Determining the Ultimate Resolution of SEM-based Unbiased Roughness Measurements

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ABSTRACT

Stochastic-induced roughness continues to be one of the major concerns for patterning at the 10-nm node and below. Stochastic effects can reduce the yield and performance of devices in several ways:

- Within-feature roughness can affect the electrical properties of a device, such as metal line resistance and gate leakage;
- Feature-to-feature size variation caused by stochastics (also called local CD uniformity, LCDU) adds to the total budget of CD variation, sometimes becoming the dominant source;
- Feature-to-feature pattern placement variation caused by stochastics (also called local pattern placement error, LPPE) adds to the total budget of PPE, sometimes becoming the dominant source;
- Rare events in the tails of the distributions of errors are more probable if those distributions have fat tails, leading to greater than expected occurrence of catastrophic bridges or breaks;
- Decisions based on metrology results (including process monitoring and control, as well as the calibration of OPC models) can be poor if those metrology results do not properly take into account stochastic variations.

For these reasons, proper measurement and characterization of stochastic-induced roughness is critical. Unfortunately, current roughness measurements (such as the measurement of linewidth roughness or line-edge roughness using a critical dimension scanning electron microscope, CD-SEM) are contaminated by large amounts of measurement noise caused by the CD-SEM. This results in a biased measurement, where the true roughness adds in quadrature with the measurement noise to produce an apparent roughness that overestimates the true roughness. Further, these biases are dependent on the CD-SEM tool settings and the properties of the features being measured.

While techniques for measuring and subtracting out this bias to produce an unbiased estimate of the roughness have been developed and proven [1,2], there is still a question as to the ultimate measurement resolution for unbiased roughness. In particular, it is unclear what is the maximum ratio of noise to signal that can be tolerated and still give acceptable answers. In other words, how small can the true roughness be while still being accurately extracted from a noisy SEM image? To answer this question, simulations will be used to probe the efficacy of unbiased roughness measurement. By generating synthetic SEM images of lines and spaces with randomly rough features of predetermined statistical properties [3], different amounts of noise can be added to those image. Analyzing these noisy SEM images as if they were experimentally generated, the measured statistical properties of the features can be compared to the true values as a function of the amount of noise. In this way, we can probe the robustness of current methods of measuring roughness in the presence of very high levels of noise and very low levels of roughness.

References:

[1] Gian F. Lorusso, Vito Rutigliani, Frieda Van Roey, and Chris A. Mack, "Unbiased roughness measurements: Subtracting out SEM effects", *Microelectronic Engineering*, **190**, 33–37 (2018).
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[3] Chris A. Mack, "Generating random rough edges, surfaces, and volumes", *Applied Optics*, **52**(7), 1472-1480 (2013).