Computational Nanometrology in Line Edge Roughness Measurements: Synthesized images and Pixelization Effects

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During the last twenty years, Line Edge Roughness (LER) of resist patterns has been a pole of unceasing interest due to its degradation effects on circuit performance. The related research concerns a) the material and process origins of LER formation, b) the accurate and complete metrology of LER and c) the modelling and measurements of LER effects on device performance. LER metrology has been mainly based on SEM imaging and analysis raising issues about the accuracy of the obtained results. In order to solve these issues, advances in the hardware of SEM have been assisted by the application of mathematical and computational methods including machine learning techniques.

In this work, we start with a short overview of the mathematical and computational methods used in LER metrology giving special emphasis on noise effects and machine learning methods. Then we focus on two related but independent issues. First, we present a mathematical modelling approach to generate synthesized SEM images in which we have the liberty to define at will the pattern and LER parameters as well as the noise level and other defects found in real images. Such images can be used to validate metrology methods and feed convolutional neural networks with training data sets. Here, we advance their generation to mimic more reliably real images. Several noise image models are tried while a variety of line/edge topology and correlation is elaborated.

Secondly, the generated synthesized SEM images are used to demonstrate the across-edge pixelization effects of SEM images on LER measurement. Given the closeness of the targeted LER values to the pixel size used in SEM measurements, these effects are expected to have a dramatic impact on the measured LER values. In synthesized images, we show that these effects can induce an error larger than 10% for pixel size values equal to 2*rms(LER). If we assume rms(LER)=0.5nm (1*sigma) then the critical pixel size is about 1nm similar to the pixels used in the current measurement protocols.

In order to remedy these effects, we develop a computational approach based on sound and innovative mathematical results. This approach enables the correction of LER measurement even when the pixel value is much larger than 3*rms(LER) justifying the critical importance of mathematical and computational methods in nanometrology.

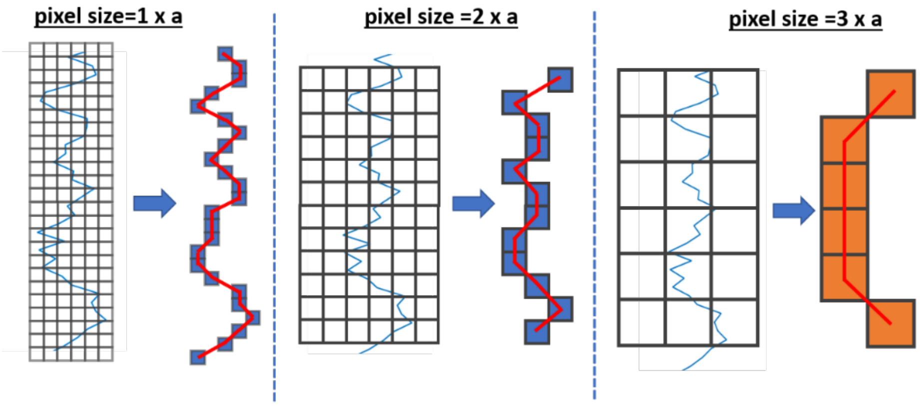
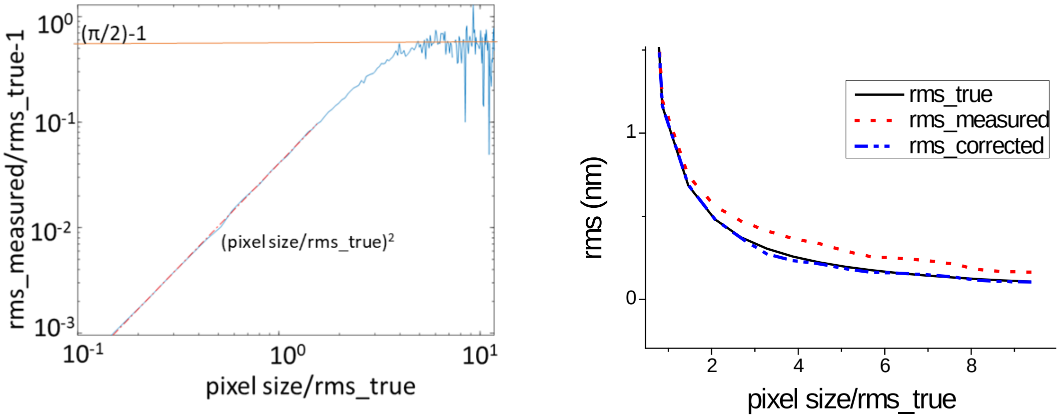


Figure 1: Effect of an increasing pixel size on the shape of the detected edge and the calculated LER parameters.



(a) (b)

Figure 2: a) Graphical representation of the mathematical relationship between the normalized deviation of the measured rms from the true value versus the ratio of the pixel size over true rms. One can notice the simple power law at small pixel size as well as the saturation at the value of π/2-1 at large pixel sizes (>5-6rms_true), b) The correction of the measured rms value using the relationship shown in (a) for various pixel sizes. One can notice the impressive prediction of the measured rms value (from red to blue curve) even at very large pixel sizes.