Using the Normalized Image Log-Slope, part 3

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As we saw in parts 1 and 2 of this series, the normalized image log-slope (NILS) is the best single metric to judge the lithographic usefulness of an aerial image. This metric is directly related to exposure latitude, so that a minimum required exposure latitude will translate into a minimum required NILS. The NILS is, fundamentally, an aerial image metric. It can be thought of as a measure of the amount of information contained in the image that defines the proper position of the desired photoresist edge. How does the photoresist come into play? How does the information of the aerial image propagate through exposure and post-exposure bake into a latent image, and through development into a resist profile? Can a similar metric be defined to judge the quality of the latent image?

To answer these questions, it is very useful to think about lithography as a sequence of information transfer steps (Figure 1). A designer lays out a desired pattern in the form of simple polygon shapes. This layout data drives a mask writer so that the information of the layout becomes a spatial variation of transmittance (chrome and glass, for example) of the photomask. The information of the layout has been transferred, though not perfectly, into the transmittance distribution of the mask. Next, the mask is used in an projection imaging tool to create an aerial image of the mask. However, due to the diffraction limitations of the wavelength and lens numerical aperture the information transmitted to the wafer is reduced. The aerial image is an imperfect representation of the information on the mask. We have used the NILS as a measure of the quality of the aerial image and, thus, of its information content.

The aerial image, through the process of exposure, transfers its information into a latent image, a spatial distribution of exposed and unexposed resist. How well is this information transfer accomplished? How can we judge the quality of the latent image? What resist or processing parameters affect latent image quality? Consider a simple yet common case: a resist with first order kinetics (almost always the case) whose optical properties do not change with exposure dose (commonly the case for chemically amplified resists). For such a case the latent image $m(x,y,z)$ is related to the intensity in the resist $I_r(x,y,z)$ by

$$m(x,y,z) = \exp(-CI_r(x,y,z)t) \qquad (1)$$

where C is the exposure rate constant of the resist, t is the exposure time, and m is the relative concentration of light sensitive resist material. For a given depth into the resist, the actual intensity of light in the resist is directly proportional to the relative intensity of the aerial image, $I(x,y)$. Equation (1) can be modified as

$$m(x,y) = \exp(-CE_z I(x,y)) \quad (2)$$

where E_z is the exposure dose at a depth z into the resist that would result for an open frame exposure of incident dose E.

Equation (2) is the exposure image transfer function, translating an aerial image into a latent image. From our experience with using the NILS, one would expect that a slope or gradient of the latent image would serve as a good metric of latent image quality. The slope of the latent image (at the nominal feature edge position, for example) can easily be derived by taking the derivative of equation (2), giving [1]

$$\frac{\partial m}{\partial x} = m \ln(m) \frac{\partial \ln I}{\partial x} \quad (3)$$

Thus, the latent image gradient is directly proportional to the image log slope (and thus the normalized latent image gradient is proportional to NILS). This entirely logical result is very satisfying, since it means that all efforts to improve the NILS will result directly in an improved latent image gradient.

Equation (3) reveals another important factor in latent image quality. The term $m\ln(m)$, which relates the image log slope to the latent image gradient, is exposure dependent (m being the relative amount of resist sensitizer that has not been exposed at the point where the latent image gradient is being described). A plot of $-m\ln(m)$ versus m shows that there is one exposure dose (one value of m) that will maximize the latent image quality (Figure 2). When $m = e^{-1} \approx 0.37$, the value of $-m\ln(m)$ reaches its maximum and the full information of the aerial image is transferred into the resist during exposure. It is interesting to note that when $m = 1$ (no exposure) and $m = 0$ (complete exposure of the resist) the latent image gradient is zero and no information is transferred from the aerial image into the resist.

There are many interesting implications that come from the simple observation of the existence of an optimum exposure dose. Often, dose is used as just a “dimension dial”, adjusting dose to obtain the desired feature size without regard to any process latitude implications. If the dose is near the optimum, this approach is valid. If however, the dose used is significantly off from optimum (say, very underexposed compared to the peak of Figure 2), changing dose will affect both dimension and overall latent image quality.

In the next issue of the *Lithography Expert*, we’ll see how the optimum dose must be coupled with the development process to find an overall optimum.

References

1. C. A. Mack, “Photoresist Process Optimization,” *KTI Microelectronics Seminar, Proc.*, (1987) pp. 153-167.

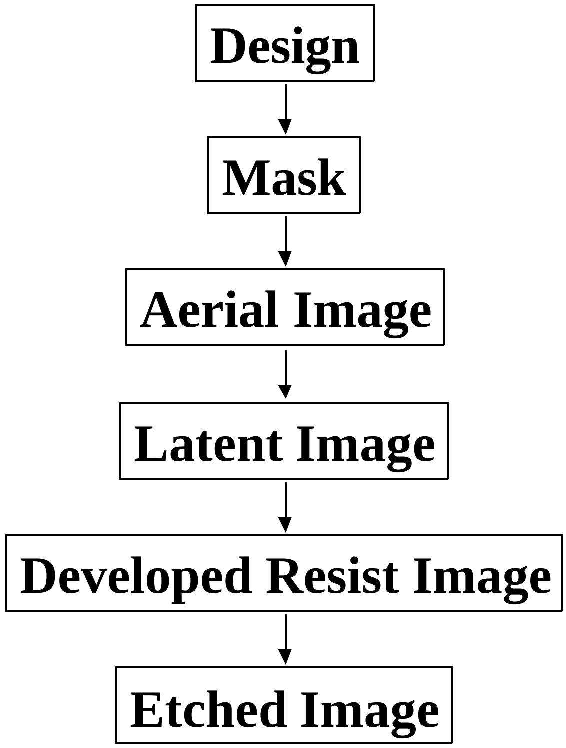

Figure 1. The lithography process expressed as a sequence of information transfer steps.

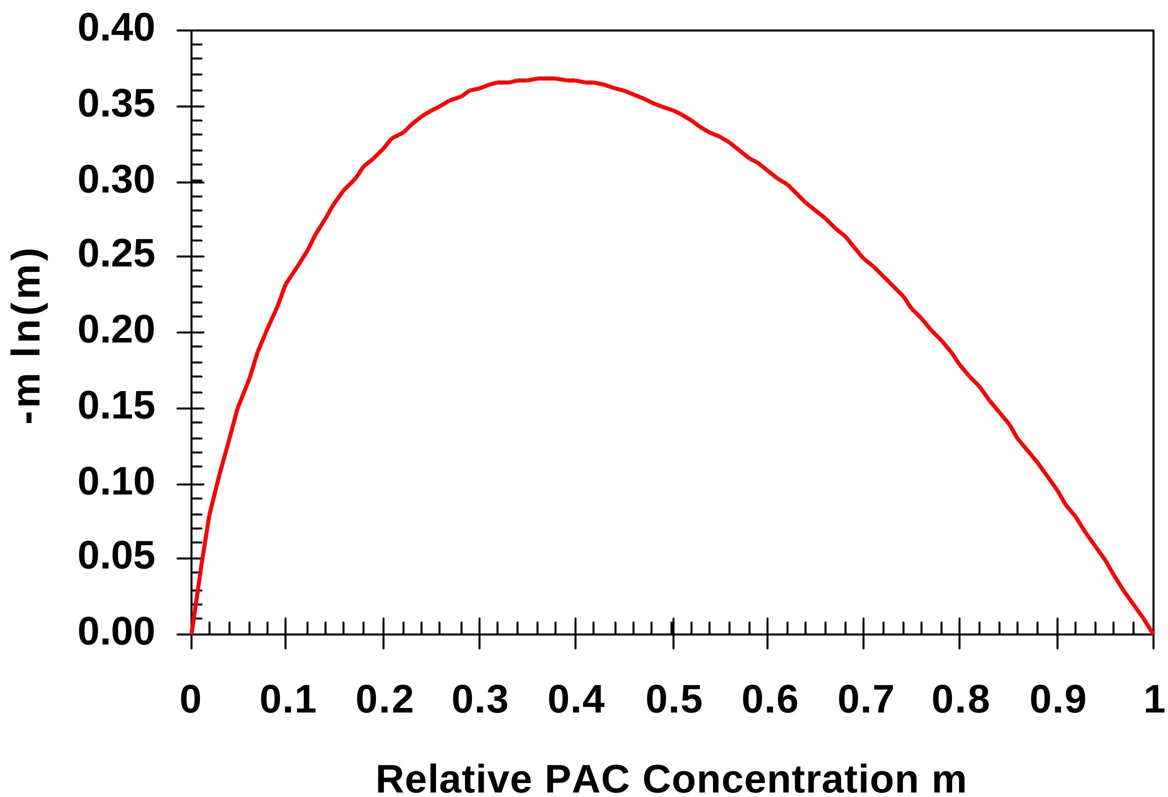

Figure 2. Plot reveals the existence of an optimum exposure, the value of *m* at which the latent image gradient is maximized. Note that *m* = 1 corresponds with unexposed resist, while *m* = 0 is completely exposed resist.