

Removal of FEG Fluctuations in STEM Imaging

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Scanning transmission electron microscopy (STEM) images often show intensity noise due to emission fluctuation. This type of image noise often happens with field emission guns (FEG) and we may call it FEG noises. The FEG noise can become readily noticeable for a certain high intensity STEM images and usually deteriorate image quality. Fig. 1A shows an annular dark field (ADF) STEM image, where the horizontal lines are due to FEG fluctuation. Not only the FEG noise creates annoying extra contrast, it also reduces the visibility of low contrast objects in the image, as shown in Fig. 1A.

The FEG noise can be reduced through image process by applying high frequency filtering in Fourier space [1]. However, this pure software method often creates undesirable image artifacts due to its non-symmetrical filtering. To remove the FEG noise with minimum artifacts, the beam intensity as a function of time is needed. In this study, we demonstrate a method to remove FEG noise using bright field STEM image as a pseudo-beam intensity meter.

With modern STEM system, multiple STEM signals can be acquired in parallel. A bright field (BF) STEM detector collects transmitted electron beam. The intensity contrast of BF STEM image is generally small in comparison to that of ADF STEM image. On a first order approximation, a BF STEM image gives a relative measure of beam intensity and can be consider as a pseudo-beam intensity monitor. Fig. 1B is the BF STEM image acquired simultaneously with the ADF STEM image of Fig. 1A. We observe that the FEG noise lines in ADF and BF STEMs are in-sync. The beam intensity fluctuation in ADF is captured in a similar way by BF STEM.

The noise in ADF can be removed by proper subtraction of BF image according to this equation,

$$[\text{Corrected ADF}] = [\text{ADF Image}] - [\text{BF Image}] * c,$$

where c is a proportion factor to be calculated with intensities from ADF and BF images. This correction process can be made automatic by computer programming. A computer program is built using Gatan Digital Micrograph scripting language (Fig. 2). The value of c is determined by the standard deviation of intensities in ADF image and BF image, over the same sampling area. The STEM correction can be made fully automatic by assuming a default sampling region for c , or semi-automatic allowing user to select the size and the location of the sampling area. Fig. 1C and Fig. 1D show the corrected ADF images with sampling area for c indicated by the dash-bordered boxes.

We notice that the noise reduction is not equal for areas of different intensities. This is expected since the beam intensity and the fluctuation are all modulated by the specimen [2]. The proportion factor c is a function of specimen. This is true even if the source intensity is used in place of BF STEM. Normally, we get the c value according to low intensity area because that is where the FEG noise is more pronounced. To get the best result of noise cancellation, we just need to point the sampling area to the region we mostly interested in.

This method can introduce minor artifacts in two aspects: 1) altered contrast due to the contrast within BF image, and 2) phase contrast from BF image. For qualitative ADF imaging, these artifacts do

not pose big problem because the contrast variation in BF image is much smaller than that in ADF image. For atomic resolution or quantitative STEM imaging, attention will be needed for these artifacts.

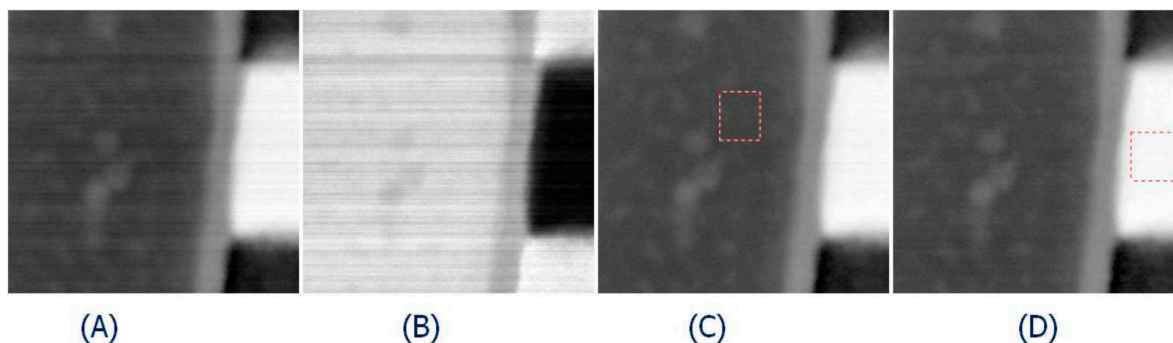


Figure. 1. (A) ADF STEM image with source noise. (B) BF STEM image collected simultaneously with (A). (C) Corrected ADF image by sampling intensity in medium intensity area. (D) Corrected ADF image by sampling intensity in high intensity area.

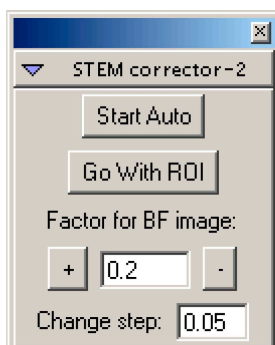


Figure. 2. Interface of the STEM corrector program built with Digital Micrograph scripting language.

References:

- [1] D. Mitchell, http://www.dmscripting.com/remove_feg_fluctuations.html.
- [2] S. J. Pennycook and P. D. Nellist, Scanning Transmission Electron Microscopy: Imaging and Analysis" (Springer, New York, 2011), pp 14-15.