Noise Filtering for Accurate Measurement of Line Edge Roughness and Critical Dimension from SEM Images

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It is often necessary to measure the line edge roughness (LER) and critical dimension (CD) from SEM images. A typical procedure is to detect the boundaries of features through image processing and quantify the LER and CD from the detected boundaries. However, SEM images usually include a significant level of noise which would affect such measurement results. Therefore, the noise level needs to be reduced before the boundary detection. A difficulty is that the noise reduction requires some kind of low pass filtering which tends to destroy fine details of the feature boundaries. Hence, a careful design of noise filter is necessary in order to minimize the measurement error introduced during processing of SEM images. In this study, the issue of determining the size and shape of a noise filter to be used for high accuracy of LER and CD measurements from SEM images has been investigated.

The noise filter employed in this study is the Gaussian filter which performs a weighted spatial averaging within a window, i.e., a low pass filter. A Gaussian filter is defined by the window size ($W \times W$) and weight distribution in the window. The weight distribution is set by specifying the standard deviation (σ) of a Gaussian function. The larger W and/or σ, the more the Gaussian filter reduces the noise level, but destroys the boundary details. The power spectral density (PSD) of a Gaussian filter is of Gaussian-shape where the shape of PSD is related to W and σ. Given a SEM image, the noise level is estimated and the PSD's of a SEM image and the estimated noise are computed (see Fig. 1). The cut-off frequency for achieving the high signal-to-noise ratio (SNR) in the filtered image is determined from the two PSD's. Then, the corresponding W and σ are derived from the cut-off frequency.

In this study, "reference SEM images" (see Fig. 2) are generated from real SEM images and employed in analyzing the accuracy of the designed Gaussian filter. The CD and LER are known for each reference image. In Table 1, the preliminary analysis results are provided where the noise level is varied. The measurement error defined as the difference between the known LER (or CD) and the measured LER (or CD) using the designed Gaussian is evaluated in each case. It can be observed in the table that the measurement error is very small in all cases. In this paper, the procedures of designing a Gaussian filter which allows for accurate measurements of the LER and CD will be described with the results from an extensive accuracy analysis.

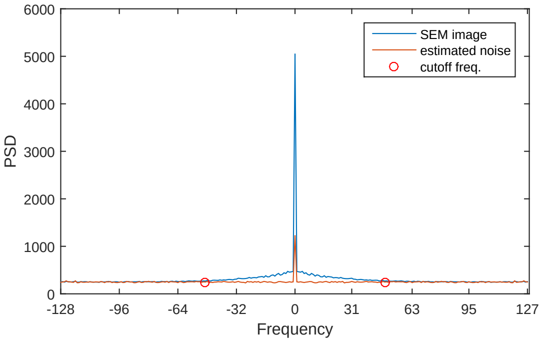

Figure 1: Power spectral densities of a SEM image (reference image) and estimated noise. An arbitrary unit is used for the PSD.

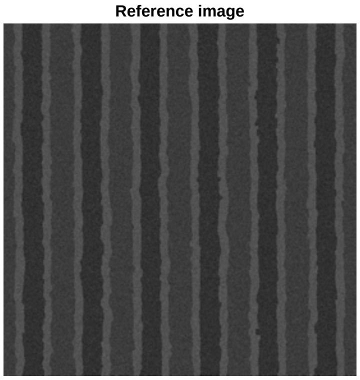

Figure 2: An example of reference image

noise level %	16	24	32	40	48	56	64
σ	0.77	1.30	1.51	1.65	1.90	2.11	2.31
$W \times W$	3×3	3×3	7×7	7×7	7×7	9×9	9×9
LER Error %	0.57	0.47	0.72	0.45	0.76	1.16	1.81
CD Error %	0.21	0.17	0.18	0.19	0.20	0.17	0.20

Table 1: Percent measurement errors of LER and CD where the known LER and CD of the reference image are 5.5nm and 116.4nm, respectively. The noise level is defined as the ratio (in percent) of the maximum (positive and negative) noise-amplitude to the average brightness of a SEM image. The unit for σ and W is in pixel where the pixel interval is 1.4nm.