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Some Thoughts on Point Spread Functions, Resolution and Image Quality

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SEM users have specific performance goals in mind when they select an instrument. A certain level of resolution is often required to see features of interest as well as to clearly distinguish them from noise or less important adjacent details. Resolution is one of the most difficult terms to understand because it is determined not only by the instrument and operating conditions used but is also sample dependent [1,2]. High resolution has always been linked to the smallest possible probe size that has adequate current needed for a satisfactory signal to noise ratio. The ability to produce small probes has been a major goal of instrument manufacturers and has largely been realized through significant improvements in electron optical systems.

Although a small probe size can be viewed as a necessary condition for achieving the highest possible resolution, sample related factors may ultimately determine the actual obtainable value. These include the signal excitation volume, signal levels, and background effects. Our research is directed at using computational methods to improve resolution without the need for hardware development. The procedure used consists of two main steps [3]. First is the determination the spatial distribution of electrons in the focused beam at and near the sample plane, the point spread function (PSF). Traditionally this has been measured by knife edge techniques where the electron beam is scanned over a sharp edge with either an emitted or transmitted signal recorded as a function of position. The derivative of this curve is the PSF and if the scan is done over a range of angles relative to the knife edge a 2D PSF is obtained. An example of a 1D scan and the resulting PSF using ImageJ [4] is given in figures 1a and 1b. Besides being tedious for 2D this approach can be limited by not having an effective knife edge or appropriate detector. Furthermore, the beam shape is often considered to be Gaussian which may not always be the case. Our approach is to image a known structure consisting of a dispersion of gold spheres and compare it to a theoretically calculated true image of the same structure for a set of fixed operating conditions including the beam energy, beam current and working distance. The PSF is then calculated from this image pair in just a minute or two longer than the time required to image the calibration standard and no assumptions are made about the shape of the PSF. Figures 1c and 1d shows the results from the particle dispersion method obtained with the same instrument and operating conditions. They show the full PSF and the resulting profile for a single scan along a horizontal line through the center if the PSF.

The second step in resolution improvement involves taking one or more images of samples of interest using the same operating conditions as those to obtain the PSF. These images are then restored by deconvolution and regularization to give higher quality images more representative of the image that would be obtained under higher resolution conditions. Essentially, it is a correction for blurring of the true image by the PSF. The two step approach is often adequate to improve overall image quality as a result of both noise reduction and improved resolution.

We recognize, however, that in some cases improvements may be limited by excitation volume and/or noise. Therefore, much of our current work is directed at low beam energy performance where probe sizes may be larger than at high energies, but the depth of excitation volumes may be smaller. As an example, figure 2 compares an as observed image of a microelectronic line edge roughness test structure taken at 2 keV with a Schottky source instrument with a restored image. Noise reduction and improved resolution is evident.

References:
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[4] ImageJ is available from the National Institutes of Health at https://imagej.nih.gov/ij/

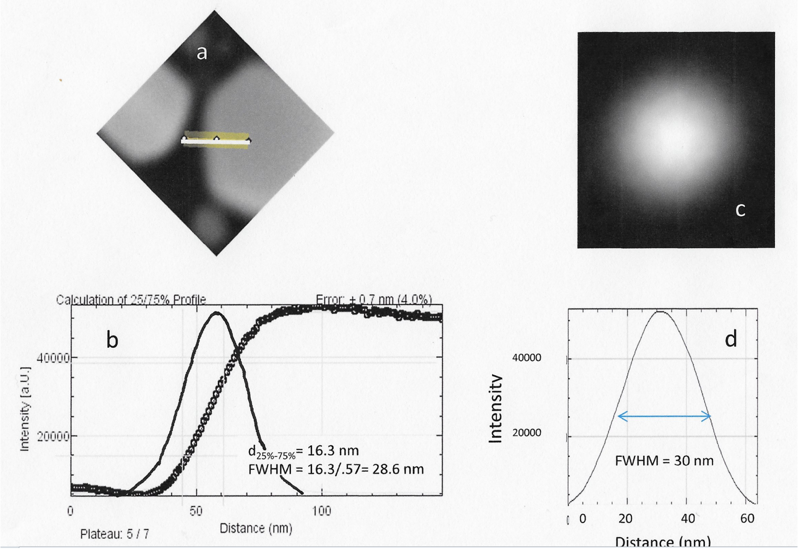
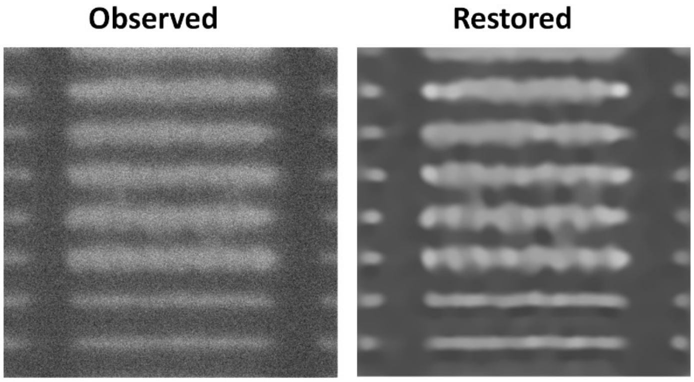


Figure 1. a) 20 keV LaB_6 image of gold on carbon, b) corresponding scan profile and PSF determined using NIH ImageJ, c) PSF determined by particle dispersion method, d) line profile from c). FWHM in both b) and d) are approximately 30 nm.



field of view 581 nm for each image

Figure 2. Line edge roughness test structure observed in a Schottky source SEM at 2 keV and then restored by method described in reference [3]