Using the Normalized Image Log-Slope, part 4

Chris A. Mack, *FINLE Technologies, A Division of KLA-Tencor, Austin, Texas*

The slope or gradient of an image near the edge of a feature to be printed in photoresist is a good representation of the information contained in the image as to where the edge should be. A large slope gives a clear indication as to where the photoresist line edge belongs. In particular, the normalized image log-slope (NILS) and the latent image gradient were found to be good metrics for the aerial image and latent image respectively. The information contained in each image propagates through the lithography process, from the formation of an aerial image $I(x)$, to the exposure of a photoresist by that image to form a latent image of chemical species $m(x)$, to post-exposure bake where diffusion and possibly reactions create a new latent image $m^*(x)$, and finally to development where the latent image produces a development rate gradient $R(x)$ that results in the definition of the feature edge.

In the last edition of this column would looked at the transfer of information during exposure and how the resulting latent image gradient depends on the NILS. Continuing with the resist processing, post-exposure bake (PEB) will change this latent image, and thus change the latent image gradient. Diffusion during PEB will spread out the latent image, degrading the information present in the image and decreasing the gradient near the line edge. The change in the latent image gradient due to diffusion can be describe approximately by

$$\frac{\partial m^*}{\partial x} \approx \frac{\partial m}{\partial x} e^{-\sigma^2 \pi^2 / 2L^2} \qquad (1)$$

where σ is the diffusion length and L is a characteristic length related to the width of the edge region (the range over which the original latent image gradient is non-zero). For a pattern of small lines and spaces, L is about equal to the half pitch of the pattern. Obviously, increased diffusion (indicated by a larger diffusion length) results in a greater degradation of the latent image gradient (Figure 1). Also, sharper edges (smaller values of L) are more sensitive to diffusion, showing a greater fractional decline in the latent image gradient for a given diffusion length.

For chemically amplified resists, diffusion during PEB is accompanied by a reaction that changes the photogenerated acid latent image into a latent image of blocked and deblocked polymer. Since reaction and diffusion occur simultaneously, rigorous evaluation of the impact on the latent gradient requires full lithography simulation approaches. A simple, approximate approach is to look at the impact of the reaction without diffusion. Ignoring the possibilities of acid loss before or during the PEB, a simple mechanism for a first order chemical amplification would give

$$m^*(x) = \exp(-a\,(1 - m(x))) \qquad (2)$$

where α is the amplification factor, proportional to the PEB time and exponentially dependent on PEB temperature [1]. This simple expression points out the tradeoff between exposure dose and thermal dose. A higher exposure dose generates more acid (larger value of 1-*m*), requiring less PEB (lower value of α) to get the same result (same value of *m**). For a given level of required amplification, thermal and exposure doses can be exchanged so long as α(1-*m*) is kept constant.

The gradient of this new latent image after amplification is then

$$\frac{\partial m^*}{\partial x} = -m^* \ln(m^*)\left(\frac{1}{1-m}\frac{\partial m}{\partial x}\right) = -m^* \ln(m^*)\left(\frac{m \ln(m)}{1-m}\right)\frac{\partial \ln I}{\partial x} \qquad (3)$$

For a given latent image after exposure (given *m(x)*), the optimum latent image after amplification occurs when $m^* = e^{-1}$, giving α(1-*m*) = 1. For a given required level of amplification (given value of *m**), the trade-off between thermal and exposure dose can be optimized to give the maximum latent image gradient after PEB. This occurs when

$$\frac{1}{1-m}\frac{\partial m}{\partial x} \propto \frac{m\,ln(m)}{1-m} = \text{maximum when } m \to 1 \qquad (4)$$

In other words, the optimum latent image gradient after PEB occurs when using a low dose and a high level of amplification (Figure 2). Carrying this idea to its extreme, however, invalidates the assumption that no diffusion occurs since higher levels of amplification necessitate higher levels of acid diffusion. Thus, the true trade-off between thermal and exposure dose must take into account the effects of diffusion as well.

It is interesting to note the difference in the optimum dose of a conventional resist (discussed in the last edition of this column) and a chemically amplified resist. The optimum *total* dose (exposure plus thermal) for a chemically amplified resist is the same as for a conventional resist (resulting in $m^* = e^{-1}$ in both cases). However, for the chemically amplified resist the added degree of freedom of dividing the dose between exposure and thermal sources means that the optimum exposure dose is very different compared to a conventional resist.

In the next issue of the *Lithography Expert*, we'll see how the latent image propagates through development to form a final resist edge.

References

1. C. A. Mack, <u>Inside PROLITH: A Comprehensive Guide to Optical Lithography Simulation</u>, FINLE Technologies (Austin, TX: 1997).

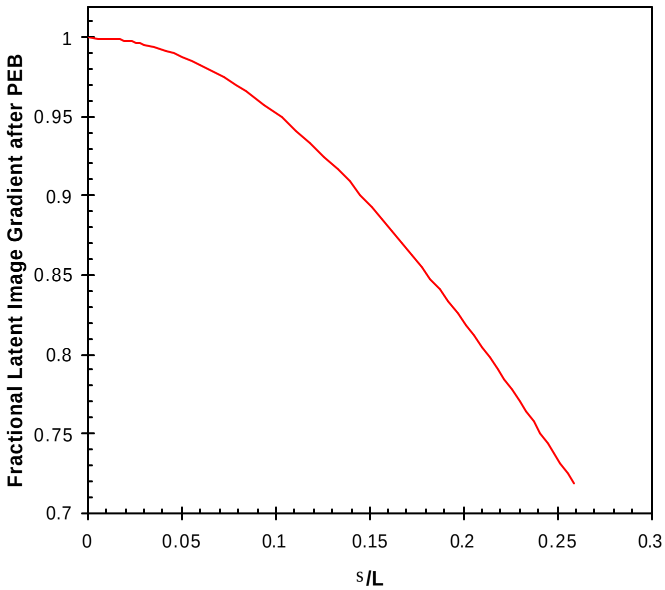

Figure 1. Increased diffusion (shown by the dimensionless quantity σ/L, the diffusion length over the width of the edge region) causes a decease in the latent image gradient after PEB.

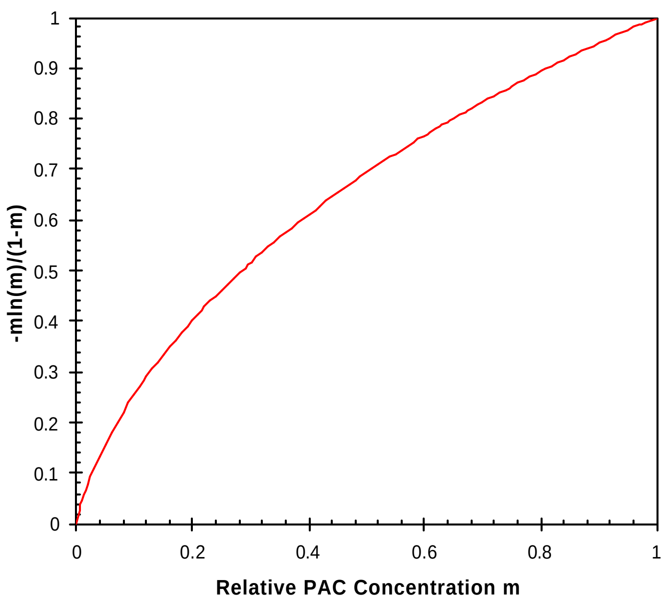

Figure 2. For a chemically amplified resist with an given required amount of amplification, the exposure dose (and thus relative sensitizer concentration m) is optimum as the dose approaches zero ($m \rightarrow 1$).