Line End Shortening, part 2

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As discussed in the last two issues of this column, control of the pattern fidelity of lithographicaly printed images involves more than just the traditional metrics of overlay and linewidth control. The three-dimensional shapes of the final printed photoresist features can affect device characteristics significantly, yet these shape variations suffer from the very real limitation of the lack of simple metrics to judge their quality. One such metric, the critical shape error (discussed in this column, *Summer 1996*), can be used in almost any circumstance, but still requires some effort to relate the numerical values of the metric to device properties. Fortunately, a metric for one important case of pattern fidelity can be easily defined, measured, and understood: line end shortening.

An isolated line of width near the resolution limit of a lithographic process will usually exhibit significant line end shortening, as illustrated in Figure 1. The end of the line is made up of two 90^o corners. But as these corners pass through an imaging process of limited resolution, the corners will, by necessity, round. If the feature width is less than the sum of the two corner rounding radii, the end of the line will pull back due to this corner rounding. What are the root causes of this corner rounding? There are actually two major causes, both contributing to the final line end shortening magnitude.

The primary corner rounding, and thus line end shortening, mechanism is the diffraction limits of aerial image formation. As an example, a 180nm isolated line imaged at 248nm with a numerical aperture (NA) of 0.688 (giving a scaled feature size of k_1 = 0.5) and with a partial coherence of 0.5 will produce an aerial image with nearly 50nm of line end shortening (LES). The amount of corner rounding is a strong function of k_1. Figure 2 shows the effect of NA on the line end shortening of the aerial image of a 180nm sized structure like that of Figure 1. Obviously, a higher NA (just like a lower wavelength or larger feature size) produces less LES. The influence of partial coherence (Figure 3) shows an enigmatic behavior that is characteristic of its seemingly unpredictable impact on partially coherent imaging.

Does the resist affect the final degree of line end shortening? Interestingly, development contrast seems to have only a small influence on the amount of LES of the final resist patterns. Diffusion during PEB, on the other hand, has a very significant effect. Figure 4 shows the simulated result of increasing diffusion length (for an idealized conventional resist) on the line end shortening. The diffusion length must be kept fairly small in order for diffusion to only marginally impact the line end shortening. The reason for the large effect of diffusion on line end shortening is the three-dimensional nature of the diffusion process: at the end of the line, chemical species from the exposed areas can diffuse from all three sides of the line end (as opposed to one direction for a line edge).

In summary, two major mechanism produce line end shortening. The fundamental limits of diffraction round the corners of aerial images producing a foreshortened line end for small features. This aerial image shortening is compounded by diffusion, attacking the line end from three sides. The result can be a significant amount of line end shortening, and a significant headache for semiconductor device manufacturers.

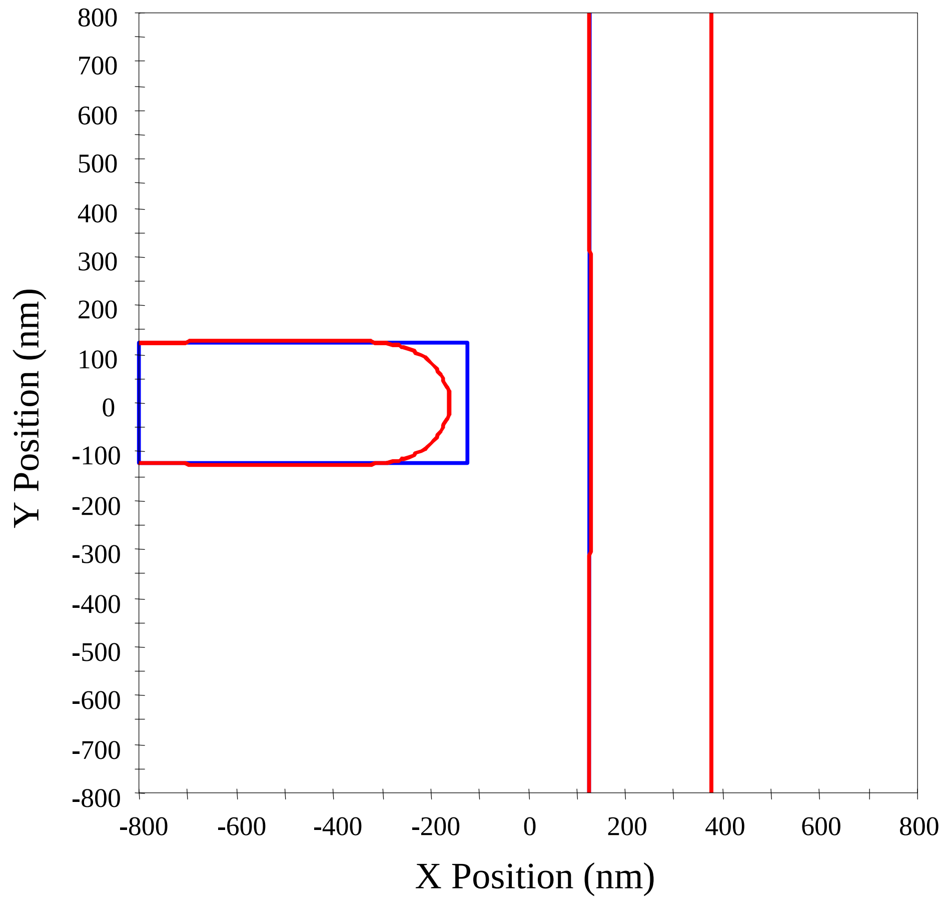

Figure 1. Outline of the printed photoresist pattern (red) superimposed on an outline of the mask (blue) shows an example of line end shortening (k_1 = 0.6).

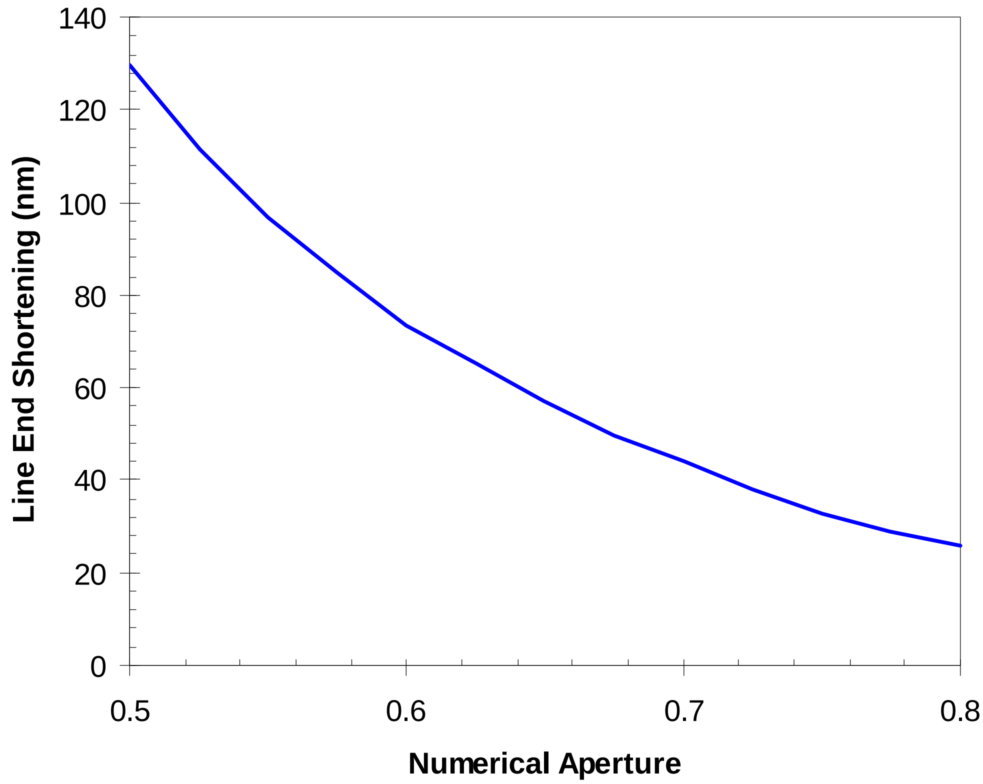

Figure 2. Larger numerical apertures reduce the loss of image fidelity due to diffraction, producing less line end shortening (180nm line, λ = 248nm, σ = 0.5).

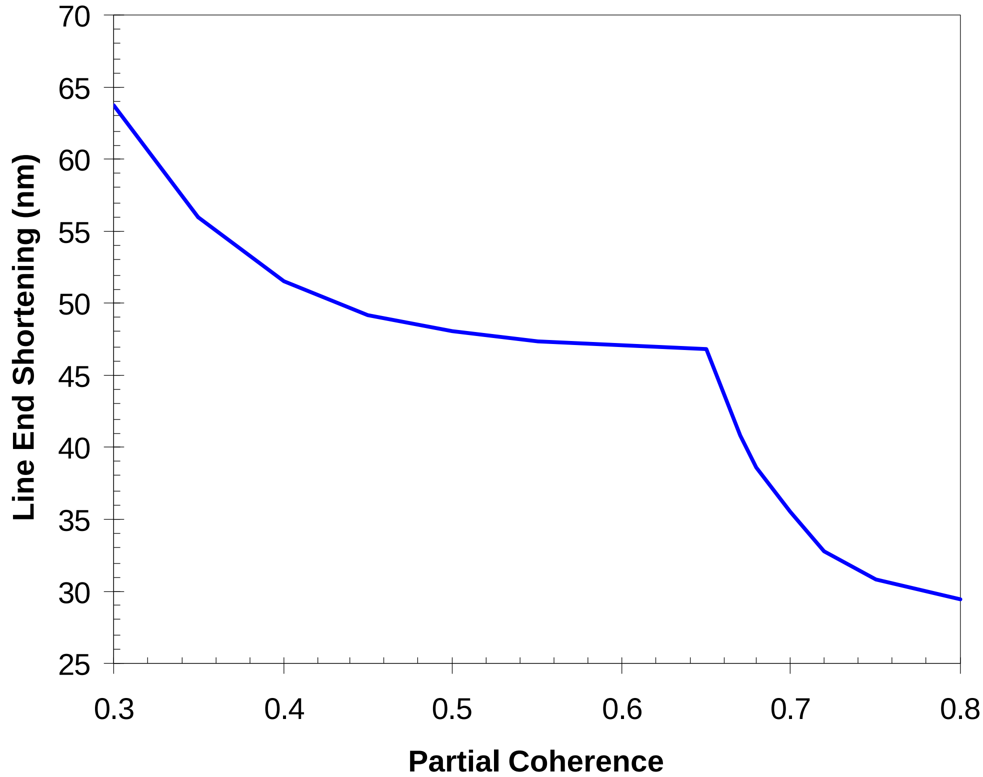

Figure 3. Partial coherence shows a somewhat discontinuous impact on the aerial image line end shortening (180nm line, λ = 248nm, NA = 0.688).

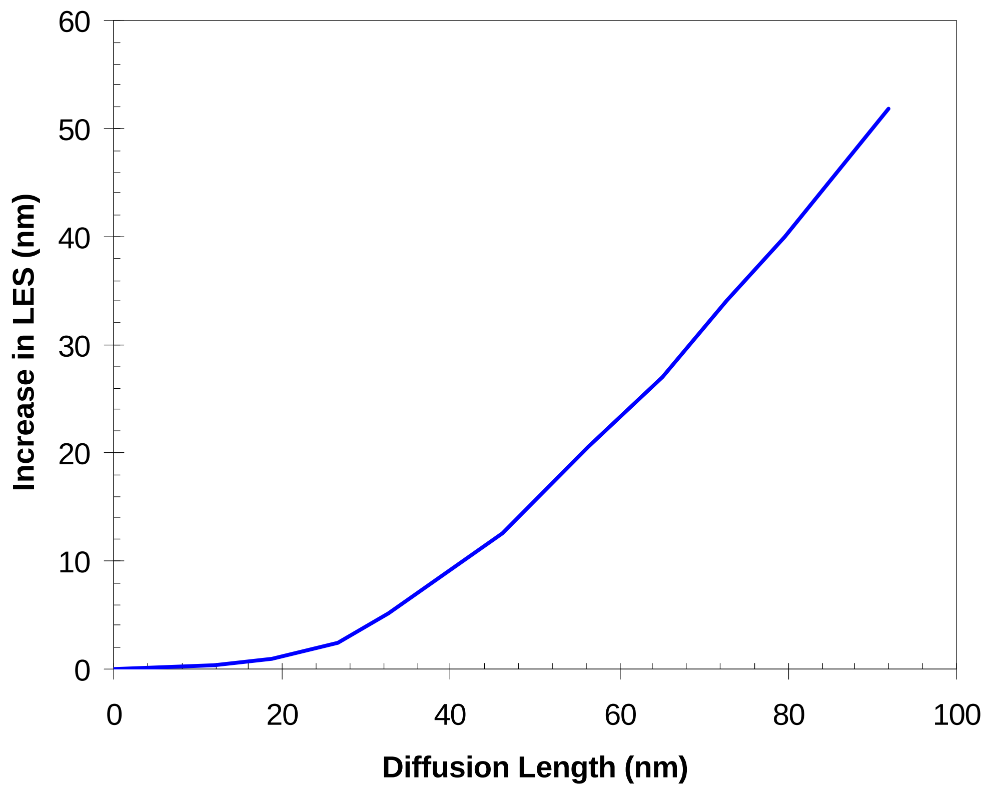

Figure 4. Diffusion can have a dramatic effect on line end shortening (180nm line, λ = 248nm, NA = 0.688, σ = 0.5).