J.C.H.Spence, U. Weierstall, Q. Chen, M. Howells* and R. Panepucci**
Physics, ASU. Tempe, AZ 85287-1504
*LBL. ** Cornell Nanofabrication Facility.
Spence@asu.edu

Experimental iterative phase retrieval with coherent electrons - Lensless imaging from diffraction patterns

The modern nanotip field-emission TEM/STEM instrument provides high quality particle beams with very high brightness, spatial and temporal coherence (E/DE = 10^6) and a deBroglie wavelength around 0.25 nm or less. However the desirable strong interaction introduces multiple scattering for sample thicknesses beyond a few nanometers. The iterative (HiO) phase retrieval algorithm due to Fienup (1) offers the possibility of recovering diffraction-limited complex images from the intensities in far-field Fraunhoffer diffraction patterns alone. (Resolution is then not limited by lens aberrations or detector pixel size). This requires assumptions about the sign of the optical potential used in the Schroedinger equation (which we discuss) and some knowledge of the object's maximum dimensions (discussed for various cases). We have applied this algorithm to experimental coherent electron nano-diffraction patterns from real objects consisting of lithographed pairs of irregularly shaped holes (spanned by the coherence width) in an otherwise opaque mask (2). A resolution of a few nanometers is obtained in the recovered image of a hole-pair. We discuss experimental problems and the results of simulations for real and complex objects which might fill the holes in our mask. We confirm that for a general complex object (eg in the presence of multiple scattering and/or inelastic scattering) two holes are needed, and the hole outlines must be accurately known and sharp.

For a strong phase object (phase shift exceeds pi, no inelastic scattering, flat ewald sphere, iconal approx) a single hole is sufficient. For a weak phase object (phase shift small, no inelastic scattering, one hole) a loose support can be used (eg a triangle larger than the object), whose size can be estimated from the object's known autocorrelation function, however the hole edges must still be reasonably sharp (not as sharp as the resolution obtainable). Converging coherent illumination provides an essential increase in intensity, but renders the object complex and the diffraction pattern sensitive to lateral source position (coherence degradation). A single hole is sufficient for a stable point source focussed onto a real sample. The use of a focussed probe using a circular aperture is not effective as a support - other shapes might be considered.

A weak phase object with complex optical potential behaves similarly to the weak phase object (for which the imaginary part of the optical potential is zero) provided that the sign of the both

parts is known. The use of apertures displaced along the beam path and Koehler illumination mode are discussed.

In the presence of multiple scattering there are two inversion problems - diffraction pattern to exit-face wavefield, and the recovery of the optical potential from this wavefield, a topic of active research, but beyond the scope of this conference (3).

The HiO algorithm opens up the possibility of imaging, for example, biomolecules, with new radiations (eg Neutrons, Helium atoms, atomic clusters) whose interactions with matter may have more desirable aspects (eg less radiation damage) than X-rays or electrons. We compare the requirements for atomic resolution imaging of biomolecules with soft X-rays, electrons, neutrons and helium atoms, in terms of sources, beam degeneracy, elastic and inelastic cross sections and detectors. Simulations for HiO recovery of images from neutron diffraction patterns are given (4).

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4. Spence, Weierstall, Friis. Proc MSA. 2001. In press.