Measurement of focal spread, beam divergence and vibration in HREM images

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Question

To simulate high-resolution images *quantitatively* we need to determine the microscope parameters accurately

How can we measure *focal spread*, *beam divergence* and *vibration* independently?

Answer

Use tilted illumination

How?

With tilted illumination, diffractograms of amorphous material show an achromatic ring whose radius depends on the beam tilt

The way the intensity of this ring changes with defocus can be used to distinguish focal spread, beam divergence and vibration, as shown with the simulations on the right

Details

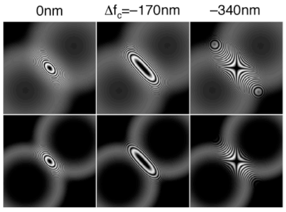
Sample: effect of sample scattering factor not included
Accelerating voltage: 297kV
Spherical aberration, $-C_s$: 0.65mm
Beam tilt, θ: 16mrad
Critical defocus, $\Delta f_c = -C_s\theta^2$: –170nm
Focal spread (unless otherwise stated): 2.45nm
(equivalent to an energy spread of 1eV)
Sample thickness: thin

Simulations of diffractograms with beam tilt

Effect of focal spread

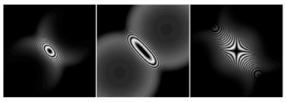
Defocus: 0nm, Δf_c=–170nm, –340nm

Focal spread: 2.45nm (top row), 4.9nm (bottom row)



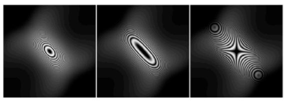
Effect of beam divergence

0.2mrad



Effect of vibration

0.015nm



Effect of focal spread

Achromatic ring does not change with defocus, ring gets narrower with larger focal spread

Ring width at defocus Δf_c –> focal spread

Effect of beam divergence

Achromatic ring disappears away from defocus Δf_c

Change with defocus –> beam divergence

Effect of vibration

Only vibration attenuates intensity of achromatic ring at defocus Δf_c

Attenuation at defocus Δf_c –> vibration

Does it work?

For experimental images measure achromatic ring width and changes in ring intensity with defocus

Compare with multislice simulations to confirm interpretation

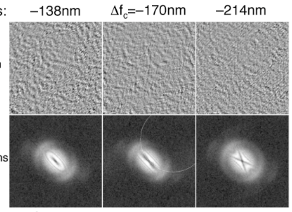
Details

Microscope: Philips CM300 FEG
Sample: amorphous carbon
Accelerating voltage: 297kV
Spherical aberration, $-C_s$: 0.65mm
Beam tilt, θ: 16mrad
Critical defocus, $\Delta f_c = -C_s\theta^2$: –170nm
Focal spread: 3.7nm (equivalent to an energy spread of 1.5eV)
Sample thickness: 25nm
Simulations: Semper (library programs amorph, mslice and image)

Experimental amorphous carbon images

Defocus: –138nm, Δf_c=–170nm, –214nm

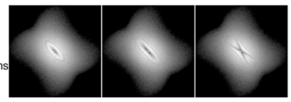
Tilted beam images (top row), Diffractograms (bottom row)



Circle marks position of (faint!) achromatic ring

Multislice simulations

Simulated tilted beam diffractograms



Graphite rings and asymmetric vibration not included in simulations

From the experimental images we can say

Ring width at critical defocus –>
focal spread 3.7nm (1.5eV)

No change in achromatic ring visibility with defocus –>
beam divergence is small (as expected from FEG)

Ring attenuation at critical defocus –>
vibration is not symmetric (due to side entry holder)