Noise Measurements for Electron Beam Lithography

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Advances in electron-beam lithography have focused on reduction in feature size through system design and resist processing, but there have been few efforts to control feature *placement* over large distances. These trends are partly driven by the needs of the semiconductor industry, where local feature overlay is more critical than long-range spatial coherence. However, precise long-range pattern placement is important for micro- and nano-photonic devices that rely on coherent interference effects, and nanoscale variations in critical dimension will likely impact the performance of next-generation devices. Electron-beam lithography systems, except under special circumstances,[1] cannot reference the beam to the substrate during an exposure. As such, noise during the exposure will displace the pattern elements from their design positions. The noise characteristics are difficult to determine with standard diagnostic techniques like scanning electron microscopy (SEM), so a suitable metrology technique would be valuable.

We demonstrate a simple method to identify noise sources in electron-beam systems and accurately quantify the resulting errors in feature placement. Line gratings with a 46 nm average pitch were patterned with electron-beam lithography and measured with transmission x-ray diffraction. The diffraction profiles contained numerous "satellite" peaks, meaning weak diffraction peaks adjacent to the strong primary nodes, that are characteristic of periodic extensions and compressions in the grating pitch. The wavelength and amplitude of these pitch variations were calculated with a simple scaling law by comparing the intensities and positions of satellite peaks relative to their primary nodes. This approach is remarkably easy to implement because it does not require any modeling of the diffracted wave amplitudes. Results were used to calculate the frequency of each noise source and the resulting variations in grating pitch. Two persistent noise frequencies were detected in the tool studied, (62 ± 2) Hz and (86 ± 3) Hz, and the tool manufacturer identified likely noise sources as electromagnetic and mechanical in nature, respectively. The 60 Hz and 86 Hz noise produced errors in a 46 nm grating pitch of $3\sigma = 1$ nm to 3 nm, where σ is the standard deviation in the grating pitch. Errors of these magnitudes can be expected to have adverse effects on coupling efficiencies, cavity quality factors, and center wavelength values in photonic devices. The magnitude of these errors also exceeds the critical dimension and overlay tolerances for 22 nm half-pitch lithography.[2]

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[1] J.T. Hastings, F. Zhang, H.I. Smith, J. Vac. Sci. Technol. B, **21** 2650 (2003)

[2] International technology roadmap for semiconductors, 2007

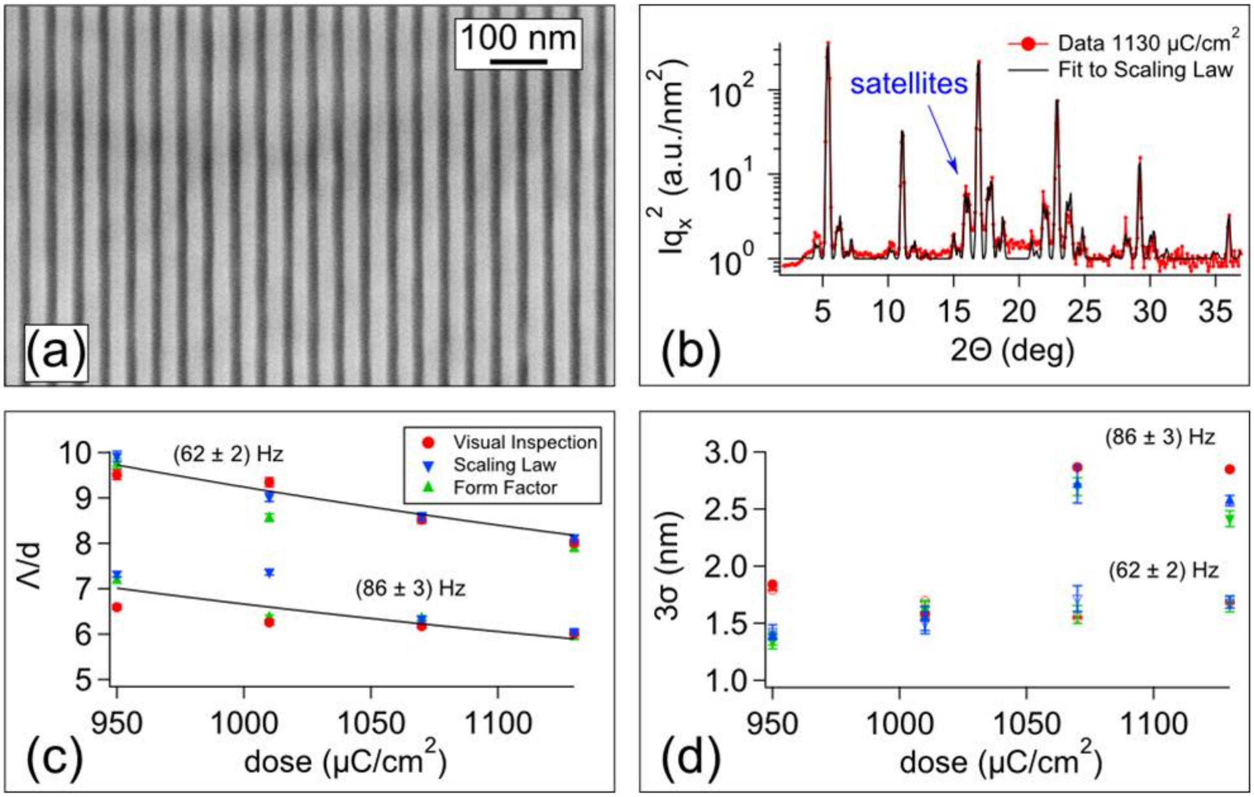

Figure 1: (a) SEM micrograph of a $d = 46$ nm pitch line grating. Resist is ZEP (distributed by Zeon Chemicals), patterned with an exposure dose of 1130 μC/cm^2. (b) Diffraction data for a 46 nm pitch line grating, exposure dose of 1130 μC/cm^2. (c) Noise frequencies calculated from the measured noise cycles Λ/d, where Λ is the wavelength of periodic extensions/compressions in pitch. Three methods were used to analyze the data. (d) Variation in the grating pitch that results from $\sim$60 Hz (open symbols) and $\sim$86 Hz (closed symbols) noise.