

Aberration Corrected Electron Microscopy: Prospects and Applications.

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Abstract- Aberration correction in the TEM is now relatively well established with more than 20 corrected instruments installed worldwide. This paper will review these instrumental advances and will also describe the underlying theory and computation required to optimise data acquisition and interpret aberration corrected images. Finally the combination of direct electron optical correction and indirect aberration compensation in exit wave reconstruction will be described.

1. Introduction

The modern High Resolution Transmission Electron Microscope (HRTEM), operating at voltages between 200 and 400kV provides sufficient resolution to directly determine the projection positions of atoms in many solids. In addition a variety of additional signals can be acquired using bright nanometre sized electron probes that provide complementary chemical and electronic structure information. It is also now possible to acquire multi-image datasets that can be reconstructed to give a full three dimensional representation of materials, albeit not currently at atomic resolution.

Over the last few years the performance of electron microscopes has undergone a dramatic improvement with significant advances in both resolution and spectroscopic capability. This has been made possible through the development of sophisticated electron optical components for the correction of the intrinsic spherical aberration present in conventional electromagnetic round lenses. It is now possible to acquire atomic resolution structural data from a wide range of materials using several alternative optical geometries and to determine electronic structure and composition with single atom sensitivity.

Aberration correction has also required advances in theory and computation. It is essential that the coefficients of the wave aberration function are measured reliably and to high accuracy using the information present in general samples including crystalline materials.

2. Instrumentation

A JEOL 200kV FEG(S)TEM with both probe and imaging aberration correctors and an in column energy filter was installed in Oxford in 2003 [1,2] (Figure 1 (a)). The correctors are based on a design due to Rose and Haider [3] in which the primary elements consist of a pair of strong hexapoles and two round-lens doublets. In practice adjustment of the imaging corrector is achieved using a Zemlin tableau of diffractograms calculated from images of a thin amorphous foil and recorded at several tilt azimuths with constant tilt magnitude [4]. These datasets provide measurements of the tilt-induced defocus and 2-fold astigmatism yielding linear estimates for the coefficients of the wave aberration function. For practical measurement a computationally efficient algorithm in which each experimental diffractogram is compared to a library of pre-calculated diffractograms is used [5]. The spherical aberration and other aberration coefficients may be set to zero for pure amplitude contrast, or the spherical aberration coefficient may be set to a small negative value for optimum phase contrast [6,7].

3. Combining Direct and Indirect Methods

Direct correction offers the advantage that it may be achieved on line with a single image and does not require post acquisition processing. However with current generation optical elements correction of aberrations in the TEM extends to third order and the recorded data comprises intensity only. In contrast indirect

compensation of the aberrations recovers the complex exit wave and correction to any order is theoretically possible, limited only by the measurement accuracy. The disadvantage is that this is an off-line technique requiring multiple image datasets.

Indirect and direct methods used in combination provide further advantages. For the focal series geometry, the elimination of tilt-induced axial coma relaxes the requirement of using parallel illumination. For a tilt series dataset, the elimination of tilt induced axial coma gives rise to less critical focus conditioning for a given tilt magnitude and multiple tilt magnitudes are possible without any induced focus change. Localised compensation of higher order aberrations up to 5th order is also possible.

Figure 1(b) illustrates a typical phase plates obtained after initial electron optical correction to third order followed by compensation to fifth order using locally determined values of the aberration coefficients, with the latter clearly showing a clear improvement in the extent of transfer within a $\pi/4$ phase limit to sub 0.1nm levels.

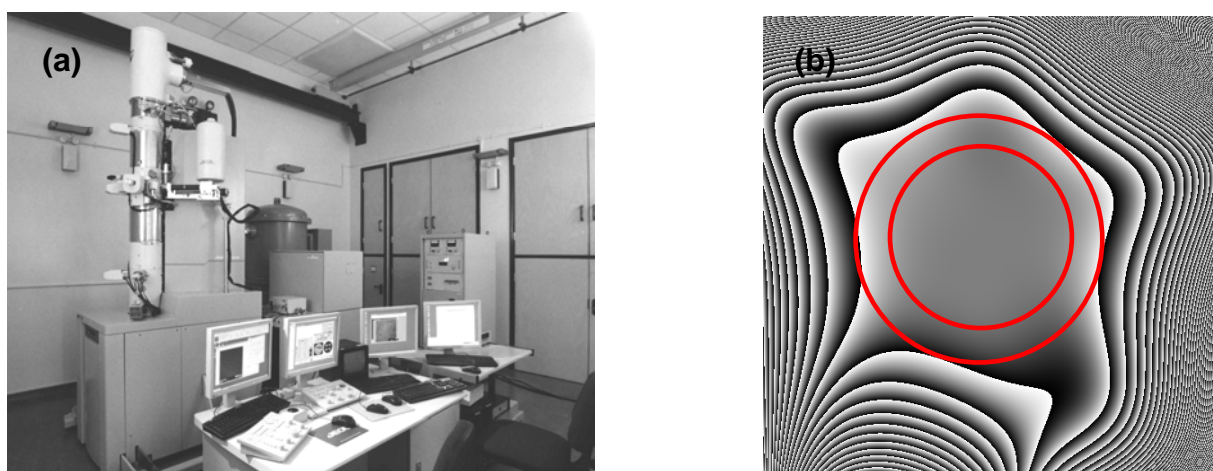


Figure 1. (a) The 200kV double aberration corrected TEM installed in Oxford. (b) Phase plate after local refinement of aberrations to 5th order. Black to white represents a phase shift of π . Inner and outer circles represent resolution limits of 0.1 and 0.08nm.

3. Conclusion

We have demonstrated the successful installation and testing of the world's first double aberration corrected instrument and have illustrated its use in a range of materials problems. The development of combination methods employing both direct and indirect correction of the aberrations has also been described.

4. References

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