Ptychography: Pushing the Limits of X-Ray Microscopy

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Abstract

Ptychography is an advanced diffraction based imaging technique that can achieve resolution of 5 nm and below. It is done by scanning a sample through a beam of focused x-rays using discrete yet overlapping scan steps. Scattering data is collected on a CCD camera, and the phase of the scattered light is reconstructed with sophisticated iterative algorithms. Because the experimental setup is similar, ptychography setups can be created by retrofitting existing STXM beam lines with new hardware. The other challenge comes in the reconstruction of the collected scattering images. Scattering data must be adjusted and packaged with experimental parameters to calibrate the reconstruction software. The necessary pre-processing of data prior to reconstruction is unique to each beamline setup, and even the optical alignments used on that particular day. Pre-processing software must be developed to be flexible and efficient in order to allow experimenters appropriate control and freedom in the analysis of their hard-won data. This paper will describe the implementation of pre-processing software which successfully connects data collection steps to reconstruction steps, letting the user accomplish accurate and reliable ptychography.

C. Fromm, T. Tyliszczak, J. Lim, Y. Li, D. Shapiro. ALS, Lawrence Berkeley National Laboratory, July 2015₄

Outline

- Motivation for Ptychography
- Theory
- Ptychography at SSRL
- Practical challenges
- Applications

The Diffraction Limit

The Diffraction Limit

$$d = \frac{\lambda}{2n \sin \theta}$$

- Smaller spot size (d) means better resolution
- Visible light:
 - λ ranges from 800nm-400nm
 - NA from 1.4-1.6
 - **Spot size from 500nm-250nm**
- X-Rays
 - λ ranges from 1nm-0.1nm
 - NA from 0.01-0.25
 - **Spot size from 10nm-0.4nm** (very difficult in practice)

STXM

(Scanning Transmission X-Ray Microscopy)

- Scanning Transmission X-Ray Microscopy
- X-rays on to sample, monoenergetic
- Transmitted light measured as sample scans through

Resolution

STXM image

Ptychography of same region

Ptychography

Ptychography at SSRL

Image Collection Process

- Beamline 13-1
- Recently changed over from STXM

Reconstruction

- Phase problem
- Image pre-processing
- Adapting software for data collection methods at 13-1

**Collaboration with ALS (Advanced Light Source)
at Lawrence Berkeley National Laboratory**

Reconstruction

STXM image

Ptychography of same region

Pre-Processing

- Cropping and centering
- Downsampling
- Exposure averaging
- Dark subtraction
- Probe retrieval

Exposure Averaging and Dark Subtraction

Background intensity

Underexposed

Overexposed

Probe Retrieval

ALS

My reconstruction
attempt

Zone Plate

Sample

CCD Output

Future Capability

- Mapping chemical composition of materials using different properties of x-rays
- Examination of processes over time (battery charge and discharge cycles)
- Imaging at ambient pressure to reduce need for vacuum cleanliness (geology, liquids)

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Appendix

- Zone Plates
- Aliasing in image processing
- Beamline science/vacuums
- More reconstructed images

Zone Plates

- Lens that uses diffraction instead of reflection or refraction
- X-rays are too short to refract and glass isn't transparent to them!

Resolution isn't very good

Fresnel lens for lighthouse

Aliasing

J. Nelson Weker

Sample chamber at ALS

Magnet removed
from beamline
13-1 to improve
beam for
ptychography