

Ion Count-Aided Microscopy for Quantitative, Shot Noise-Mitigated Secondary Electron Imaging

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Secondary electron imaging (SEI) is widely used for nanoscale material characterization [1]. In this technique, a focused, high-energy beam of electrons or ions is raster scanned across the sample, initiating the emission of SEs. An SE detector maps the detected SE intensity to a pixel brightness to create the final image. The quality of SEI is affected by three identifiable noise sources – randomness in incident particle number (*source shot noise*), randomness in emitted SE number (*target shot noise*), and noise in the SE detector [2]. Imaging noise increases the required particle dose, potentially damaging radiation-sensitive samples. Further, the lack of knowledge of the detector’s gain and efficiency results in SEI being qualitative rather than a precise measurement of the pixelwise *SE yield*, i.e., the average number of SEs emitted per incident particle.

We have developed ion count-aided microscopy (ICAM), which transforms SEI into a low-noise, quantitative metrology tool [3]. ICAM measures the intensity and number of discrete SE detection events from each pixel to estimate the number of incident particles per pixel, thereby mitigating source shot noise [4-6]. Statistical modeling of SE imaging [5] indicates that ICAM optimally measures the SE yield. Here, we demonstrate nanoscale SE yield metrology and imaging dose reduction by up to a factor of 3 with ICAM in a helium ion microscope (HIM).

Figure 1 shows our setup for ICAM on a Zeiss Orion Plus HIM, operating at a beam energy of 30 keV and current of 0.1 pA. We coupled the signals from the SE detector and the horizontal beam scan coils to a 100 MHz, 100MS/s analog-to-digital converter (Gage RazorExpress 1642). Figure 1(b) shows one line of the horizontal scan (top) and the synchronized SE detector signal (bottom). Custom MATLAB scripts [7] measured the height and number of discrete SE detections (i.e. pulses) at each pixel. These measurements, along with previously measured SE detector parameters [6], were used to create both conventional and ICAM images (Figure 1(c)).

Figure 2 shows an example of conventional and ICAM images of nanoscale features on a silicon chip, at the same total imaging dose of 24 ions/pixel. In both images, the grayscale corresponds to measured SE yield per pixel. In Figure 2(c), we quantify noise in each image by measuring the standard deviation (SD) of SE yields as a function of imaging dose. We can see that ICAM achieves the same SD as conventional imaging at a dose lower by a factor of about 2.6. This reduction in noise leads to a ~20% improvement in Fourier-Ring Correlation resolution at constant dose [8]. The noise reduction factor varied between 2 and 3 for different samples we imaged. In conclusion, ICAM makes shot-noise mitigation and SE yield metrology possible, enabling quantitative nanoscale materials characterization using SEI.

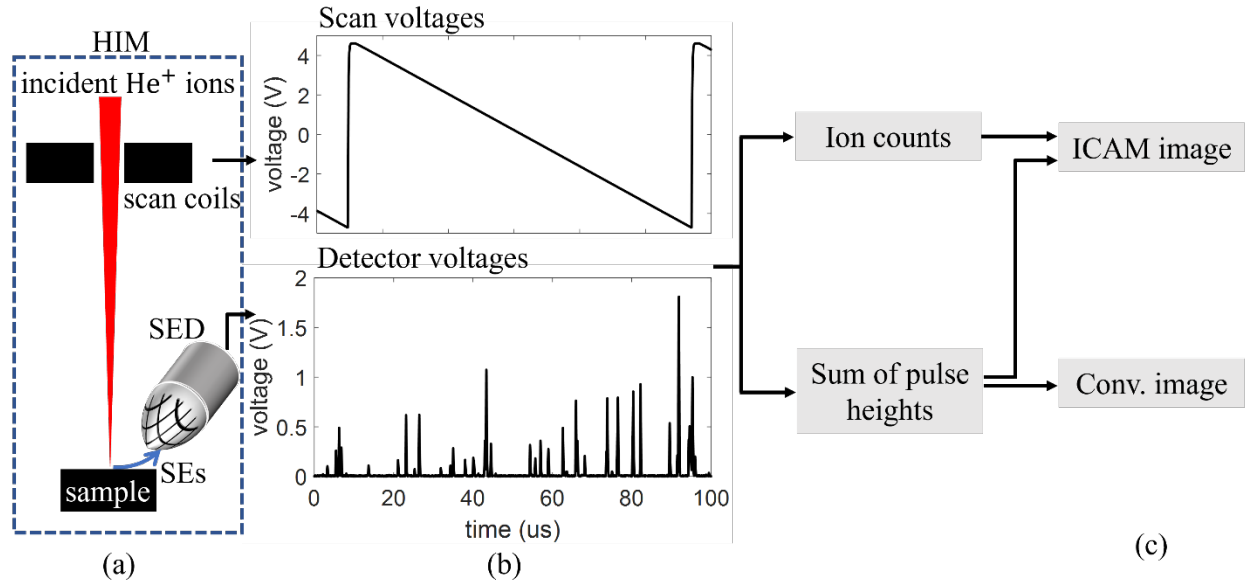


Figure 1: ICAM imaging setup. (a) The sample is imaged in an HIM, with the (b, top) horizontal beam scan and (b, bottom) SE detector voltages outcoupled. Ion counts and pulse heights measured from the detector voltage are used to create (c, top) ICAM and (c, bottom) conventional images.

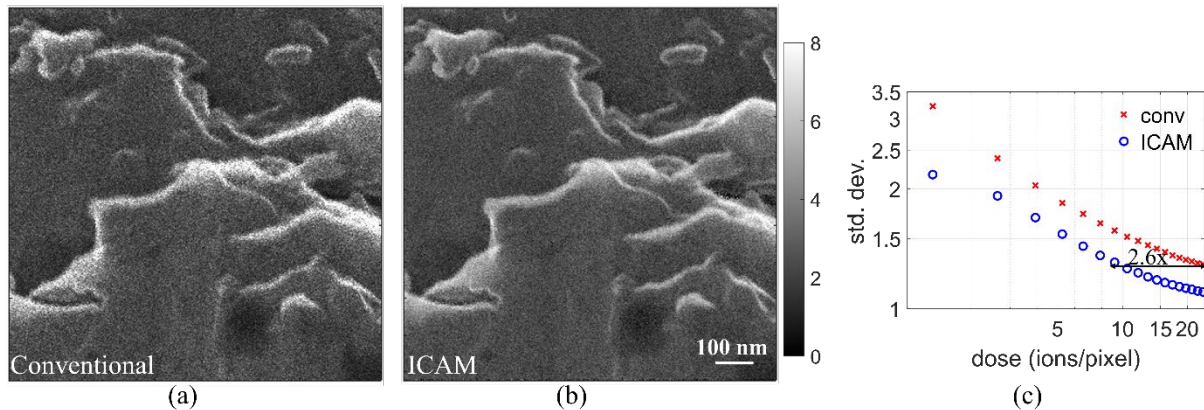


Figure 2: Shot noise mitigation with ICAM. (a) Conventional image and (b) ICAM image of silicon sample. (c) Standard deviation of images (a) and (b), showing reduced noise in the ICAM image (blue circles) compared to conventional (red crosses) due to shot-noise mitigation.

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