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3D Atomic Resolution Imaging through Aberration-Corrected STEM

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With a Nion aberration-corrector installed on the 300 kV VG Microscopes' HB603U STEM at Oak Ridge National Laboratory the imaging of single atoms within materials or on their surfaces has become routine [1-3]. The improvement in sensitivity is far more rapid than the improvement in resolution. The peak signal from an atom increases as $1/d^2$, where d is beam diameter, while the background from the surroundings decreases as d^2 . Therefore the signal to background ratio increases as the fourth power of beam diameter. A somewhat surprising additional benefit of aberration correction is that the increased probe aperture angle results in a decreased depth of focus. It becomes possible to focus on different depths within a sample and a through-focal series now becomes a through-depth series which can be recombined into a 3D data set. Lateral resolution remains at the atomic level and depth resolution is presently at the nanometer scale.

Figure 1 shows selected frames of a through-depth image series taken from a Pt_2Ru_4 cluster-derived catalyst on a γ -alumina support using a 22 mrad probe-forming aperture. At -8 nm defocus the lower right hand corner of the alumina comes into focus and shows a lattice image. Individual Pt atoms are visible as bright spots. In longer scans the Ru atoms show as less bright spots [4], but are rather noisy in the short 4 second scans used for this through-depth sequence in order to minimize beam damage. As the defocus increases the focused region moves towards the upper left of the field of view. Profiles across the image frames show the probe FWHM of 0.07 nm. At -16 nm defocus a rather brighter nanocrystal raft is seen. Intensity profiles across this suggest it is two or three monolayers in thickness. Each image shows also the outline of the alumina support, and so it should be feasible to recombine this information and recover the 3D shape of the support, and the location of each atom can be extracted to Ångstrom resolution laterally and nanometer resolution in depth.

Future generations of aberration corrector will allow even larger probe forming angles to be used, providing depth resolution into the sub-nm scale. Furthermore, with such apertures most of the incident beam is traveling at a high angle to the optic axis. Calculations show that even with a crystal aligned to a low-index zone axis, only a small fraction of the beam is captured into the 1s channeling state [5]. Depth sectioning appears feasible therefore even for aligned crystals, and will allow dopant atoms to be located in specific atomic columns laterally and with nm accuracy in depth, a powerful method for studying grain boundary segregation. In principle, exactly the same methodology could be employed for EELS analysis, although the limitations of beam damage will be more severe because of the lower scattering cross sections of EELS [6].

References:

- [1] S. J. Pennycook et al., Proc. MRS 748 (2003) G1.1
- [2] S. Wang, A. Borisevich et al., Nature Materials, in press
- [3] N. Shibata et al., Nature, in press, also these proceedings
- [4] A. Borisevich et al., these proceedings
- [5] Y. Peng et al., these proceedings

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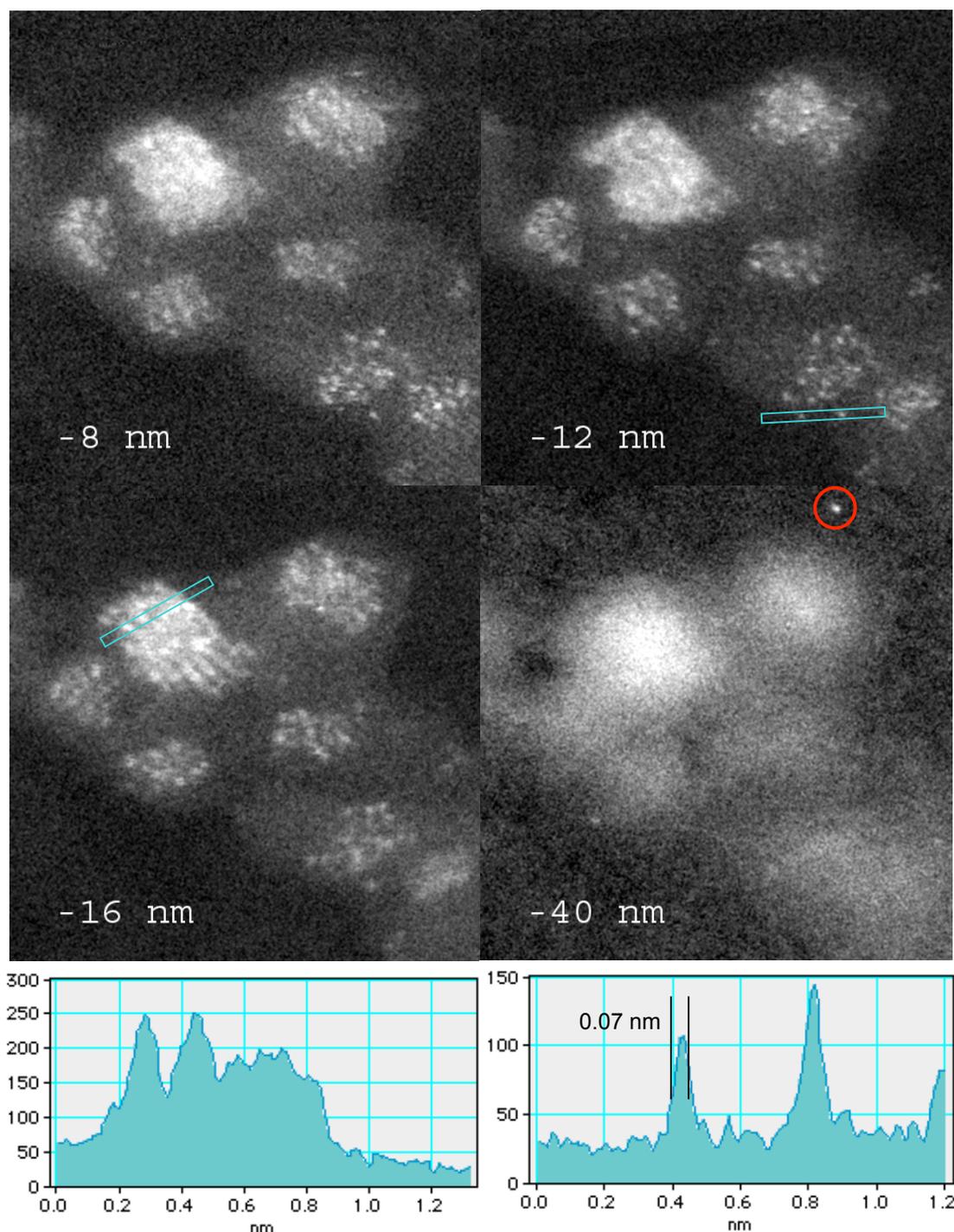


Fig. 1. Four frames from a through-depth series of images of a Pt₂Ru₄ catalyst supported on γ -alumina. The alumina is three-dimensional with thin, raft-like Pt-Ru clusters on its surface. Different clusters are resolved at different depths, until, at -40 nm defocus, the carbon support film is reached and a single Pt atom comes into focus (circled). Line profiles correspond to the rectangles shown in the images.