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AC Focusing of an Electron Microscope Objective Lens

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Control of phase contrast in electron microscope images is presently achieved by fine vernier control of the dc objective lens current. An incremental change δJ in lens current produces a corresponding increment δf in focal length and a focal separation in object space of δL_o. L_o is the distance from lens to conjugate object plane so that ΔL_o is the axial separation of conjugate object plane and scattering specimen. The defocus phase at the image plane of a ray scattered at angle β relative to the axial ray is

$$\chi = \frac{|K|}{2} \Delta L_o \beta^2 \tag{1}$$

with $|K| = 2\pi/\lambda$. The phase contrast G in the image goes as

$$G \sim \sin \chi = \sin \frac{|K|}{2} \Delta L_o \beta^2 \tag{2}$$

ignoring spherical aberration, astigmatism, etc., for this purpose. Precise control of phase contrast for a spacing "a" $= \lambda\beta^{-1}$ requires that the focal separation increments δL_o be as small as 100 Å and preferably less.[1, 2]

For unsaturated magnetic lenses the change in focal length with lens current is taken as[3]

$$\delta f = -2C_{ch} \frac{\delta J}{J} \tag{3}$$

with C_{ch} the chromatic coefficient. The focal increment $\delta L_0 \approx \delta f$ in this case. For saturated lenses δL_o and δf may not be equal so that it is important to calibrate δL_o in terms of the objective vernier control using a Bragg beam from a crystal.

As a result of re-examining the effect of drift and ripple in the high tension and in the objective lens current, the possibility of achieving a selective or "tuned" focus for certain desired object spacings suggested itself. If the lens current has a harmonic ripple sin ωt, then the focal separation ΔL_o is likewise a periodic function of time and so is the phase contrast (2). The response of the regulated dc supply to an ac voltage applied across the lens through a condenser apparently results in a time-dependent focal separation that behaves like

$$\Delta L_0(t) = -\varphi_o(1 + \sin \omega t) \tag{4}$$

with φ_o the amplitude in angstroms proportional to the applied ac voltage. The time average phase contrast obtained by using (4) in (2) is found to be

$$\langle G \rangle_t \sim J_o\left(\frac{K}{2}\,\varphi_o\beta^2\right) \sin \frac{K}{2}\,(\Delta L_o - \varphi_o)\beta^2. \tag{5}$$

If φ_o is zero, the Bessel function is unity and there is just the usual phase contrast. J_o has appreciable values at its subsidiary maxima or side bands being −0.4, +0.3, −0.23, etc., occurring at $(K/2)\ \varphi_o\beta^2 =$ 3.8, 6.9, 10.1, etc., respectively. Since it is very difficult to reduce the ripple in a power supply below about 1 mv it is seen that for certain values of residual ripple it is feasible that the Bessel function in (5) could be zero for certain object distances. The injection of an amplitude φ_o of the right amount could give "side band contrast" in J_o for a particular distance "a" in the object.

Fig. 1 is an example of the effectiveness of this type of focusing. These photographs are from a focal series taken of a graphitized carbon black particle and exhibit the 3.4 Å (002) spacing of graphite. Growth defects in the form of dislocations and curvature of the planes are evident. The ac injection increments in Fig. 1 are 1.5 mv, 2.5 mv and 5 mv, with the corresponding amplitudes φ_o roughly 300, 500, and 1000 Å, respectively. Both the Bessel function and the dc effect of φ_o are operative in the contrast. The micrographs were taken with a Siemens Eleniskop I modified for short focal length (2.4 mv at 100 KV).

Since the ripple in the high tension is an uncertainty the absolute values of φ_o to achieve maximum side band contrast are uncertain. A continuously variable ac potential is thus desirable with the lens voltage being monitored by an oscilloscope.

The possible advantage of "side band" or "microphase" focusing lies in obtaining useful contrast at spacings $a \leqq 2$ Å. To fall well within the principle maximum of J_o, the residual ripple for a 1.5 Å spacing must be below 1 part in 10^6. The injection of $\varphi_o \approx 75$ Å, 125 Å, or

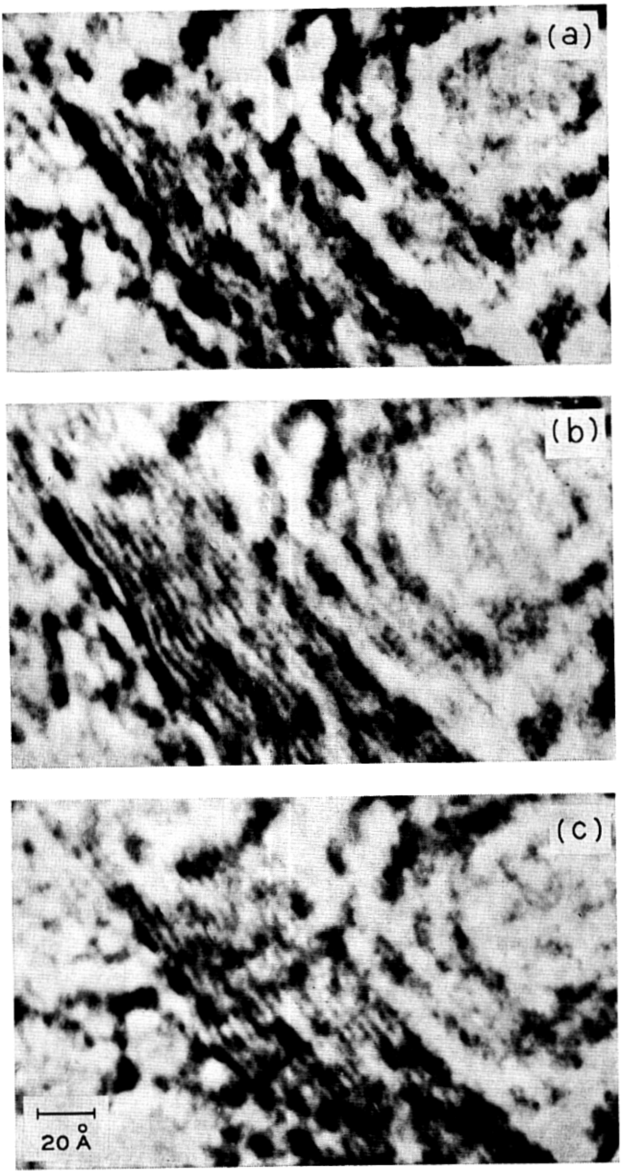

Fig. 1 — Electron micrographs showing the 3.4 Å (002) spacing in graphitized carbon black. By injecting 1.5, 2.5, and 5 mv of 60 cycle ac into the lens coil, the focal series shown by a, b, and c, respectively, was obtained. The center picture is very near optimum and shows growth defects in the lattice, whereas a is underfocused and c slightly overfocused for the 3.4 Å spacing.

225 Å ac should "tune" the respective side bands for the 1.5 Å spacing. The (004) period of 1.7 Å in graphite has been imaged in this way using carefully aligned, *axial* illuminations.

References

1. Heidenreich, R. D., "Electron Phase Contrast Images of Molecular Detail," Jour. Electron Microscopy, *16,* No. 1 (1967), pp. 23–38.
2. Thon, F., "Zur Defokussierungsabhängigkeit des Phasenkontrastes bei der elektronenmikroskopischen Abbildung," Z. Naturforschung, *21* (1966), p. 476.
3. Haine, M., *The Electron Microscope,* New York: Interscience Publishers, (1961), p. 13.