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Experience with the IBM Sub-Angstrom STEM

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After installation of the Nion spherical aberration corrector in the IBM 120kV VG Microscopes HB501 STEM, it has been apparent that the probe size has become about 0.78 Å, somewhat smaller than expected. [1, 2] While this is a welcome outcome, it does present difficulties in understanding, particularly given that we have identified some very real issues relating to interpretation of the results. [3]

Figure 1 summarizes the performance to date. In 1a) I show an unfiltered image of a $Si_{70}Ge_{30}$ sample, oriented with the [001] direction aligned perpendicular to the scan direction. The auto-correlation power spectrum in the insert shows spatial frequencies out to about 0.9 Å (a [006] forbidden spot). The overall impact of the image is disappointing, though, due to instabilities, statistical noise and periodic (AC) interference. Low pass filtering this image to 2.0 Å as in 1b) produces the familiar blurred dumbbell atom column image typically obtained with the VG high resolution polepiece (C_s=1.3 mm). Use of a 1.2 Å filter in c) shows that the dumbbells are readily resolved, and that some column intensity variations are apparent, although there are clear long ranged undulations in the column positions that are interference related. Filtering out to 0.6 Å in d) admits higher frequency AC instabilities, making interpretation again difficult. Examination of a small region of the data in e) and f) shows that the probe size is in fact of order 0.78 Å.

The better than expected resolution appears to be arise from an unexpectedly small 5th order aberration coefficient, which in this system is a combination aberration caused by the fact that the aberration correction is not made within the objective lens. I measure $C_5 \approx 1.6$ cm, giving a limiting resolution of 0.59 Å.[4] We expect $C_5 \approx 10$ cm, giving an optical limit closer to 0.8-0.9 Å.[5] This estimate, in turn, depends strongly on details of the objective lens, in particular the ratio $(C_s/f)^2 \approx 0.36$ in the standard 100 kV system. In the IBM 120kV machine, the objective lens is run quite far into saturation, and this ratio is somewhat smaller, $(C_s/f)^2 \approx 0.17$, giving some justification for the smaller value for C_5.

Activity is now directed towards curing the instabilities by careful attention to electrical and environmental interference, and integrating the operation of the corrector with the STEM, EELS and monochromator control – each of which are not without complexity. It is also clear from Figure 1e) that, once the instabilities are reduced, then a denser set of image pixels will be needed to fully utilize the new resolution, while preserving a useful field of view. A new image acquisition system is therefore also being installed to help with this.

[1] N. Dellby, O.L. Krivanek, P.D. Nellist, P.E. Batson, and A.R. Lupini, *J. Electron Microscopy*, 50 (2001)177.
[2] P.E. Batson, Niklas Dellby, and O.L. Krivanek, *Nature*, 418 (2002)617.
[3] Z. Yu, P.E. Batson, and J. Silcox, *Ultramicroscopy*, in press.

[4] P.E. Batson, *Ultramicroscopy*, in press.
[5] O.L. Krivanek, P.D. Nellist, N. Dellby, M.F. Murfitt, and Z. Szilagyi, *Ultramicroscopy*, in press.

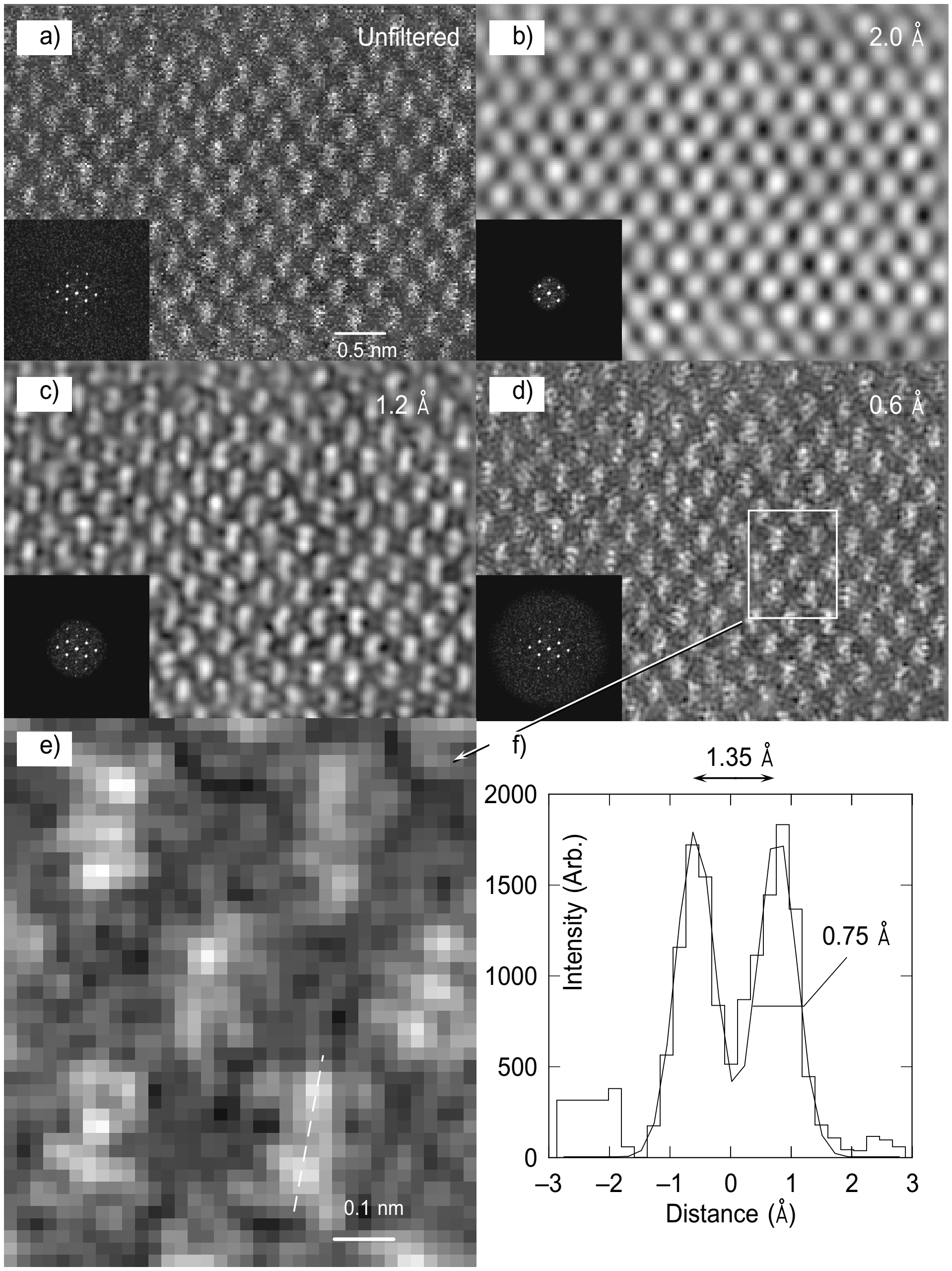

Fig. 1. $Si_{70}Ge_{30}$ image. a) Unfiltered. b), c), d) Low pass filtered out to 2.0, 1.2 and 0.6 Å respectively. e) Indicated cut from d). f) Line profile from region of d) fitted with 0.75 Å width gaussian profiles separated by 1.35 Å.

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