Observations and simulations of imaging techniques with an X-ray laboratory source

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Introduction

The Micro X-ray Computed Tomography (MXCT) laboratory source at La Trobe University has been used to image a variety of samples. Many samples of interest have low absorption contrast when imaged with a laboratory source and are therefore best imaged using phase contrast. Recently Arhatari et al. (Optics Express, accepted 2008) showed how phase retrieval of a sample, imaged with a polychromatic laboratory source, can be achieved using an extended single-plane transport of intensity equation (TIE). As the MXCT source is further characterised, the technical details specific to this device can be applied to simulations to further improve the imaging process. This study looks at images obtained with the MXCT source under differing conditions of a gold test sample. We compare simulations and actual images to validate the simulations that have been produced.

Phase Retrieval

Phase retrieval of a free space propagated image can be attempted using a variety of different techniques. Those involving the contrast transfer function (CTF), the transport of intensity equation (TIE) and Gerchberg-Saxton iterative approaches have all been demonstrated in differing conditions. Most methods are extremely useful when working with monochromatic or highly spatially coherent light sources (such as those found at synchrotrons) but as x-ray laboratory sources are typically used without significant monochromatisation, a new approach is needed.

This study is focused primarily on using the extended TIE method (B.A. Arhatari et al, Optics Express accepted 2008) This approach takes the standard single-plane TIE and applies a weak absorption approximation to the single plane TIE:

$$I^{z}_{poly}(r) = I_0\left[1 - \mu_{poly}T(r) + z\delta_{poly}\nabla^2 T(r)\right]$$

where $I^{z}_{poly}(r)$ is the measured and I_0 the incident intensity, μ_{poly} is the average linear attenuation coefficient weighted with respect to the transmitted spectrum and the detector response function, δ_{poly} is the decrement from unity of the real part of the refractive index correspondingly treated and $T(r)$ is the projected thickness of the sample. The condition limiting this is approach is that the sample be weakly absorbing.

Spectral Response

For the analysis to proceed the spectral response function of the system must be known. This is a combination of the source spectrum, the response function of the detector used to measure the source spectrum, absorption in the optical path and the response function of the imaging detector. The spectral response function used here came from the source at the accelerating voltages used (40 kV, 100 kV, 150 kV), a CdTe spectrum analyser that was used to detect the spectrum, air path and a CsI scintillator optically coupled to a CCD. The results can be seen below.

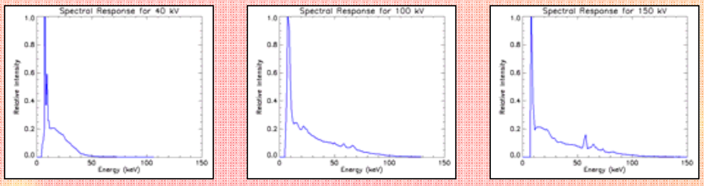

Fig. 1: (From left to right) The spectral response functions used for accelerating voltages of 40 kV, 100 kV and 150 kV respectively.

The Test Sample

The sample used was a gold L shaped object of dimensions 130 μm along the long side and 85 μm along the short with a sample thickness of 100 nm ± 10 nm. An image approximating this sample was created for the simulations.

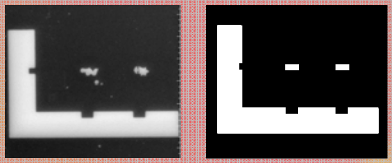

Fig. 2: An optical image of the gold test sample (left) and its corresponding simulated image (right).

Absorption Images

As a comparison of the simulation results to the measured images, a contact absorption image was taken of the sample at an accelerating voltage of 40 kV. Due to the test sample having a thickness corresponding to only 100 nm, both the real and simulation image show poor contrast as seen below.

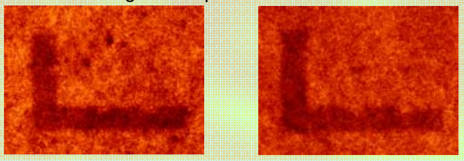

Fig. 3: An absorption image of the gold test sample (left) and its corresponding simulation image (right).

Phase Retrieved Images

The imaging and simulations, including phase retrieval, were performed for three different accelerating voltages (40 kV, 100 kV, 150 kV).

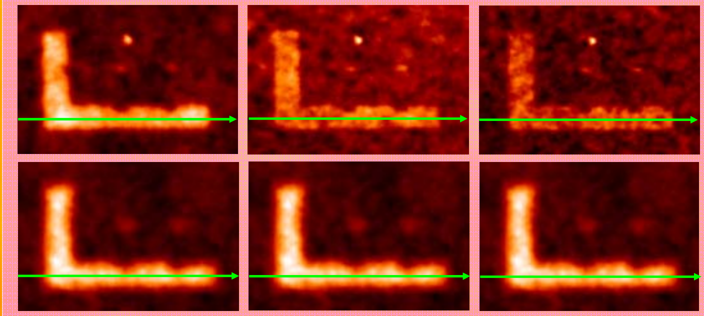

Fig. 4: (From left to right) Top line: Phase retrieval from 40 kV image, 100 kV image and 150 kV image. Bottom line: Simulated phase retrieved images for the same accelerating voltages. The green lines indicate the position for the line plots shown below. The bright point in the middle of the experimental data is due to a contaminant that violates the weakly absorbing approximation, and which also probably has different material parameters. Nevertheless, the results in the non-contaminated region appear to be stable.

We can then take line plots through the images above as indicated to recover the thickness of the sample.

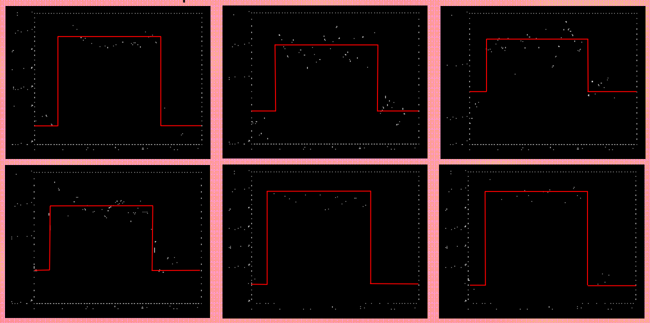

Fig. 5: Plots of sample thickness corresponding to the green lines in each of the corresponding images in Fig. 4.

Conclusion and Acknowledgements

Our simulations approximate the conditions inside our laboratory source so that images produced are qualitatively the same as the measured data. We see that this technique applied to phase retrieval of a polychromatic beam in a thin, weakly absorbing material is quite accurate. Furthermore the results are stable even to the presence of materials in the sample that violate the approximations in the method. We have demonstrated that we can use this approach to further test the extended TIE based phase retrieval method.

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