Optimum Exposure Parameters for High-Resolution Scanning Electron Beam Lithography

Bryan Cord, Joel Yang, Karl K. Berggren
Massachusetts Institute of Technology, Cambridge, MA

The resolution of a scanning electron beam lithography (SEBL) exposure process is primarily limited by two processes: forward scattering of the incident beam and the range of secondary electrons produced by interactions between the primary beam and the resist.[1,2] The forward scattering behavior has been well-characterized, and its extent is known to be proportional to the resist thickness and inversely proportional to the primary beam energy.[3] The behavior of the secondary electrons is less well-documented, but their approximate range is thought to be independent of resist thickness and either independent of[2] or weakly proportional to[4] the primary beam energy.

The dependencies of these two limiting factors suggest that, for a given resist thickness, there exists a "crossover" energy where the process is balanced between the forward-scattering- and secondary-electron-limited regimes and further increase in the beam energy does not result in increased resolution. While it is known that secondary electron range is the main resolution limiter in most thin-resist applications[1], the exact energies at which forward scattering becomes irrelevant have never been quantitatively determined.

Using Monte Carlo simulations[5], we have calculated the forward scattering length over a range of beam energies and resist thicknesses. These values are plotted in figure 1, along with Joy's 1983 energy-independent estimate of the secondary electron range.[2] The results suggest that, for resists thinner than 100 nm, the crossover beam energy occurs at approximately 30-40 keV, suggesting in turn that thin-film lithographic resolution on relatively low-cost 30 keV SEBL tools may be equal or superior to that attainable on high-end, high-beam-energy systems. This hypothesis is partially supported by the micrographs in figure 2, which demonstrate sub-10-nm lithographic resolution in 100-nm-thick films of PMMA[6] and HSQ[7] using MIT's 30 keV Raith-150 SEBL tool.

Using both simulations of the secondary electron behavior and experimental characterization of the resolution, we have investigated the effects of beam energy and resist thickness on SEBL resolution and will present a model for determining the optimum exposure parameters for a given SEBL process.

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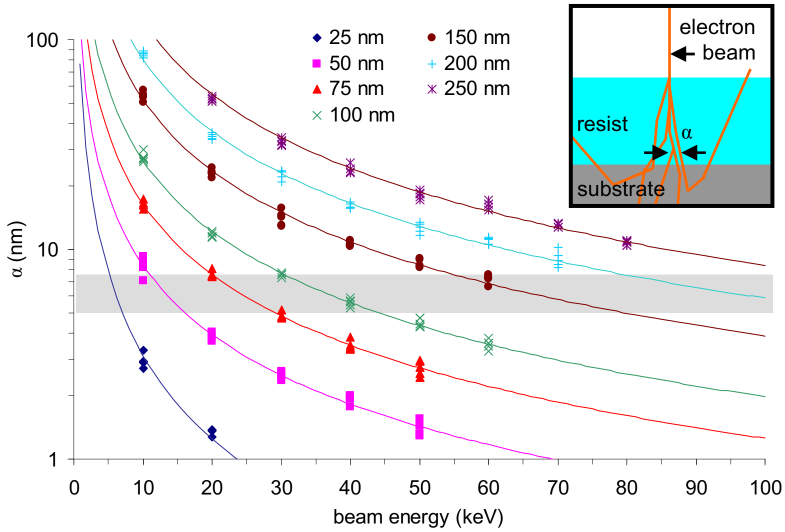

Figure 2: Forward scattering (α) coefficients (see inset) for various beam energies and PMMA thicknesses, calculated using CASINO, with fit functions (solid lines). The grey band represents the approximate secondary electron range of 5-7.5 nm estimated by Joy in 1983.

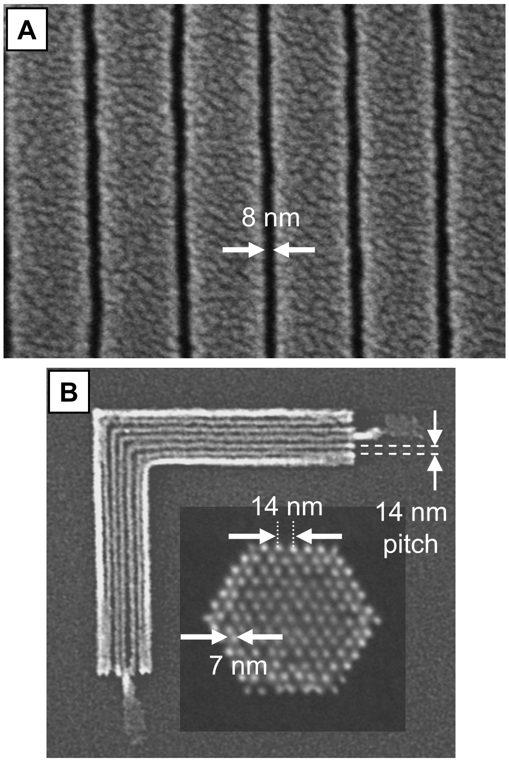

Figure 3: A) 8-nm-wide trenches on a 60 nm pitch, fabricated using 100-nm-thick PMMA and etched into Si. B) Nested “L” structure with 14 nm pitch and 7-nm-wide dots on a 14 nm pitch (inset), fabricated using 100-nm-thick HSQ. For both structures, the beam energy used was only 30 KeV.