Unbiased Roughness Measurements: Subtracting out SEM Effects, part 2

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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 specific CD-SEM tool used and on its settings. In this context, prior attempts at providing unbiased roughness estimates [1-6] often struggle in many of today's applications due to the smaller feature sizes and higher levels of SEM noise.

In a previous study, a new technique for producing unbiased estimates of roughness parameters was investigated [7]. It is based on the use of an analytical model for SEM scattering behavior that predicts linescans for a given feature geometry. Run in reverse, an Inverse Linescan Model can be used for edge detection in such a way that SEM noise can be adequately measured and statistically subtracted from the roughness measurement, thus providing unbiased estimates of the roughness parameters. The previous study investigated the impact of pixel size/magnification and number of measurement frames averaged (i.e., electron dose) on the measured roughness. In this study, a given sample set (with given roughness characteristics) will be measured under a variety of CD-SEM conditions: SEM voltage; rectangular versus square pixels; multiple CD-SEM tools. Further, efforts to better measure roughness at very low electron doses will be tested. Ideally, each of these measurement tool settings will only have negligible impact on the unbiased roughness measurements, even though they are known to have a significant impact on biased roughness measurement.

Keywords: stochastics, linewidth roughness, line-edge roughness, LWR, LER, CD-SEM

References:

[1] Benjamin D. Bunday, Michael Bishop, Donald McCormack, et al., “Determination of Optimal Parameters for CD-SEM Measurement of Line Edge Roughness”, *Metrology, Inspection, and Process Control for Microlithography XVIII*, SPIE Vol. 5375, 515 (2004).

[2] J. S. Villarrubia and B. D. Bunday, “Unbiased Estimation of Linewidth Roughness”, *Metrology, Inspection, and Process Control for Microlithography XIX*, SPIE Vol. 5752, 480 (2005).

[3] R. Katz, C.D. Chase, R. Kris, R. Peltinov, J. Villarrubia, and B. Bunday, “Bias reduction in roughness measurement through SEM noise removal”, *Metrology, Inspection, and Process Control for Microlithography XX*, SPIE Vol. 6152, 61524L, (2006).

[4] A. Yamaguchi, R. Steffen, H. Kawada and T. Iizumi “Bias-Free Measurement of LER/LWR with Low Damage of CD-SEM” *Metrology, Inspection, and Process Control for Microlithography XX*, SPIE Vol. 6152, 61522D (2006).

[5] S.-B. Wang, Y.H. Chiu, H.J. Tao, and Y.J. Mii, “Practical and Bias-Free LWR Measurement by CDSEM”, *Metrology, Inspection, and Process Control for Microlithography XXII*, Proc. of SPIE Vol. 6922, 692222, (2008).

[6] Vassilios Constantoudis and Evangelos Gogolides, “Noise-free estimation of spatial Line Edge/Width Roughness parameters” *Metrology, Inspection, and Process Control for Microlithography XXIII*, SPIE Vol. 7272, 72724B-1 (2009).

[7] 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).