Automated SEM metrology workflows for lithography and nanofabrication

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Modern nanofabrication facilities require metrology solutions that support both exploratory process development and long-term process monitoring. Scanning Electron Microscopy (SEM) remains a key technique for critical dimension (CD) measurements and structural inspection at the micro- and nanoscale[1]. However, while dedicated CD-SEMs provide highly automated and precise metrology[2], their cost and limited versatility restrict their deployment in many shared cleanroom environments. Consequently, standard SEMs are still largely operated manually, limiting throughput, reproducibility, and scalability.

This work presents a versatile SEM-based approach for automated imaging and metrology with an integrated solution. The methodology relies on robust sample alignment, image-to-layout matching, and robust autofocus, enabling reliable repositioning and image acquisition beyond the intrinsic positioning accuracy of conventional SEM stages. At low resolution, rapid autofocused imaging enables fast visual inspection and across-wafer pattern assessment without submicron-scale alignment while still employing layout-based navigation. This mode is well suited for large-area inspection or exposure tests where pattern fidelity may be strongly degraded. At higher resolution and structure quality, precise imaging combined with pattern recognition enables quantitative metrology, including CD uniformity evaluation and linewidth measurements for process characterization.

Wafer-scale experiments on 4-inch substrates demonstrate the approach, with 216 nanostructures of nominal CDs of 100 nm, 200 nm, and 400 nm (Figure 1) automatically imaged and measured in less than one hour under conditions providing sufficient resolution for reliable CD extraction. The resulting structured datasets enable advanced post-processing, including statistical analysis, comparison of process conditions, and long-term monitoring (Figure 2). The approach is demonstrated across multiple lithography processes, including Electron Beam Lithography (EBL), etching Statistical Process Control (SPC), as well as applications involving larger CDs typical of optical and DUV photolithography. Overall, automated SEM imaging combined with integrated metrology extends standard SEM platforms toward flexible, high-performance metrology well suited to shared nanofabrication facilities where versatility, consistency, and scalability are essential.

[1] Liddle, J. A., & Gallatin, G. M. (2011), https://doi.org/10.1039/c1nr10046g
[2] T. Iwamatsu, K. Hiruta, H. Morimoto et al. (2001), https://doi.org/10.1116/1.1381064

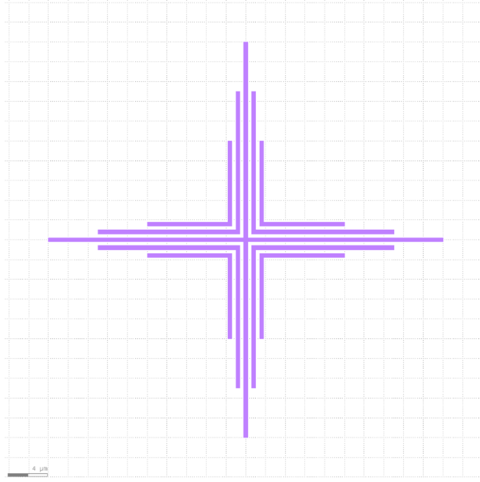

Figure 1: Multi-density cross test pattern for wafer-scale etch uniformity: Schematic of a multi-density, stacked cross test pattern designed for wafer-scale dry etch uniformity assessment. Each die contains three repetitions of the cross motif, composed of line-and-space arrays with nominal critical dimensions of 100 nm, 200 nm, and 400 nm, respectively. The orthogonal cross geometry enables simultaneous characterization of horizontal and vertical CDs. For each density level, CD measurements are extracted on two perpendicular arms of the cross.

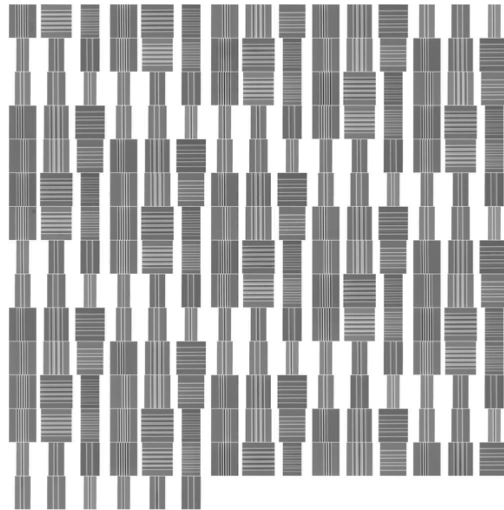

Figure 2: Wafer-scale automated SEM acquisition map (216 images): Overview of the complete automated SEM image acquisition used for dry etch uniformity characterization across a 4-inch wafer. A total of 216 images are acquired on 12 dies, distributed along two orthogonal wafer directions, with six dies sampled in each direction. For each die, stacked cross test patterns with three density levels are imaged, and CD measurements are extracted on two perpendicular arms of the cross for each density. This acquisition strategy enables a systematic evaluation of horizontal and vertical CDs as a function of position, providing a quantitative assessment of both directional and radial etch uniformity at the wafer scale.