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THE DEPENDENCE OF SECONDARY ELECTRON IMAGE CONTRAST OF PERIODIC OBJECTS UPON PROBE DIAMETER*

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The effect of probe diameter upon secondary electron image contrast of periodic objects has been studied systematically. Interest in the topic arose following the observation of "out-of-focus" SEM images of conventional mesh support grids, where the basic periodicity was visible even with probe diameters many times the periodic spacing. The instrument used was a JEM-120CX/ASID operated in the SEM mode at low magnification with the objective lens off and other lenses in the free-control mode. The probe diameter at the specimen position was controlled by the continuously variable second condenser lens current. The first intermediate lens was focussed at the specimen position, thus allowing a determination of the probe diameter from the magnified shadow image, which could be photographed using the conventional TEM camera. The specimen used was a copper bar grid with spacings ≈125 μm.

Figure 1 shows the secondary electron micrographs, fig. 2 the corresponding line scans across the center of the images and fig. 3 the TEM shadow images of the probe. Figure 1(a) is the "in-focus" image. As the probe diameter is increased the edge definition decreases until fig. 1(b) is obtained, which corresponds to D=1, where D is the "reduced" probe diameter (i.e. probe diameter/grid spacing). A further slight increase in D results in a rapid decrease in contrast until fig. 1(c), which exhibits harmonics of the fundamental grid spacing of small amplitude, is obtained. A further increase in D causes the contrast to increase but the contrast is reversed with respect to fig. 1(a,b). The contrast reaches a maximum when D≈1.5 which is shown in fig. 1(d). The contrast reverses at D≈2.2 and reaches a maximum at D≈2.6 [fig. 1(e)]. Continued increases in probe diameter result in similar behavior (except for an overall decrease in contrast) with contrast maxima occurring at D≈n+0.6, where n is an integer, and contrast reversal occurring at D≈n+0.16. Images with D≈n exhibit the contrast typified by fig. 2(b). Figure 1(f) was obtained with D≈4.6. Micrographs exhibiting the basic periodicity have been obtained with D>5 but the signal-to-noise ratio decreases markedly as D increases.

Simple calculations of the image contrast were made using a one-dimensional model as illustrated, together with definitions of symbols, in fig. 4. For mathematical convenience the grid bars of finite width are represented simply as lines. The intensity, I, was assumed to be proportional to the length of grid line within the probe and was normalized to constant probe current by dividing by the "area" of the probe. Thus

$$I = \sum_n \{2(D^2/4 - [x+n]^2)^{0.5}\}/D^2 \quad . \; . \; . \; . \; . \; . \quad (1)$$

where n_{min} = -(integer part of[{D/2}+x]) and n_{max} = (integer part of[{D/2}-x]). Equation (1) was evaluated for $-\frac{1}{2}<x<\frac{1}{2}$ and appropriate values of D. The main features of these simple calculations, such as the positions of contrast reversal and contrast maxima agreed with the experimental observations.

There are several implications of the present results. The first is that periodic objects may not be desirable as specimens for SEM resolution tests if information about the probe size is required. In this respect there is some similarity to the use of lattice images in TEM, where proof of the

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stability of the instrument is demonstrated. A second implication concerns STEM lattice images. Normally phase contrast images are used, where of necessity the probe diameter is larger than the atomic plane spacing.[1] However, it has been proposed that incoherent scattering contrast may be obtained with an in-focus probe of diameter less than the d-spacing using a dark-field imaging technique.[2] Even in this latter case, however, the present results indicate that it is still possible to obtain a "scattering contrast" periodic image with a probe diameter larger than the d-spacing of interest.

1. J. C. H. Spence and J. M. Cowley, *Optik* 50 (1978) 129.
2. G. Hubert, et al., in *Proc. 9th Int. Cong. on Elec. Microsc.*, Toronto, 1978, Vol. 1, pp. 22-23.

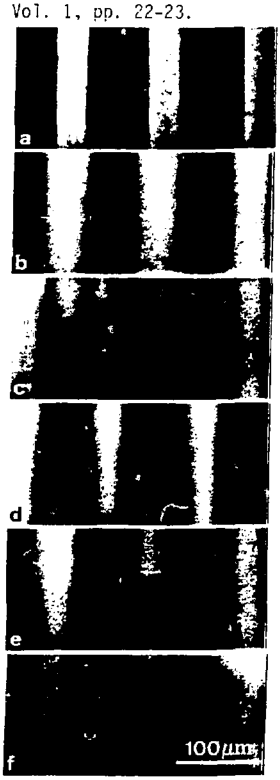

FIG. 1

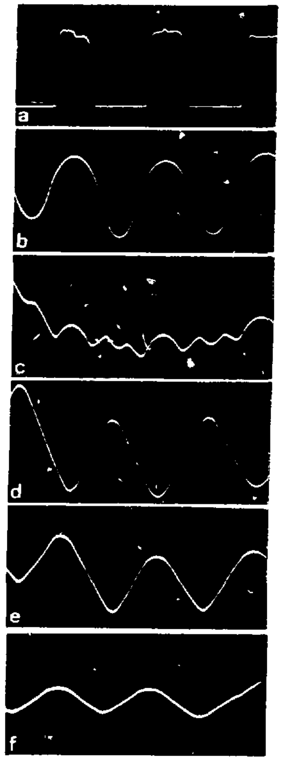

FIG. 2

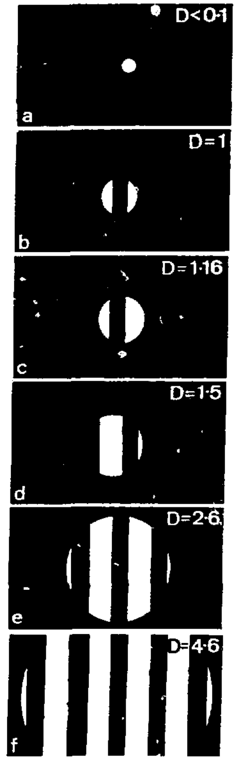

FIG. 3

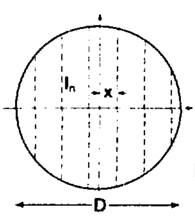

FIG.4

Fig. 1. Secondary electron images of a bar grid as a function of probe diameter.
Fig. 2. Secondary electron intensity profiles corresponding to the images of figure 1.
Fig. 3. TEM shadow images of the probe. The reduced probe diameter, D, is indicated.
Fig. 4. Diagram showing the geometry used in the calculations. The grid lines (dotted) have unit spacing, D = probe diameter, l_n = length of the n^{th} grid line, x = displacement of the zeroth grid line from the co-ordinate system origin.