Characterizing Environmental Vibration Impacts on Electron-Beam Lithography Using Exposure-Induced Pattern Signatures

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Abstract: Environmental vibration is a critical yet often under-quantified factor limiting pattern fidelity in electron-beam lithography (EBL), especially for sub-20 nm features and long-duration exposures. Here we propose a process-based approach to characterize vibration impacts directly from printed patterns, enabling vibration assessment without dedicated vibration sensors during exposure. A set of vibration-sensitive test structures, including dense line/space arrays and/or stitching-relevant layouts, is designed and exposed under controlled process conditions. High-resolution microscopy images are analyzed using an edge extraction pipeline to obtain spatially resolved edge displacement trajectories and metrology descriptors such as line-edge roughness (LER), line-width roughness (LWR), and systematic placement errors. By transforming edge displacement signals into the frequency domain, vibration features (dominant frequencies, bandwidth, and relative amplitudes) are identified and linked to pattern degradation metrics. The proposed framework further provides a quantitative mapping between vibration-induced pattern signatures and exposure parameters (e.g., dwell time, scan strategy, and write-field configuration), allowing sensitivity tuning and facilitating cross-tool comparison. Validation is performed by correlating extracted spectral components with independent vibration measurements (when available) and by demonstrating consistent trends under varied vibration conditions. This work establishes EBL patterning as an in situ diagnostic of environmental vibration, offering a practical route to monitor and mitigate vibration-limited lithography performance in research and low-cost EBL platforms.

Keyword: Electron-beam lithography; Environmental vibration; Pattern metrology; Edge displacement; LER/LWR; Frequency-domain analysis; Stitching error; Process monitoring