Crossdisciplinary Applications of Microscopy Techniques, e.g. Physic-Life Science Interfaces

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A new level-dependent noise reduction method applied to high resolution SEM images

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State of the art scanning electron microscopes (SEM) are equipped with in-lens detectors which clearly separate between SE- and BSE-signals and even perform energy filtered electron detection. This gives the ability to investigate a wide spectrum of samples from metals to organics with low atomic number and poor contrast like carbon nanotubes or insulating materials like organic layers in thin film transistors. But there are several acquisition conditions leading to a low number of detected electrons:

- To keep the interaction volume of the detected electrons small, we have to use a low accelerating voltage.
- To prevent the sample from radiation damage and contamination, the probe current must be set very low.
- In order to not modify the sample surface, there is no sputter coating with gold or other metals.
- To avoid charging of non-conductive samples, the scan speed has to be fast.

The low electron count produces a weak signal, which has to be strongly amplified leading to increased image noise.

In [1], a noise estimation method for SEM images is proposed. The basic assumption is that the image intensity I is a linear function of the number of detected electrons C: $I = aC + b$. The parameters of this linear function are changed by the microscope operator using the contrast (a) and brightness (b) settings. The method tries to estimate these parameters so that the strength of the noise can be calculated from the local image brightness. The noise variance $\mathrm{Var}(N)$ is a linear function of the expected image brightness $\mathrm{E}(I)$ depending on the estimated parameters: $\mathrm{Var}(N) = a\mathrm{E}(I) - ab$. This means that the absolute noise level is higher in brighter parts of the image than in darker areas. This kind of noise is called shot noise or Poisson noise. It occurs where independent events such as electrons are counted. Common noise removal methods assume a constant noise strength. This results in filtered images where dark parts are filtered too much whereas bright areas stay noisy. To circumvent this problem, we use a combination of noise estimation from [1], Anscombe transformation [2] and non-local means noise filtering [3] as proposed in [1]. At first, the parameters a and b are estimated. Then, the number of electrons C is recovered: $C = (I - b) / a$. Next, the Anscombe variance stabilizing transformation is applied in order to make the noise level constant. After that, non-local means is applied with h = sqrt(2). As a last step, the Anscombe transformation is reversed and the image intensity is recomputed using $I = aC + b$. Because of the properties of non-local means, the filter does preserve edges as opposed to other common noise removal methods based on smoothing. Even SEM artifacts are preserved which speaks for the filter's ability to remove noise while keeping all other image features. Another side effect of the noise estimation method is that, because it estimates the scaling parameters, it is possible to compute the number of electrons gathered to produce each pixel without any knowledge except the image itself. The employed filter can be applied to any image generated by counting independent events. This means, it can also be applied to X-ray maps or transmission electron microscopy (TEM) images.

The effect of the filter proposed in [1] can be seen in Fig. 1-4. In the filtered image, small features which are concealed in the originally noisy image become visible and thus the effective image resolution is improved. The resolution change for several images is given in Table 1.

The images were recorded with a Hitachi SU8030 SEM with cold field emitter source, equipped with a DISS 5 image acquisition system from point electronic.

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Unfiltered	2.7	2.1	3.2	8.7	4.8	2.9
Filtered	1.9	1.8	2.2	6.0	3.2	2.7

Table 1. Resolution [nm] of several images before and after the noise filter was applied. The images were taken from a gold-on-carbon sample, using variable accelerating voltages, probe currents and detector signals, thus leading to different noise levels.

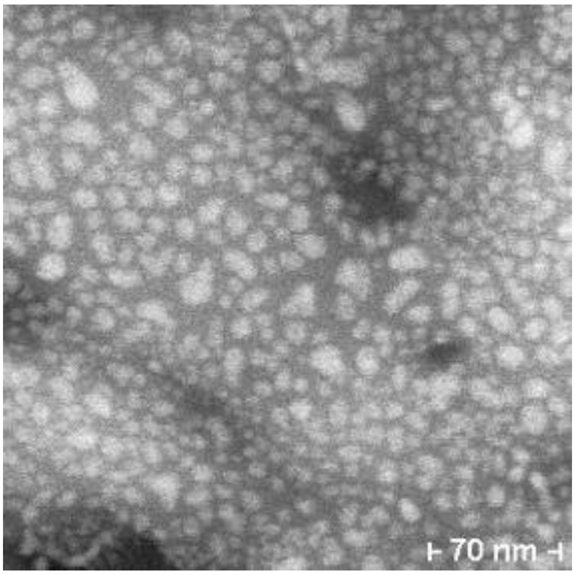

Figure 1. Detail of an original BSE image of gold-sputtered magnetic tape

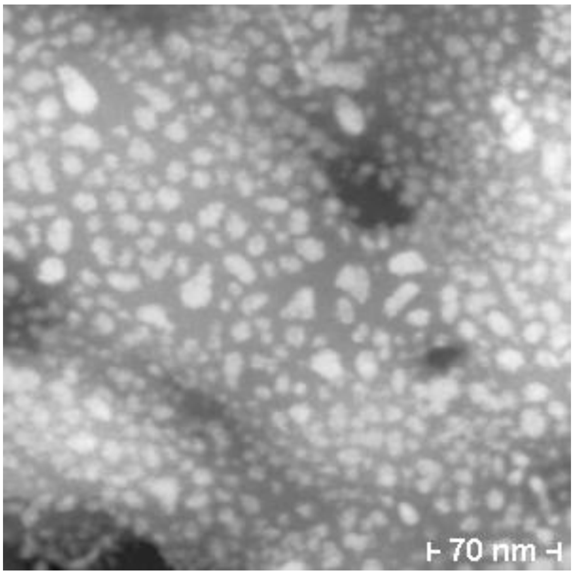

Figure 2. Detail of the filtered BSE image of gold-sputtered magnetic tape

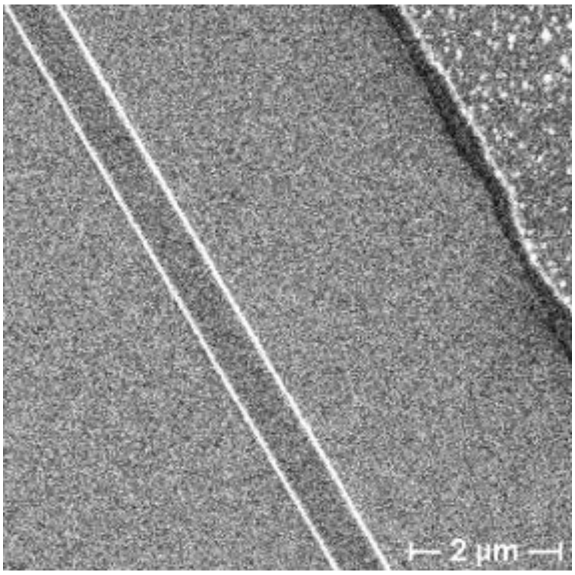

Figure 3. Detail of an original in-lens SE image of silicon etch structures

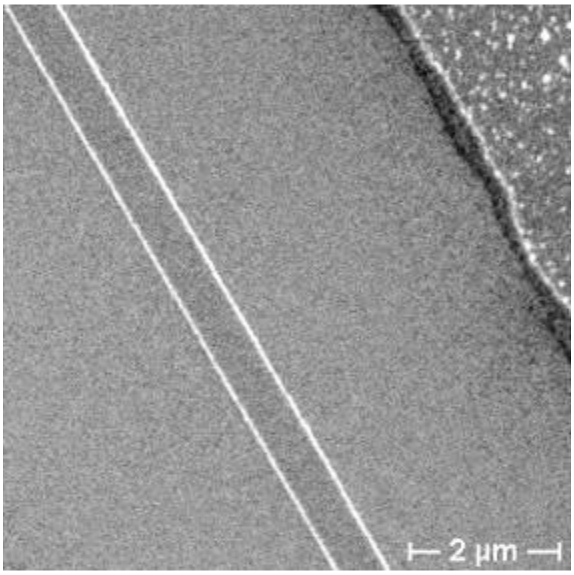

Figure 4. Detail of the filtered in-lens SE image of silicon etch structures