Subtracting SEM errors during the measurement of stochastic-induced feature roughness

Chris A. Mack
Lithoguru.com, 1605 Watchhill Rd, Austin, TX 78703

Stochastic-induced roughness is a major problem for semiconductor lithography when feature sizes extend far below 100 nm. The march of Moore's Law has meant ever-shrinking mean feature sizes, but the roughness associated with each feature has remained nearly constant. As a consequence, the magnitude of the roughness as a fraction of the mean feature size has been growing steadily. To measure and characterize this roughness, critical dimension scanning electron microscopes (CD-SEMs) are used to take top-down images. From these images, edge detection algorithms identify the rough edge positions, which are then compared to ideal smooth lines. Often, full frequency analysis such as the use of power spectral densities (PSD) or height-height correlation functions (HHCF) is employed. [1-3]

Unfortunately, the measurement of roughness in a CD-SEM is biased by systematic and random errors inherent in the measurement. Noise in the grayscale values of a captured SEM image causes noise in the detected edge positions, appearing essentially as white noise added to the true PSD of the feature. The noise is made worse by the low electron doses commonly used to prevent shrinking of resist features. This white noise affects all frequencies, but is most apparent in the high-frequency regime. On the other hand, systematic field distortions in the SEM image appear as low-frequency edge errors that produce a troubling increase in the low-frequency region of the PSD. Finally, electron scattering within the sample produces a detected signal that is some average of the shape of the feature over a range of a few nanometers. This probe-width averaging causes a smoothing of the high-frequency roughness and an increase in the apparent roughness correlation length.

Extracting the true roughness, including its frequency response, requires characterizing and then subtracting out the systematic and random biases introduced by the CD-SEM. In this paper a methodology will be presented and demonstrated for doing just that. By averaging the measurement of many SEM images from nominally identical patterns, good statistics can be obtained for even very small SEM errors. Using the pitch of a dense pattern of lines spaces as a ruler, even very small (sub-nanometer) field distortions can be detected. The noise in each image can be characterized using the properties of the PSD, so long as sufficient averaging is done and proper statistical methods are employed. Finally, the effect of probe-width averaging provides a more challenging problem, especially for resist process with correlation lengths on the order of or less than 10 nm. A method for dealing with this phenomenon will also be proposed. The result will be a significantly more accurate assessment of the frequency behavior of the stochastic-induced roughness of lithographic features.

[1] Chris A. Mack, "Systematic Errors in the Measurement of Power Spectral Density*", Journal of Micro/Nanolithography, MEMS, and MOEMS*, **12**(3), 033016 (2013).
[2] Chris A. Mack, "More systematic errors in the measurement of power spectral density", *J. Micro/Nanolith. MEMS MOEMS,* **14**(3), 033502 (2015).
[3] Chris A. Mack, "Biases and uncertainties in the use of autocovariance and height–height covariance functions to characterize roughness", *Journal of Vacuum Science & Technology B,* **34**(6), 06K701 (Nov/Dec, 2016).