Impact of Resist on the Mask Error Enhancement Factor

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In previous editions of this column (*Winter, 1999, Fall 1999*) I described the importance of the Mask Error Enhancement Factor (MEEF) and provided a simple description of how the aerial image forms the basis for the non-linear imaging that results in MEEF values different from 1. As the feature size approaches the resolution limits of the imaging tool, the non-linear nature of aerial image formation results in non-unit MEEF values, even for a perfect, infinite contrast resist. But for a given aerial image response, the response of a real, finite contrast resist will change the value of the MEEF, sometimes dramatically.

There are two basic areas where the properties of the resist affect the value of the mask error enhancement factor: resist contrast (how dissolution rate varies with exposure and/or degree of chemical amplification) and diffusion (in particular, diffusion of photoreaction products during a post exposure bake). Although it is difficult to systematically and controllably vary these two resist properties experimentally, simulation provides an effective tool for exploring their impact on MEEF theoretically. Consider a simple baseline process of 248nm exposure with a 0.6 NA, 0.5 partial coherence imaging tool using 500nm thick UV6 on AR2 bottom ARC on silicon. The contrast of the resist is controlled by essentially one simulation parameter, the dissolution selectivity parameter n of the Mack dissolution rate model [1]. High values of n correspond to high values of resist contrast. For this example, we'll use n = 5 for a low contrast resist, n = 10 for a mid contrast resist, and n = 25 for a high contrast resist.

The variation of MEEF with nominal mask feature size for these three virtual resists is shown in Figure 1 for a mask pattern of equal lines and spaces. For larger feature sizes, the MEEF is near 1.0 for all resists. However, as the feature sizes approach the resolution limit, the characteristic skyrocketing MEEF is observed. (In fact, this dramatic increase in MEEF for smaller features can be used as one definition of resolution: the smallest feature size that keeps the MEEF below some critical value, say 2.0.) As can be seen from the figure, the major impact of resist contrast is to determine at what feature size the MEEF begins its dramatic rise. Above k_1 (= feature size*NA/λ) values of about 0.6, MEEF values are near 1.0 or below, and resist contrast has little impact. Below this value, the MEEF rises rapidly. Resist contrast affects the steepness of this rise.

Obviously, resist contrast has a huge effect on the MEEF for features pushing the resolution limits. At a k_1 value of 0.5, the MEEF for the high contrast resist is 1.5, for the mid contrast resist it is

2.0, and for the low contrast resist the MEEF has grown to greater than 3.0! As is seen in so many ways, improvements in resist contrast can dramatically improve the ability to control high resolution linewidths on the wafer, in this case in the presence of mask errors.

The second way in which the photoresist affects MEEF is through diffusion. Diffusion during PEB spreads out the latent image, reducing the gradient of photoproducts between the nominally exposed and unexposed parts of the resist. This reduced gradient makes the images more sensitive to errors that also affect the shape of the latent image, such as mask errors. Figure 2 show the effect of adding an extra 30 nm to the diffusion length of the photoacid of the baseline UV6 simulation process. Like lower resist contrast, increased diffusion essentially steepens the increase in MEEF at the resolution limit of the process.

Although it may be stating the obvious, characterization of MEEF near the resolution limit (which is where MEEF gets interesting) is resist dependent. Although the aerial image provides the basic non-linear behavior that gives rise to rising MEEF at small feature sizes, the finite contrast and non-zero diffusion of the resist adds to this non-linearity, accelerating the deleterious increase in sensitivity to mask errors.

References

1. C. A. Mack, Inside PROLITH, FINLE Technologies (1997: Austin, Texas).

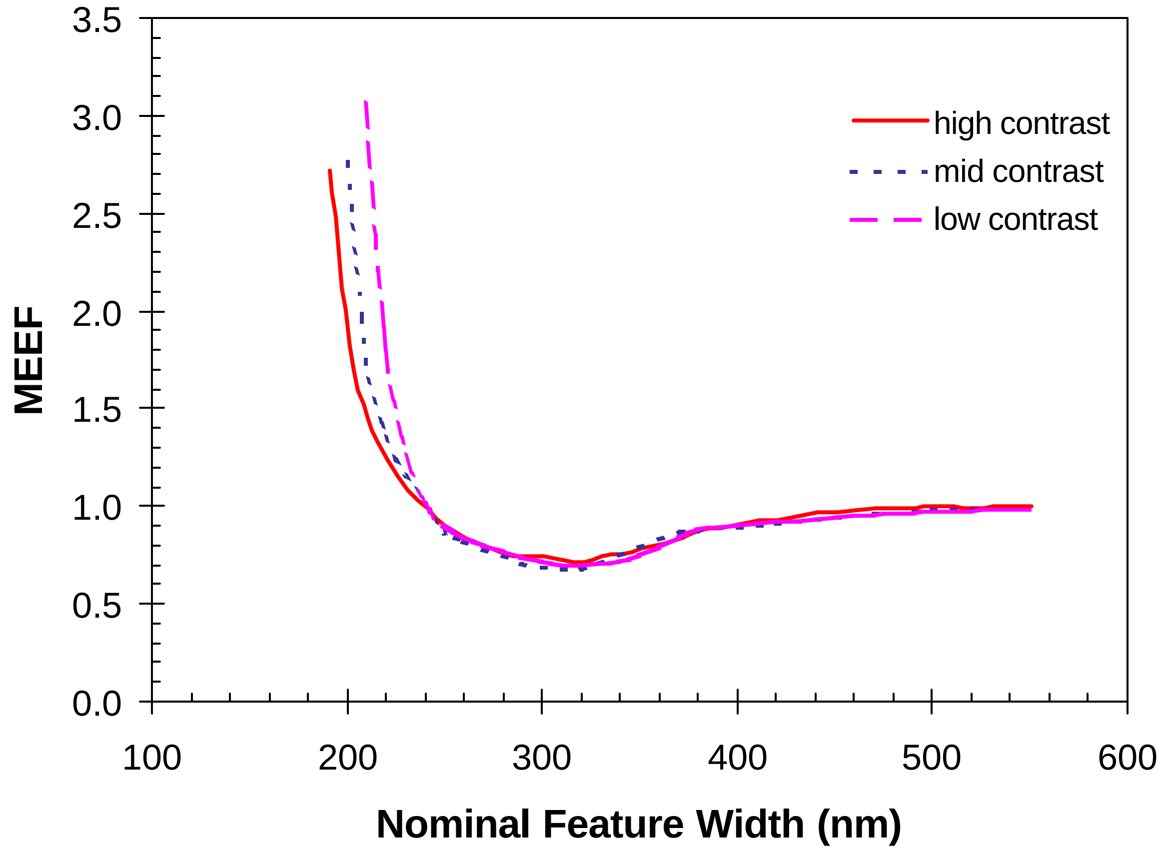

Figure 1. Resist contrast affects the mask error enhancement factor (MEEF) dramatically near the resolution limit.

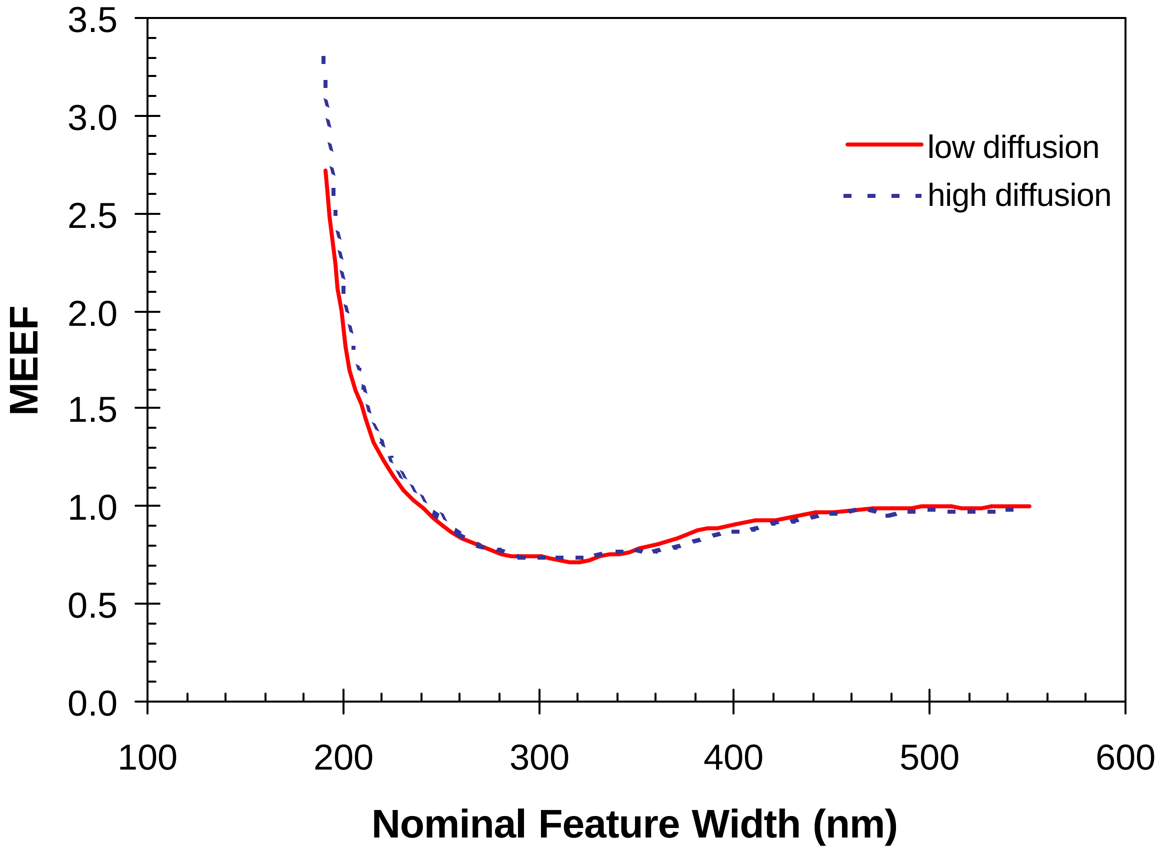

Figure 2.   Increased resist diffusion has the same effect on MEEF as lower resist contrast.