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Publication Date
2002-01-23

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EXIT WAVE RECONSTRUCTION, Cs CORRECTION, Z-CONTRAST MICROSCOPY: COMPARATIVE STRENGTHS AND LIMITATIONS

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Currently available electron microscopes are at the threshold of routine operation with sub Angstrom spatial resolution together with around 100 meV energy resolution [1,2]. Moreover, theory and experiment merge on this scale since computational abilities have improved to a point where materials properties can be predicted from computer models that contain a similar number of atoms as those observable by high resolution TEM. To benefit fully from this unique development it is crucial to develop a methodology that is capable of comparing quantitatively the strengths and limitations of different microscopes and emerging techniques such as exit wave reconstruction [3], Z-contrast imaging [4] and Cs correction [5,6].

In a series of experiments on gold [110] and silicon [110] (Figure 1), quantitative data about sensitivities, precision, and resolution of these techniques were produced and will be reported. For the particular case of sensitivities in phase contrast microscopy we find it convenient to compare the maximum phase change of an extinction oscillation in gold [110] to the recorded noise level. This allows sensitivity limits to be given in terms of a phase change per atom and compared to noise levels. The procedure can easily be extended to include other elements and provides a figure of merit for the performance of microscopes that is shown in figure 2. A quantitative comparison between sensitivities of phase- and Z-contrast microscopy becomes possible through a quantification of the Rutherford scattering that underlies the image formation process in High Angle Annular Dark Field imaging. Our procedure recovers total scattering cross sections and allows for a distinction between single gold atoms in a column and the related noise levels. As a result, we can reconstruct the sample thickness as shown in figure 3. Known dependencies of the scattering process on the atomic weight can be exploited to expand this knowledge to other elements. The results enable us to compare quantitatively different microscopes and recording techniques. Discrepancies between theory and experiments will be discussed [7].

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7. The project was sponsored by the Director, Office of Science, Office of Basic Energy Sciences, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

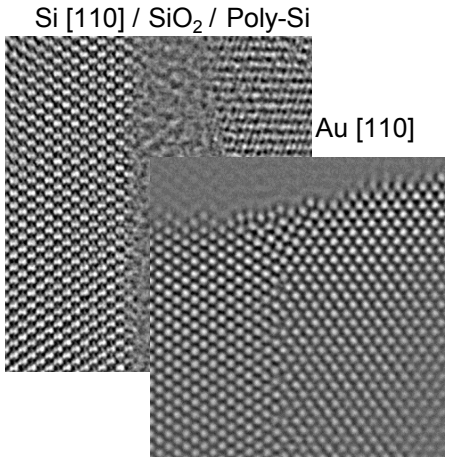

Fig. 1a: EWR, phase (CM300)

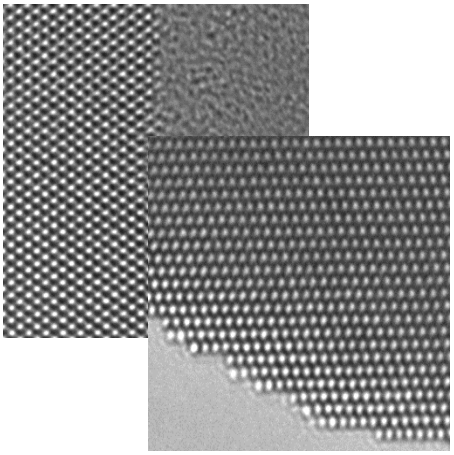

Fig. 1b: Lattice image, Cs=0 (CM200)

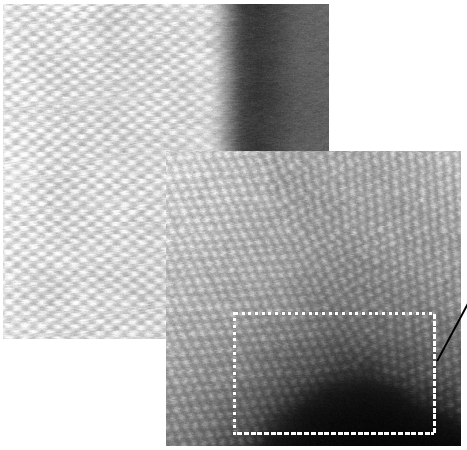

Fig.1c: Z-contrast (Tecnai F20)

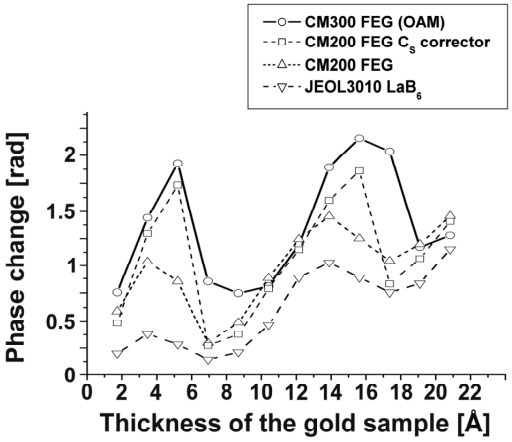

Fig. 2: Figure of merit for sensitivity of selected phase contrast microscopes. Multi-slice calculation for lattice images. Phase deduced by Exit Wave Reconstruction from simulated lattice images.

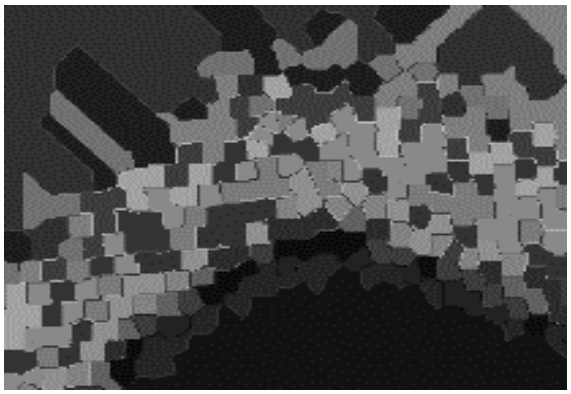

Fig. 3: Thickness mapping through quantification of Rutherford scattering. Gray levels distinguish single gold atoms in columns