Design of an Anisotropic Noise Filter for Measuring Critical Dimension and Line Edge Roughness from SEM Images

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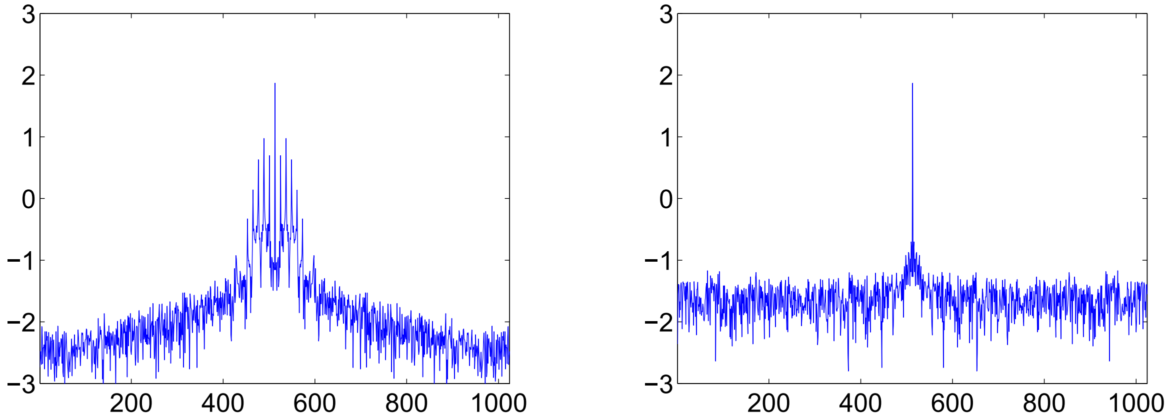
It is often required to measure the critical dimensions (CD) and line edge roughness (LER) from SEM images. A typical method employed in the measurement is to detect the boundaries of features using image processing techniques. An essential step in the method is to reduce the noise level before the boundary detection which normally involves some form of differentiation. A difficulty in designing a noise filter is that the noise needs to be reduced without destroying the boundary detail. A method for designing a noise filter adaptive to the noise level in a SEM image was previously developed and the isotropic Gaussian filter designed by the method was shown to be effective in accurately measuring the CD and LER for L/S patterns. Nevertheless, a drawback is that the filter is not as effective for small line-widths as for relatively large line-widths. Hence, in this study, a new method of designing a noise filter has been developed to address the drawback.

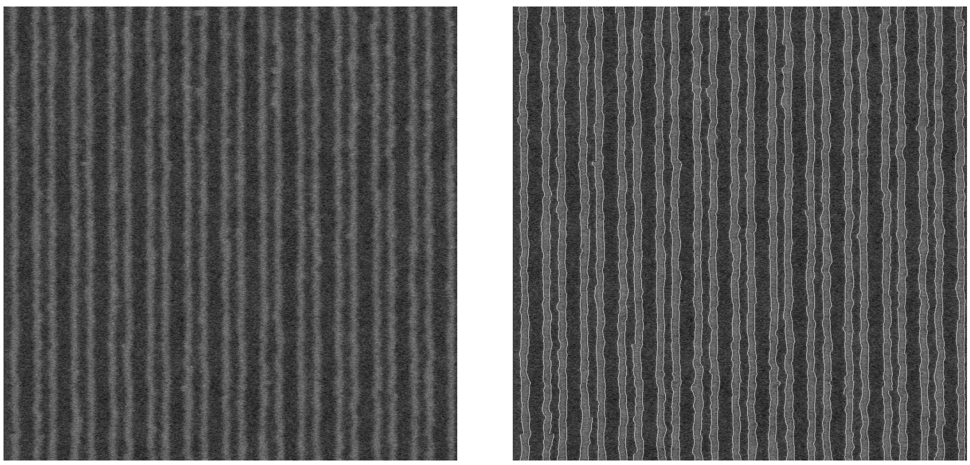
The new method is based on the observation that the power spectral density (PSD) of a SEM image is in general not isotropic as shown in Fig. 1. Most features have a certain spatial orientation such as vertical or horizontal lines and therefore the PSD of signal (feature) can be higher along a frequency dimension (dominant dimension) than the other dimension. Also, the noise tends to be more spatially-correlated in the scanning direction of SEM, which makes the PSD of noise broader in the corresponding dimension. In the new method, a Gaussian noise filter is designed to be adaptive to this anisotropic nature of PSD as well as the noise level. The cutoff frequency in the dominant dimension is set such that most of the signal power is included. Then, the cutoff frequency in the other dimension is determined to maintain the signal-to-noise ratio at 1. The resulted noise filter tends to be anisotropic and is capable of reducing the noise level more adaptively to a given SEM image, compared to an isotropic filter.

The performance of noise filter designed by the new method has been tested using reference SEM images (see Fig. 2-(a)) for which the CD and LER are known. The noise level in the reference SEM images is reduced by the noise filter and the feature boundaries are subsequently found by an edge detector (Sobel operator). From the feature boundaries (see Fig. 2-(b)), the CD and LER are measured. In Table. 1, a set of results is provided where it can be seen that the CD error is very small in both cases, but the LER error achieved by the anisotropic noise filter is significantly lower than those by the isotropic noise filter. In this paper, the design procedure will be described in detail with results from an extensive comparison study.



(a) (b)

Figure 1: The power spectral density of a typical SEM image (a) in the direction perpendicular to lines and (b) in the direction parallel with lines.



(a) (b)

Figure 2: (a) A noisy reference image and (b) the respective edge detection result (detected edges are overlaid with the reference image without noise).

Noise level (%)	3.61		9.11		14.59		20.05	
Filter type	Isotropic	Anisotropic	Isotropic	Anisotropic	Isotropic	Anisotropic	Isotropic	Anisotropic
σ_x, σ_y (pixel)	1.17, 1.17	2.72, 0.62	2.33, 2.33	2.72, 2.12	3.26, 3.26	3.40, 3.26	4.53, 4.53	3.54, 5.43
$W_x \times W_y$ (pixel)	7×7	9×3	9×9	9×9	13×13	13×13	15×15	13×19
LER error (%)	5.82	-4.57	7.91	2.85	5.22	3.82	-6.25	-0.26
CD error (%)	-0.11	-0.15	-0.01	-0.03	-0.23	-0.23	-0.39	-0.13

Table 1: CD and LER errors defined as the deviations from the known CD and LER of the reference image of L/S pattern, respectively. The noise level is the ratio of the root mean square of noise power to that of signal power. The known CD and LER are 78.04 nm and 2.23 nm, respectively. The size of Gaussian filter is $W_x \times W_y$, and the standard deviations in the X and Y dimensions are σ_x and σ_y, respectively. The pixel interval is 1.41 nm.