's Advanced Photon Source because it is particularly useful when using higher photon energies, as is commonly done there. In the future, it could be very attractive for the upcoming NSLS-II and its proposed x-ray nanoprobes.



Images of a Germanium test pattern. Top left: Traditional absorption image, obtained by summing up all detector segments (see inset). Top right: Differential phase contrast image, obtained from the difference signal of left and right segments. The differential nature of the image leads to a three-dimensional appearance. Bottom left: Amplitude attenuation reconstructed by Fourier filtering. Bottom right: Reconstructed phase shift. Note that the phase image shows more detail than the amplitude image in particular at the center of the pattern, which is mostly due to the phase shift being stronger than the amplitude attenuation for Germanium at the photon energy of 525 eV used for this experiment.