High-frequency noise artefacts in scanning microscopy – Identification and mitigation

Meyer-Plath, A.[1], Gernert, U.[2], Thim, C.[1] and Dziurowitz, N.[1]

[1] Federal Institute for Occupational Safety and Health, Germany, [2] Center for Electron Microscopy (ZELMI), Technische Universität Berlin, Germany

Scanning techniques are widely applied, e.g., in confocal and near-field optical, electron beam (SEM, TSEM, STEM) and probe (STM, AFM, TERS) microscopy. Different to full-frame imaging in optical microscopy and TEM, scanning microscopy exhibits a special class of artefacts that arise from the sequential nature of image generation. Progress in microscopic resolution therefore not alone depends on further reducing the beam or probe tip interaction volume but also requires improving the correlation between the predicted and the true locus and size of interaction volume. Transient and periodic dislocations of a probe or beam as well as beam defocusing can give rise to characteristic scanning artefacts that bring pixelated specimen information in disorder. It is important to study the structure of such disorder in order to recognize artefacts and to understand and mitigate their origin. To start with, relevant dislocation frequencies have to be set in relation to the pixel scan rate. While low noise frequencies dislocate the beam during large fractions of an image line to neighbouring surface areas, high noise frequencies give rise to short ranged disorder.
State-of-the-art SEMs achieve pixel scan rates as high as a few 10 MHz and can thus not only be affected by the well-known electromagnetic noise at power line frequency but also by high-frequency (HF) noise, as our study of six different SEM instruments showed. HF spectral analyses performed with our Fourier image analysis tool coded in *Mathematica*™ revealed that the image spectra of three instruments reproducibly contained HF noise peaks. We conclude that an SEM, operated at high pixel scan rates, can be used as a sensitive tool to detect HF electromagnetic noise that enters the chamber. Such HF noise, even of significant amplitude, may remain undetected at slow scan rates since it "only" blurs the image by averaging beam oscillations around a target pixel during a single-pixel dwell time. At high scan rates however, similar to a streak camera, such beam oscillations are stretched over several spatially separated pixels, modulate the image data and thus become accessible to spectral analysis. Numerical simulation of such periodic dislocation effects enabled us reproducing experimentally observed, vertically-structured artefacts and noise spectra, see Figure. The spectral peak shape even allows determining the orientation of the effective electromagnetic field component relative to the scan direction due to Doppler splitting.
For our instruments, harmonic electromagnetic noise from switching power supplies operating in the range from 15 to 25 kHz was made responsible for previously unidentified artefacts. The noise was picked up by stage actuator feedthroughs that acted as HF antennas. Knowing its origin, the effect was successfully mitigated and the image quality significantly improved. We are convinced that HF noise frequency identification is a very valuable technique for daily SEM operation and maintenance that may become essential for further progress in SEM image quality.

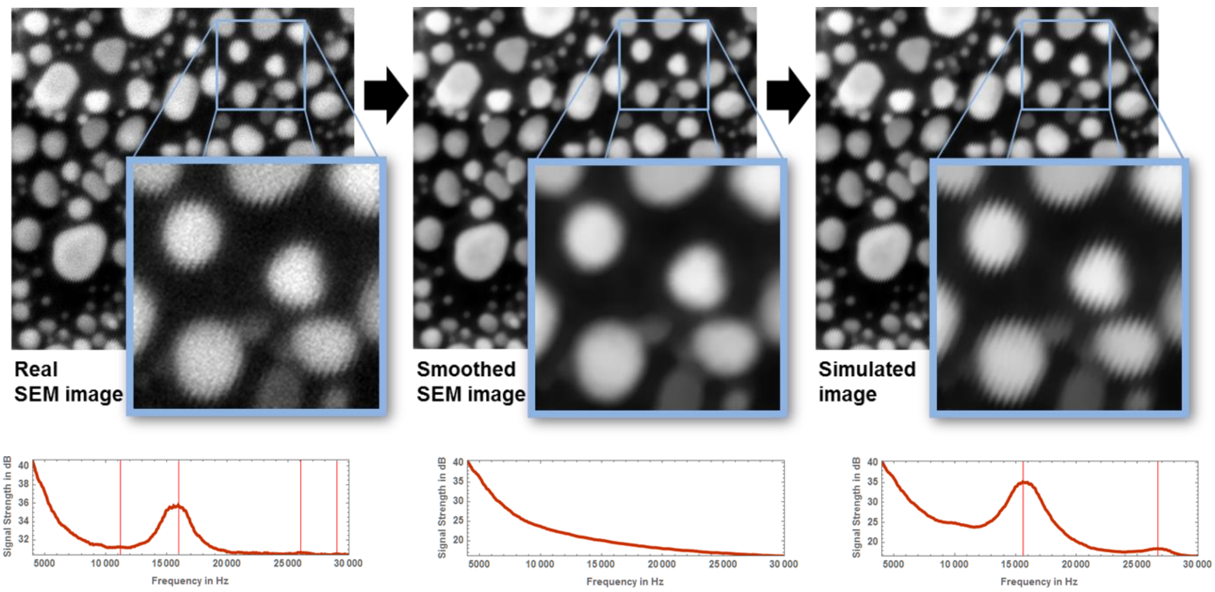

Figure: Top row: SEM image exhibiting high frequency noise artefacts (left). Numerically smoothed and sharpened image (centre) used for numerical simulation of electron beam dislocation-induced effects (right). Bottom row: Spectral analysis results of the real and synthetic images.