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Challenges in Achieving High Resolution at Low Voltages in the SEM

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Low beam voltage operation of the SEM is not normally considered to be a route to high image resolution. This approach limits the secondary electron signal to a shallow surface region but at the expense of limited lateral image resolution. Low kV operation also has the added advantage that comes from the increase in the secondary electron yield with a decrease in the primary electron energy. The ability to form small electron probes is limited in practice by the initial probe size, spherical aberration and chromatic aberration. Spherical aberration correctors have been developed for SEM, but the improvements in image resolution come at a cost of increased operational difficulty and a greatly reduced depth of focus due to the large convergence angles that are required.[1] At low voltages, chromatic aberration, due to the spread of electron energies emitted by the electron source, dominates the probe size and limits the image resolution of low voltage secondary electron imaging. The use of room temperature FE sources has resulted in improved low voltage image resolution in the SEM, due to the smaller energy spread produced by the room temperature FE source (about 0.3 ev) as compared to the thermal or Schottky FE source with a larger energy spread (0.7-1.0 ev). It is now possible to reduce the energy spread of the thermal FE source through the use of a monochromator, thus allowing better image resolution to be achieved at low voltages without the use of room temperature FE sources and preserving the high current capabilities of the thermal Schottky sources. Improvements in resolution as result of using a monochromatic primary beam will be shown in this paper as well as other considerations that arise from low and very low voltage operation.

A FEI Magellan 400 SEM was used in these studies. This instrument is equipped with a fixed energy spread monochromator in the electron gun that limits the energy spread of the electron beam to less than 0.2 ev and is operable when the primary beam voltage is 5kV or less. In this study we have used the contrast transfer function to describe the image resolution of the SEM. The use of the contrast transfer function is a better indication of how the SEM will image a variety of samples, not just samples with high contrast features.[2] Finding samples that exhibit surface features at the sub-nm level can be difficult and so a variety of test samples have been used in this study. This study has used Pt disc-shaped particles that are about 100 nm in diameter with a thickness of 3 nm and ion beam sputtered Pt on C support films as test samples.

Figure 1 was obtained at 1kV using the monochromator of a Pt particle on a gold substrate. There is very good image detail visible. Figure 1b is the contrast transfer function of figure 1a calculated using the routines provided in the SMARTJ plugin for IMAGEJ.[3] The CTF shows significant contrast is transferred below 1 nm and resolution at the point when the S/N reaches 1 is 0.7 nm. CTF plots for operation at 0.5 kV, 1 kV and 5 kV are shown in Figure 2. These CTFs show that there is significant image detail transfer below 1 nm and even at 0.5 kV the useful image information limit is

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no worse than 1.1 nm. CTFs of images obtained at 0.5 kV with and without the use of the monochromator are shown in Figure 3. Here the improvement in resolution with the monochromator is very apparent with information limits of 1.6 nm under normal conditions and 1.1nm with monochromator in use. These data show that, at low kV, the use of low energy spread electron beams as produced by a monochromator can produce images that provide information at the sub-nm level.

References

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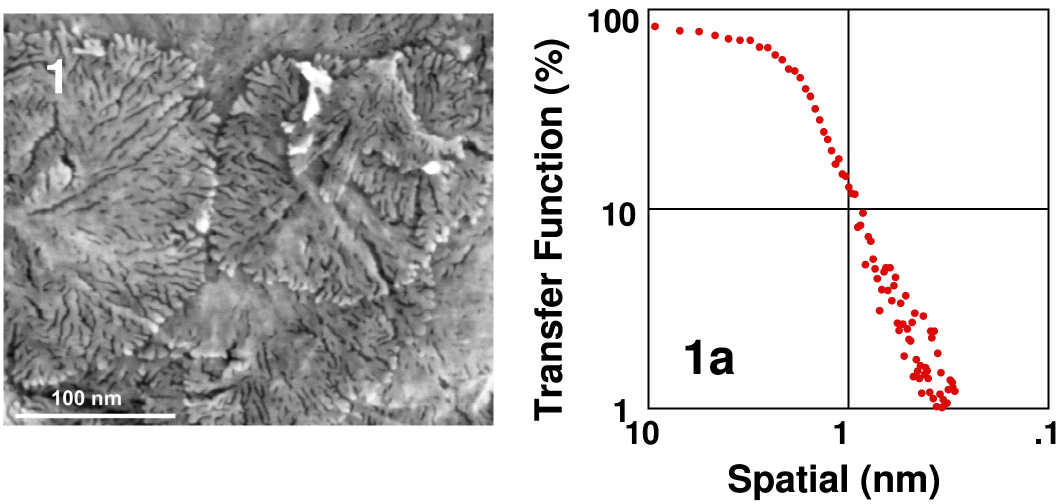
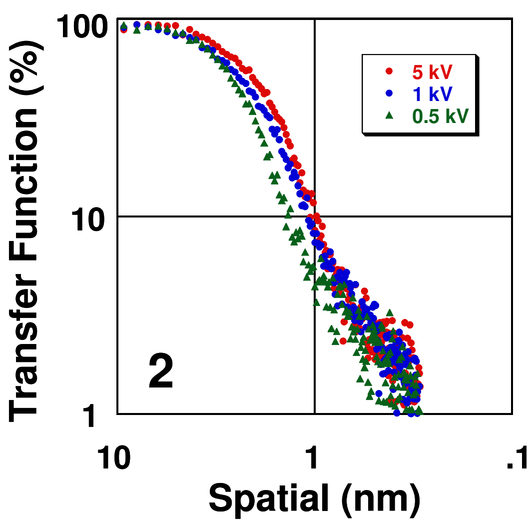
[3] IMAGEJ written by Wayne Rasband is available from (http://rsb.ifo.nih.gov/ij/), SMARTJ plug-in is available from D. C. Joy (djoy@utk.edu).

[4] Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy (DOE) under contract DE-AC0494AL85000.





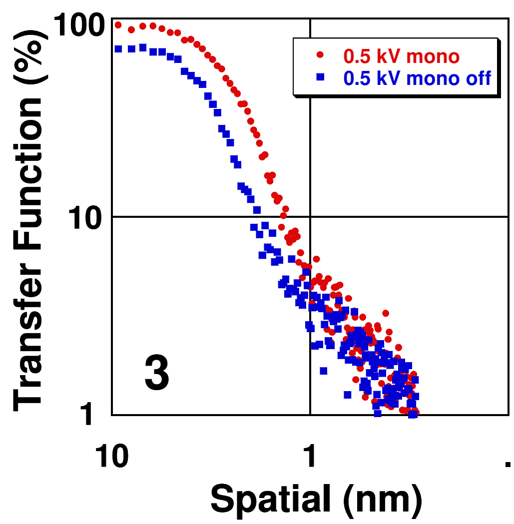


Figure 1. Pt particles imaged at 1 kV with monochromator in use. a) CTF obtained from figure 1. Figure 2. OTFs obtained at 0.5 kV, 1 kV and 5 kV with monochromator in use. Figure 3 OTFs obtained at 0.5 kV demonstrating resolution improvement with monochromator use.

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