Step Width Adjustment in Fabrication of Staircase Structures

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Multi-level structures are used in various devices such as DOE's (Diffractive Optical Elements), MEMS and NEMS. Their performance is known to be highly sensitive to their dimensional fidelity. Therefore, it is essential to control the feature size accurately, in order to be able to fabricate such devices with the desired characteristics. Fabrication of such structures often relies on electron-beam (e-beam) grayscale lithography. However, as the feature size decreases, proximity effect due to electron scattering and lateral development of resist can make dimensions of the written features in a device substantially different from the target ones. This issue has been addressed in this study using staircase structures, specifically, minimizing the difference between the target and actual widths of a step.

The deviation of step width is mainly due to the fact that resist development process is isotropic. The slope of step edge is also affected by proximity effect and is not usually vertical. For simplicity, the width of a step is measured at the middle level between two adjacent steps as illustrated in Figure 1. A practical scheme for adjusting step widths has been developed, which minimizes the computational requirement by avoiding a complete resist development simulation. It is assumed that the step length is much greater than the step width such that any exposure variation along the length dimension (y) can be ignored. The scheme proceeds as follows. *Step 1*: A 2-D exposure distribution $e(x,z)$ in the cross-section perpendicular to the Y-axis is computed by the PYRAMID software which takes an efficient two-level approach to large-scale convolution between the dose distribution of a staircase structure and the point spread function for a substrate system and beam energy. *Step 2*: The resist developing rate $r(x,z)$ is computed according to a conversion (exposure to developing rate) formula derived based on experimental results. *Step 3*: The step width deviation, $\triangle W_i$, is estimated for each step, given a developing time, noting the fact that resist development progresses mostly vertically within each step. That is, the time duration, $\triangle t_{i,}$ required for a half of the final step height to develop is computed and $\triangle W_i$ is estimated from $\triangle t_i$ considering the lateral development at the step boundary. *Step 4*: How much each W_i is to be adjusted in the specification of the staircase structure, in order to compensate for $\triangle W_i$, is computed. In some cases, one may not achieve the target widths with high precision due to the fact that the step width can be adjusted only by whole pixels. *Step 5*: For a finer control of step width, the dose adjustment may be combined with the width adjustment. However, adjusting dose changes not only the step width but also the step depth. Hence, W_i is pre-adjusted before dose adjustment, taking $\triangle W_i$, and the target step depth into account.

This width adjustment scheme has been implemented and tested for staircase structures with varying step width and resist thickness. In Figure 2, a set of the simulation results is provided. The symmetric staircase structure considered consists of 9 steps, the substrate system is composed of 1000 *n*m PMMA on Si, and the beam energy is 50 KeV. It can be seen that the resist profile before any adjustment shows a significant width deviation of each step, a larger deviation for a deeper step, as shown in Figure 2-(a). The final profile achieved by both width and dose adjustments is much closer to the target profile as seen in Figure 2-(b). These simulation results have been verified through experiments as shown in Figure 3. In this paper, the effective step width adjustment scheme for grayscale e-beam lithography will be described in detail and results from the extensive computer simulation and experiments will be presented.

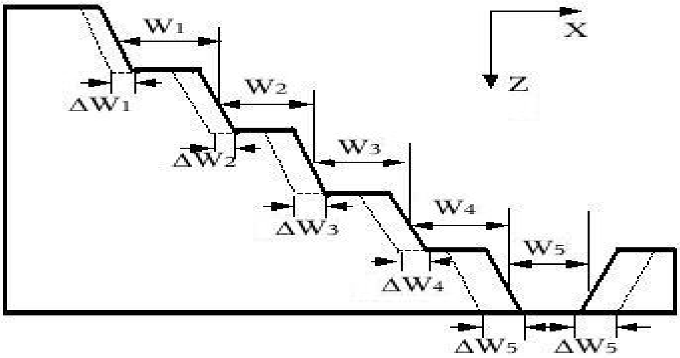
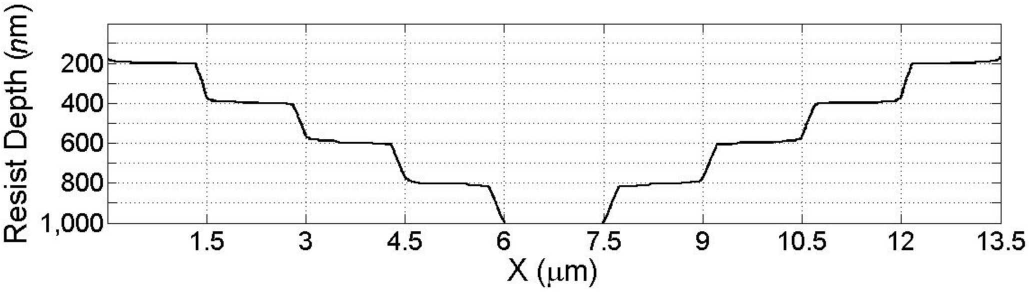
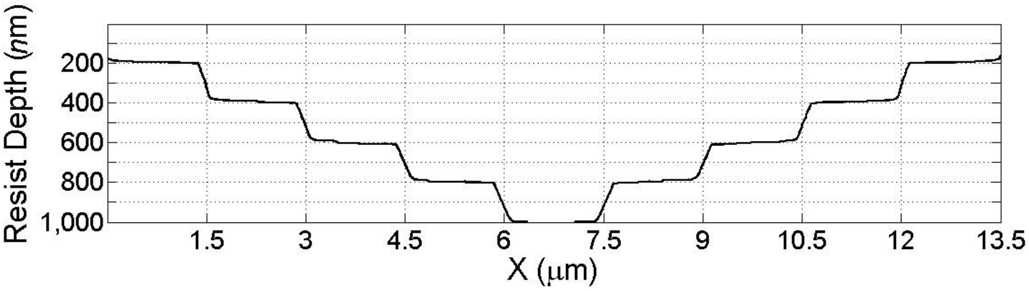


Figure 1.   Step widths and their deviations in a staircase structure

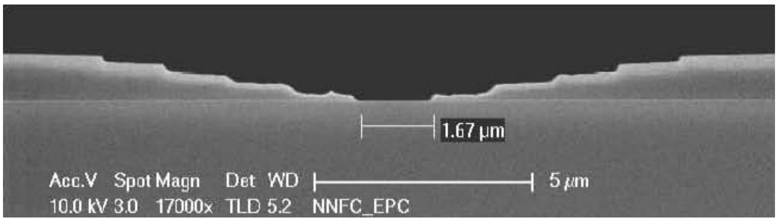


(a) step width errors: {△Wi }={45,25,20,35,250,35, 20,25,45*nm* }

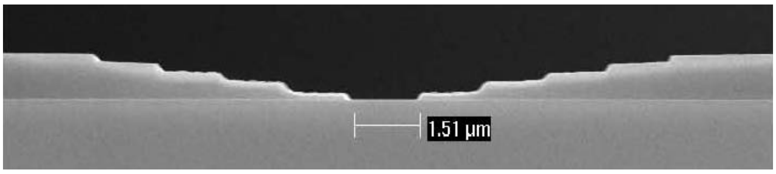


(b) step width errors: {△Wi }={0,0,0,0,0,0, 0,0,0*nm*}

Figure 2: Simulated profiles (a) before adjustment and (b) after step width and dose adjustments where target step width: 1.5 µm, target step height: 200 *n*m, resist thickness: 1000 *n*m (50 keV).



(a)



(b)

Figure 3: Experimental results (a) before adjustment and (b) after step width and dose adjustments where target step width: 1.5 µm, target step height: 200 *n*m, resist thickness of 1000 *n*m (50 keV).