Title
Phase Change on Electron Wave Scattering from Thin Objects

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PHASE CHANGE ON ELECTRON WAVE SCATTERING FROM THIN OBJECTS

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The assumption of a $\pi/2$ phase difference in the diffracted electron wave relative to the undiffracted wave is an essential aspect of image analysis and evaluation for weak phase objects. Two factors could contribute a significant component whose phase shift is π. The first is a spatially varying attenuation of the transmitted elastic wave due to inelastic scattering. The second is the quadratic term in the series expansion of a phase object's transmittance function, $\exp(-i\eta)$. When the latter effect becomes important, as is expected with carbon films thicker than ~100Å or with thin specimens composed of heavy atoms, the object is no longer a weak phase object.

We have directly measured the total effective phase shift by use of the Thon-Hoppe diffractogram in combination with an independent measurement of focus. Focus was determined from the displacement between corresponding bright field and dark field images of small (50Å - 100Å) gold crystals supported on thin (~50Å) carbon films. This displacement is related both to focus (Heidenreich 1942) and to spherical aberration (Hall 1949, Riecke 1961):

$$|\vec{a}| = C_s\ \lambda^3 |\vec{g}|^3 - \Delta f \lambda |\vec{g}|; \qquad (1)$$

C_s is the spherical aberration, λ is the de Broglie wavelength, $\vec{g}$ the reciprocal space vector for the diffracting crystal lattice plane, and Δf the degree of misfocus. An example of the displacement effect is shown in Figure 1. Spherical aberration can be accurately determined by measuring the displacements a_1 and a_2 corresponding to different reciprocal lattice vectors for two crystals on the same micrograph:

$$C_s = \frac{a_1 g_2 - a_2 g_1}{\lambda^3\ (g_1^3 g_2 - g_1 g_2^3)} \qquad (2)$$

With independent calibration of wave length and magnification, and with care in astigmatism correction and voltage axis alinement, an accuracy of 3% in C_s is possible. The value measured for an AEI 802 instrument was 3.4 mm ± 0.13 mm, which agrees with the manufacturer's stated value of 3.5 mm. Then using Equation 1, focus can be measured to ± 500Å.

The Thon-Hoppe diffractogram reveals the spatial frequencies of maximum and minimum contrast:

$$S_{max} = \frac{1}{\Lambda} = \frac{1}{\lambda}\left\{\frac{\Delta f}{C_s} \pm \left(\frac{\Delta f^2}{C_s^2} - \frac{2\lambda}{C_s}\left(\frac{\theta}{\pi} - n\right)\right)^{1/2}\right\}^{+1/2}; \qquad (3)$$

θ is the phase shift of the diffracted wave and n is the diffraction order in the optical diffractogram. The phase shift can be determined as a parameter when fitting such curves to experimental data obtained at the independently determined values of defocus. Curves fitted in this way are shown in Figure 2, for a series of through-focus micrographs (such as those illustrated in Figure 3). For a 50 Å-thick carbon support film the effective phase shift of the scattered wave has been measured in this manner to be $\pi/2$. The accuracy of this approach is $\pm\ \pi/8$.

Heidenreich R D 1942 Phys. Rev. 62 291

Hall C E 1949 J. Appl. Physics 20 63

Riecke W D 1961 Optik 19 278

DISCLAIMER

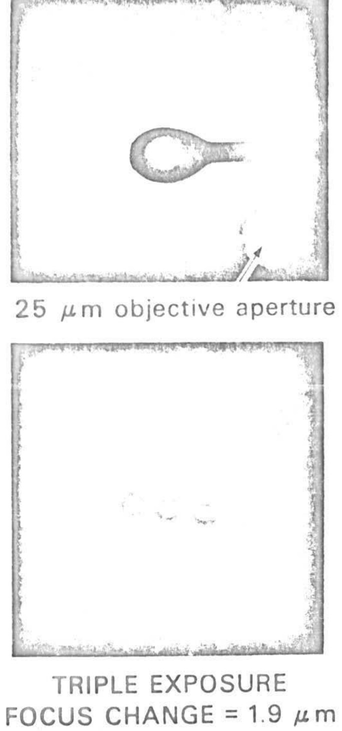

Fig. 1 Triple exposure of the dark field images formed by the Bragg diffracted beam associated with the gold {200} lattice. Reflection selected by 25 μm objective aperture.

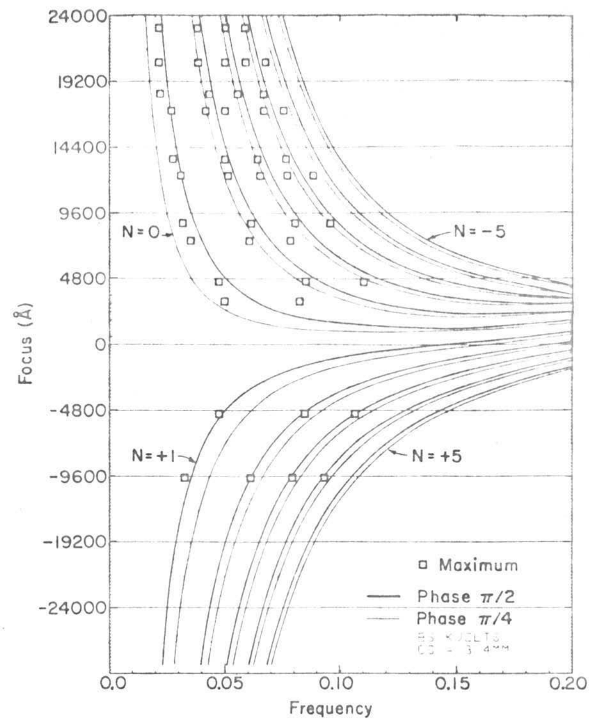

Fig. 2 Relationship of the measured frequency at maximum contrast to that predicted for π/2 and π/4 phase change. This illustrates the sensitivity of the technique for measurement of the phase shift on scattering.

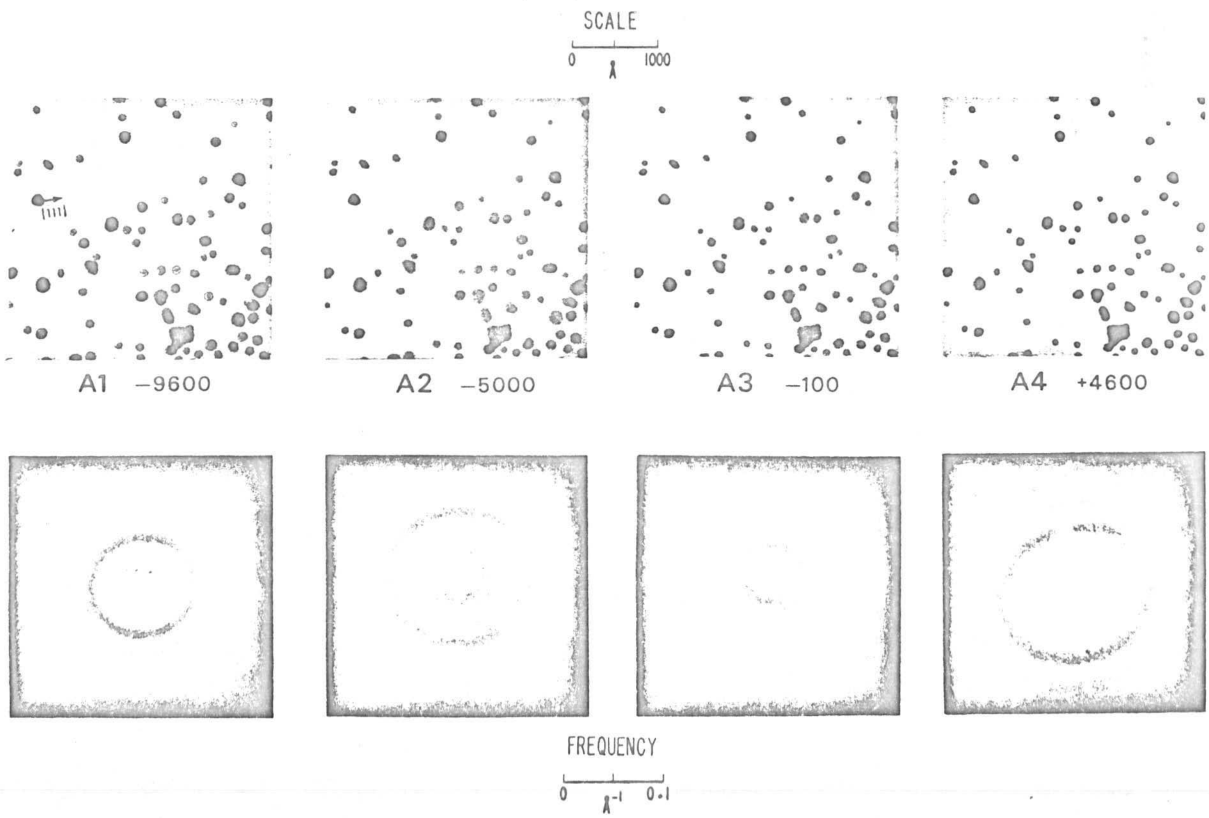

Fig. 3 Electronmicrographs of gold colloid on ~50Å carbon film (upper) and the corresponding diffractograms. Focus was determined from the dark field/bright field image displacement method.