LER Measurement in Low Dose CD-SEM Images

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The minimization of Line Edge Roughness (LER) and Line Width Roughness (LWR) is an active field of study as semiconductor devices decrease in dimensions. The edge fluctuations are typically determined in images such as fig.1[1], using edge-detection algorithms like the Canny edge-detection filter[2]. Such peak based detection algorithms often do not find the edge or find too many edges in noisy images. Working with low-noise images has two problems: they take a long time to accumulate and there is a risk of resist shrinkage[3]. An obvious way to reduce the noise is applying a filter to the image. When we try that, we see that the power spectrum density of the LER (a typical way of analyzing the LER, see ref [4]) changes, which gives a systematic error to the estimated LER[5]. Fig.2 shows a line scan from the unfiltered image in fig.1 to illustrate the problems for an edge detector. Fig.3 shows the effect of a symmetric Gaussian filter on the PSD (power spectrum density). This was the weakest filter that could be used for applying an edge detection method.

The unfiltered PSD in fig.3 is obtained by using a different algorithm: We approximate the signal profile of the scanning electron microscope by integrating the image in the direction of the edges. Then we cross-correlate this with the line profile to find the best fit. This yields the line position. We can now find the unfiltered PSD.

Using this edge detector, it is possible to ask the question: what is the minimum dose for finding a good LER value? In a simulation study, similar to ref.[6], rough edges are created and subsequently, using the CD-SEM response function found earlier, images are obtained (fig.4). Different amounts of image noise can now be added (fig.5). It turns out that very noisy images still give a surprisingly exact value for the LER, if the noise in the PSD is taken into account appropriately. The PSD's of fig.6 are averaged over many lines, but even a single image as fig.5, gives a value for the LER with a relative error of only 10%.

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[1] recorded by J. Jussot (CNRS-LTM/CEA-LETI)
[2] Patsis, G. P. etAl, JVST. B: 21(3), 1008 (2003).
[3] Yamaguchi, A. etAl, 6152, 61522D–61522D–8 (2006)
[4] Azarnouche, L. etAl., Journal of Applied Physics 111(8), 084318 (2012).
[5] Mack, C. A., Journal of Micro/Nanolithography, MEMS, and MOEMS 12, 033016 (2013)
[6] Mack, C. A., Applied optics 52, 1472–80 (2013)

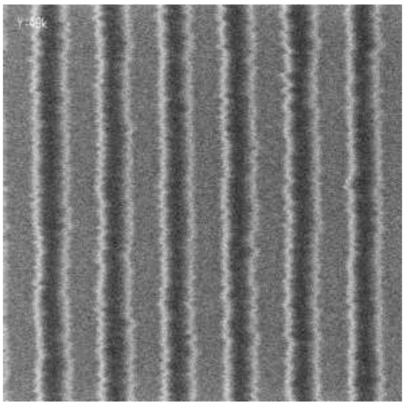

Fig.1: Experimental CD-SEM image, 2755 nm vertical, 450 nm horizontal.

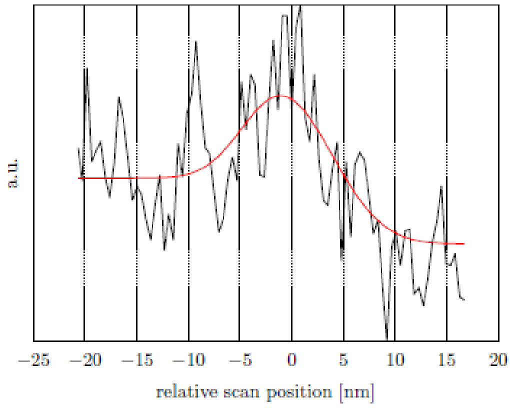

Fig.2: Fitting the average edge shape to a single line in the experimental image.

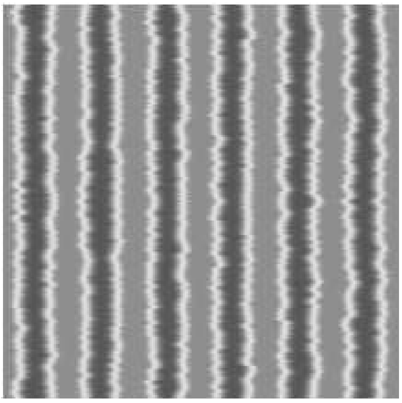

Fig.4: Simulated CD-SEM image without image noise.

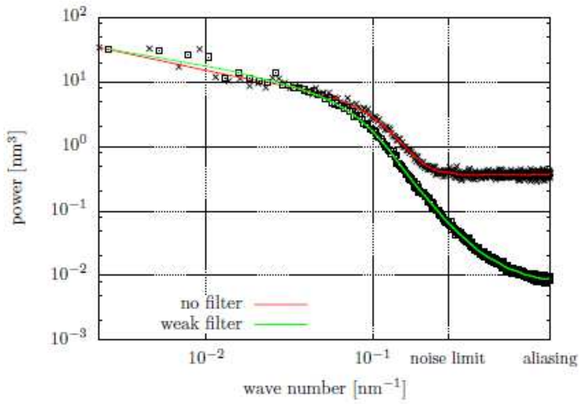

Fig.3: Power Spectrum Density of the LER in the image of fig.1.

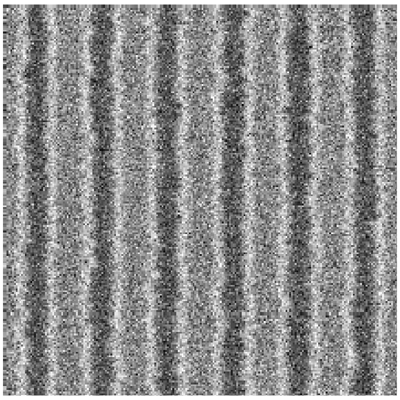

Fig.5: Simulated CD-SEM image with an average of 2 electrons per 3.5 x 3.5 nm pixel

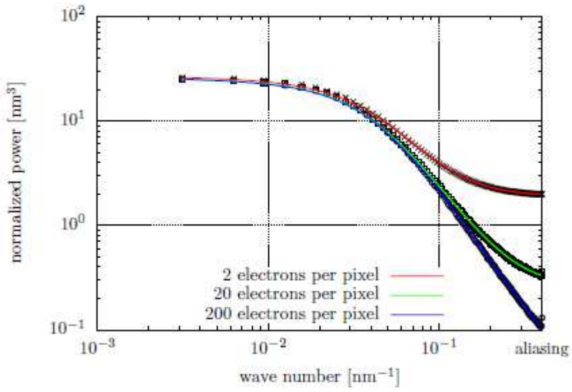

Fig.6: Power Spectrum Density of the LER in simulated images of the type of fig.5.