

# Improved Low Voltage SEM Image Resolution Through the Use of Image Restoration Techniques

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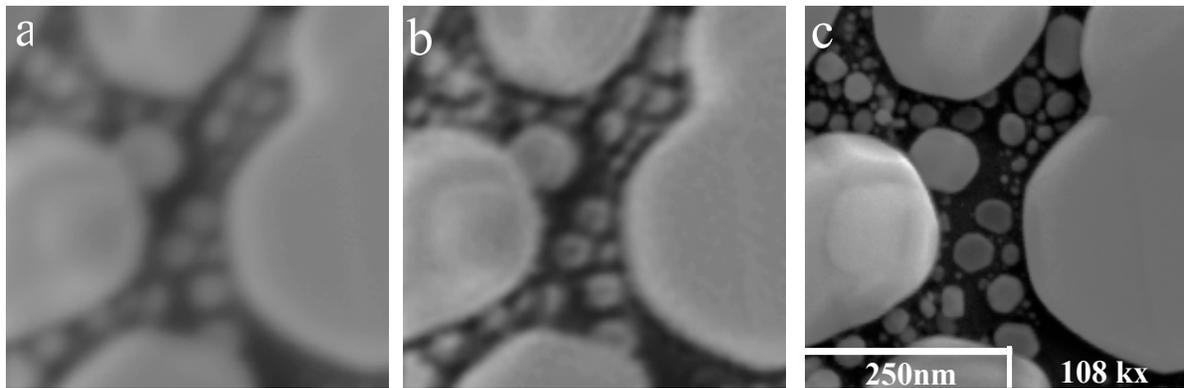
Improving spatial resolution has been a major goal of scanning electron microscope (SEM) development since the first commercial instrument was introduced in the mid-1960s. An area of particular interest to modern users is Low Voltage SEM or LV-SEM ( $< 5$  KeV). LV-SEM offers a more detailed look at the surface topography of a sample relative to higher energy images. In addition depending on the sample material of interest, operating an SEM at lower voltages may be necessary to avoid undesirable sample/beam interaction such as with photoresist and biological samples. Edge brightening effects and broadening of type 2 secondary electron (SE2) generation due to high energy of the backscatter electrons can be mitigated by going to lower accelerating voltages as well.

In spite of these apparent advantages, LV-SEM is plagued by notoriously poor resolution. For thermionic sources, this is primarily due to insufficient probe current (ip) at low voltage which results in a very low signal to noise ratio. A way to get around this issue is to move to sources with greater overall brightness such as field emission guns (FEGs). Although this leads to a great improvement over thermionic sources, there is still the issue of chromatic aberrations. The influence of chromatic aberrations is proportional to the energy spread of the electron beam over the primary energy of the gun. Therefore, as the beam energy is lowered, chromatic aberrations will increase and will eventually become the dominating factor in determining the final probe size (df). A more recent innovation is the use of a “retarding field” right before the sample surface. This field is capable of taking a beam of high energy and effectively lowering its energy such that the landing potential is several kv below the original energy of the gun. This technique maintains the beam quality down the column while simultaneously yielding an accurate, low voltage image of the sample. Although these innovations have led to low voltage resolution improvement, the minimum obtainable resolution is still fundamentally limited by the final probe size. With the use of complex image processing algorithms and modern computing power, however, we have developed a method for low voltage resolution improvement that is capable of going beyond this lower limit.

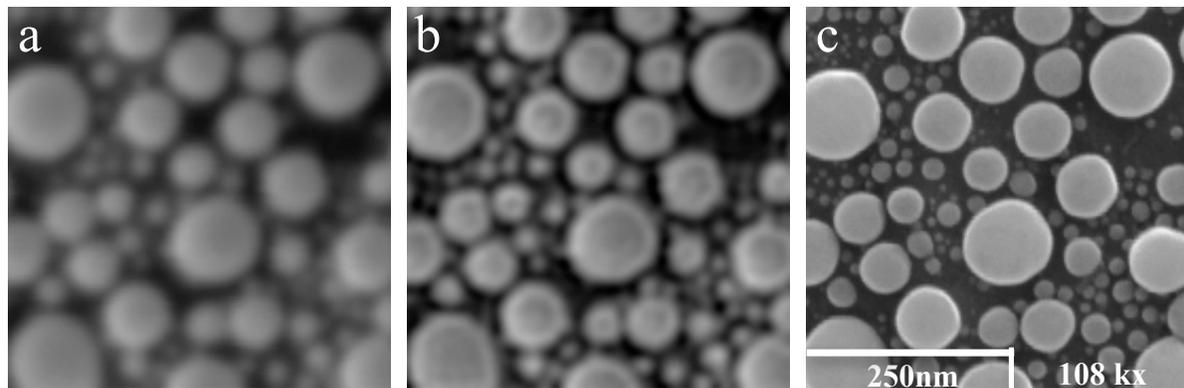
The method involves obtaining a reference image (RI) of a given area at high energy (20 eV). This image must have pixel level resolution which occurs when the pixel size is approximately equal to the probe size. This ensures that each pixel in the image contains unique information to that pixel, a situation we refer to as “exact sampling” [reference?]. The image is then re-casted as a low kv image (2 eV). This process entails performing brightness and contrast adjustments which correlate to the change in SE yield as a function of energy for each material present in the sampling area (in our case, a gold on carbon reference standard). After this adjustment is made, a second image at low kv (2 KeV) is taken of the same area. Using the adjusted 2 KV reference image and the actual 2 KV image, the point spread function PSF can be determined from the technique put forth by Lifshin et al []. When the point spread function of the beam is known, it can be used on any image taken at the same operating conditions under which the image used to determine the psf was taken and provide resolution improvement. Figure 1

**References:**

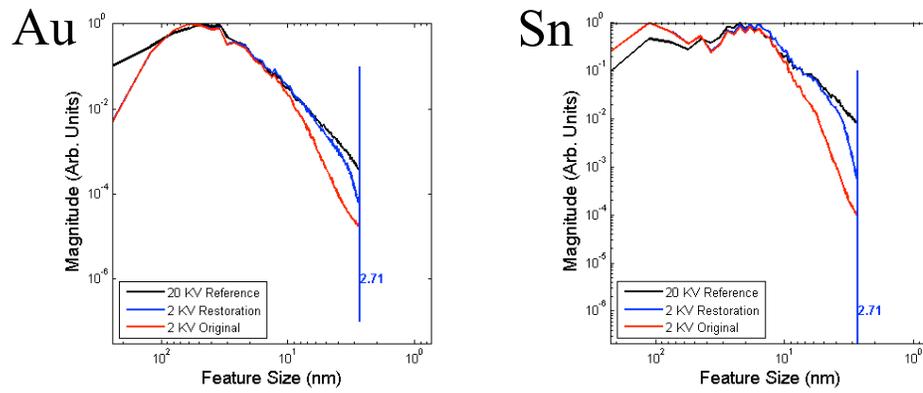
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- [4] The authors acknowledge the support of Mr. Jeffrey Moskin, President of Nanojehm for providing the resources that made this study possible as well as TESCAN for providing instrumental support.



**Figure 1.** Restored gold (Au) standard SEM image obtained at 2 KV: (a) a blurred image obtained with beam energy of 2 KV, (b) the restored image (c) a pixel level resolution image that was re-casted for 2 KV.



**Figure 2.** Restored tin (Sn) standard SEM image obtained at 2 KV: (a) a blurred image obtained with beam energy of 2 KV, (b) the restored image (c) a pixel level resolution image that was re-casted for 2 KV.



**Figure 3.** The contrast transfer functions for the Au and Sn samples and there reconstructions