Optical Proximity Effects, part 3

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In the last two editions of the *Lithography Expert*, we examined optical proximity effects: the ability to print a given feature is influenced by the proximity of other nearby features. As a simple example, the width of a small isolated photoresist line will, in general, be different than the width of a line in an array of equal lines and spaces, even if the mask widths are the same. This "error" in linewidth means that it is not possible to print both dense and isolated lines at the same time such that both features match the mask width. Of course, there are an infinite number of possible combinations of features in proximity with other features - the isolated to dense bias is just one representative example.

As we saw in the previous two *Lithography Expert* columns, the root cause of these proximity effects is the aerial image. The nature of the imaging process means that the aerial image of a feature is dependent on its surroundings. While this statement is certainly true, it is not correct to say that the photoresist does not play a role in determining the magnitude of the proximity effect. Although a difference in the aerial image is the cause, the response of the photoresist to this error will determine the ultimate difference in printed linewidths.

How does the photoresist influence proximity effects? There are many possibilities, but a systematic study using lithography simulation showed that the only resist property that significantly influences proximity effects is resist contrast [1]. In simulation terminology, it is the resist dissolution selectivity parameter *n* of the Mack development model [2] (which is directly proportional to resist contrast [3]) that influences proximity effects. To see an example of how an optical proximity effect might change with resist contrast, Figure 1 shows the influence of the next nearest feature on the linewidth of a nominal 0.4 μm feature. No proximity effects would result in the flat line shown at 0.4 μm linewidth. Five curves are shown corresponding to five different resist contrasts (subjectively called low, medium, high, state-of-the-art and future contrast resists). These resist correspond to dissolution selectivity parameters of 4, 5.5, 7, 10, and 16, respectively. The infinite contrast resist corresponds to the width of the aerial image itself since an infinite contrast resist will reproduce the aerial image exactly.

Obviously, resist contrast plays an important role in determining the actual printed proximity effect. For example, the iso-dense bias (the difference in linewidth between isolated and dense features) for the state-of-the-art resist is twice that of the low contrast resist for the case shown in Figure 1. Also, the lower contrast resists show a dip in linewidth as the spacewidth is initially increased. Incidentally, the range of printed linewidths often exceeds the iso-dense bias quite significantly, as Figure 1 clearly shows.

The significant impact of resist contrast on proximity effects poses a serious problem for optical proximity correction (OPC) -- the modification of feature sizes on the mask to obtain the proper feature sizes on the wafer. The implementation of an OPC scheme requires a knowledge of how changes in the mask size affect the final resist size. But, as Figure 1 clearly shows, this relationship will depend on the resist contrast. Which resist should be used when designing on OPC algorithm or rule table? How will future changes in the resist affect the OPC rules?

Figure 2 shows some example OPC design curves (the amount the mask must be changed to get the nominal linewidth printed in resist). Each graph shows the mask bias as a function of feature size for a given ratio of linewidth to spacewidth. The four graphs show equal lines and spaces up to isolated lines. Within each graph are the resulting design curves for five different photoresists. Again, it is quite apparent that the design curves used to modify a mask vary greatly with photoresist contrast. As a result, any effort at OPC would result in a mask set design to work with a specific photoresist (or at least a specific class of photoresists with similar contrast). If a fab were using a state-of-the-art resist, a mask set with no OPC could very well give better results than a mask set with OPC designed for a medium contrast resist. It is also important to note that a mask set with OPC designed using an infinite contrast resist (i.e., designed using aerial image simulations only) may also give poor results when used with a real photoresist.

As much as we may not want to admit it, proximity effects, and thus OPC, cannot be characterized outside of the context of a specific photoresist process. And since the optical properties of the stepper also impact the proximity effects, the conclusion is inescapable: OPC requires a complete lithography system approach to be effective.

References

1. Graham Arthur and Brian Martin, “Investigation of Photoresist-Specific Optical Proximity Effect,” *Micro- and Nano-Engineering ‘95*, Aix-en-Provence, France (Sep. 1995).

2. C. A. Mack, “Development of Positive Photoresist,” *Jour. Electrochemical Society,* Vol. 134, No. 1 (Jan. 1987) pp. 148-152.

3. C. A. Mack, “Lithographic Optimization Using Photoresist Contrast,” *KTI Microlithography Seminar, Proc.*, (1990) pp. 1-12, and *Microelectronics Manufacturing Technology*, Vol. 14, No. 1 (Jan. 1991) pp. 36-42.

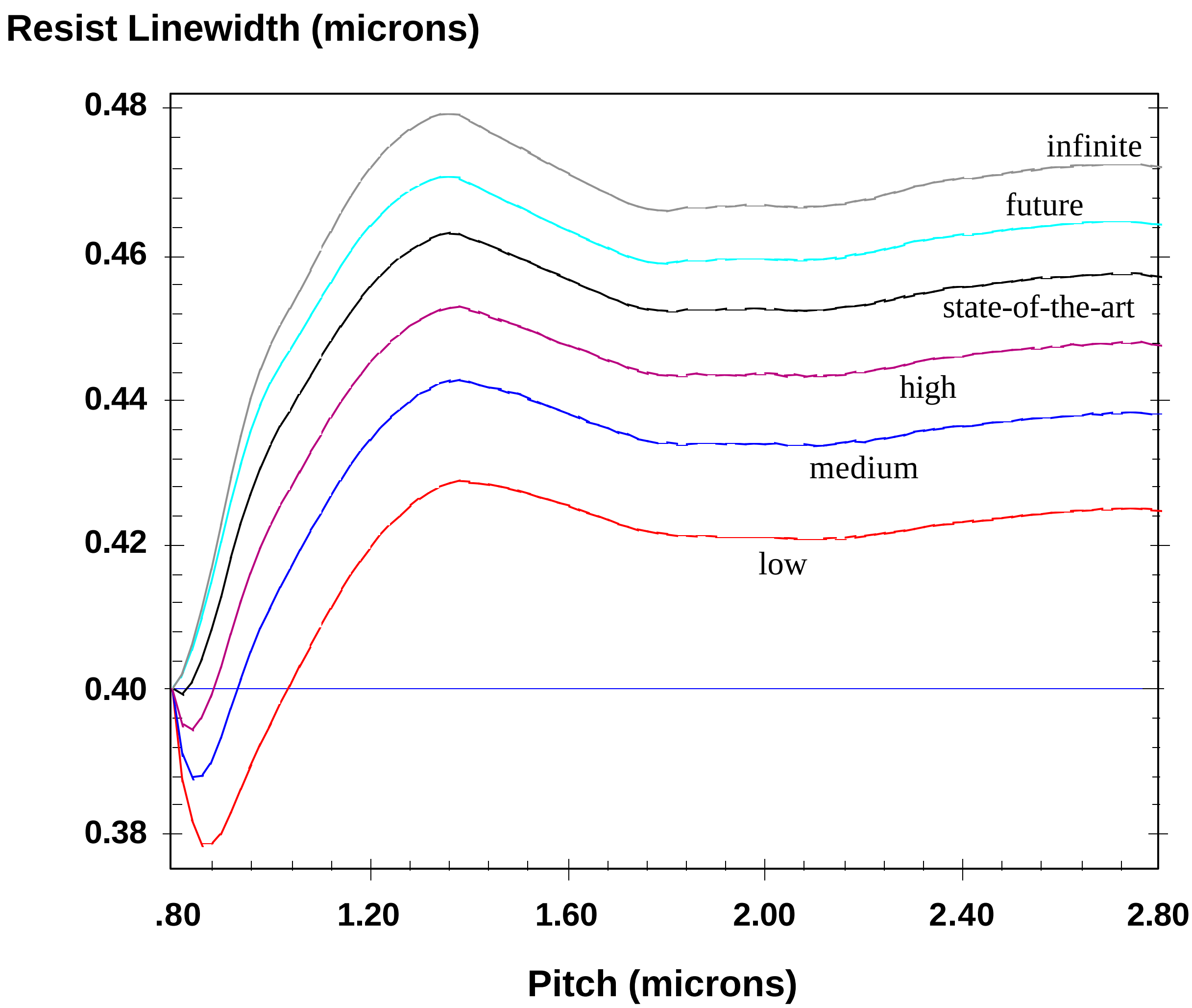

Figure 1. Proximity effects for different resist contrasts (0.4μm nominal features, NA = 0.52, σ = 0.5, i-line). The increasing pitch corresponds to the increasing distance between 0.4μm lines.

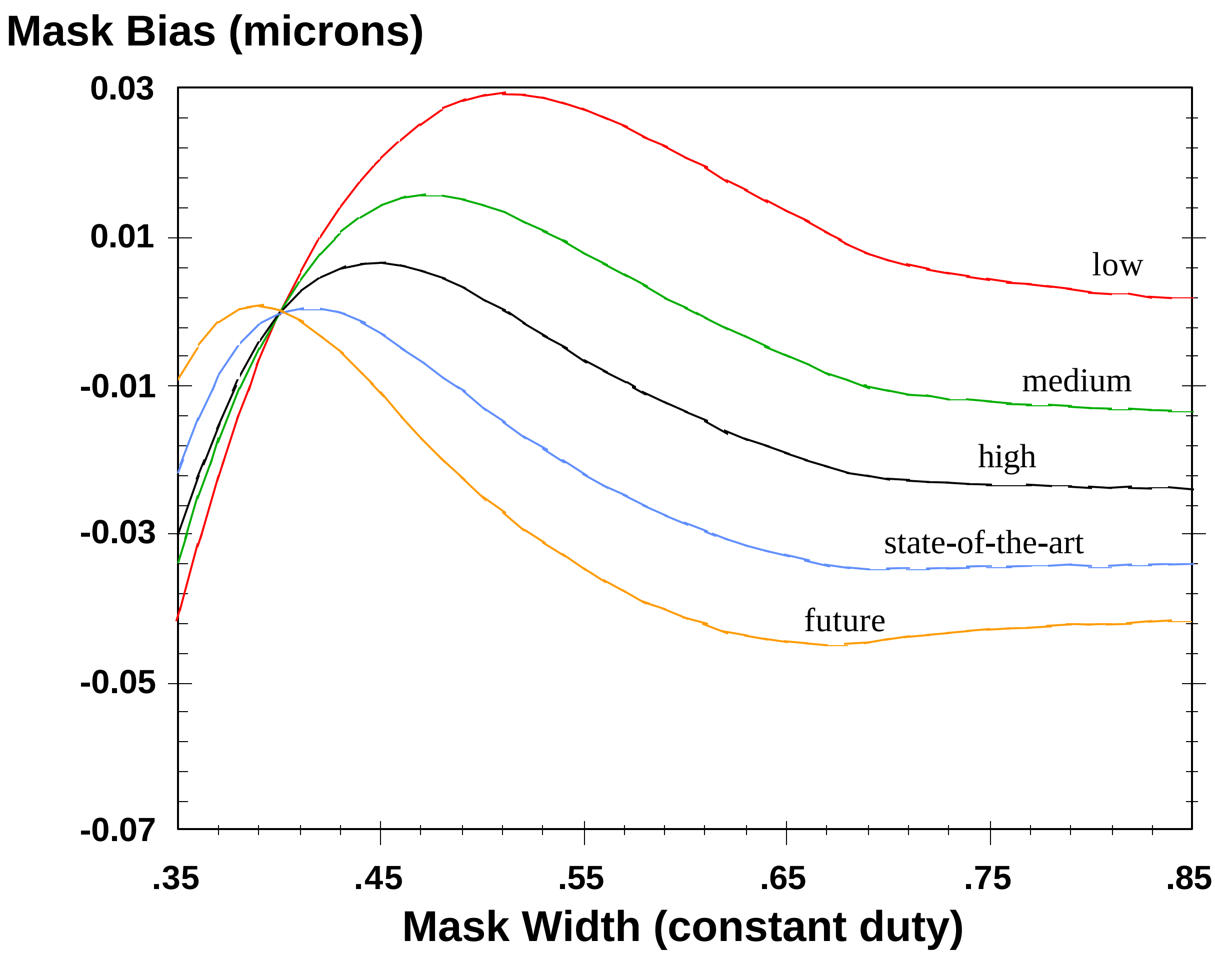

Figure 2a. Proximity correction design curves for equal lines and spaces as a function of resist contrast (NA = 0.52, σ = 0.5, i-line). Curves were constrained to have zero correction at the 0.4μm equal lines and spaces.

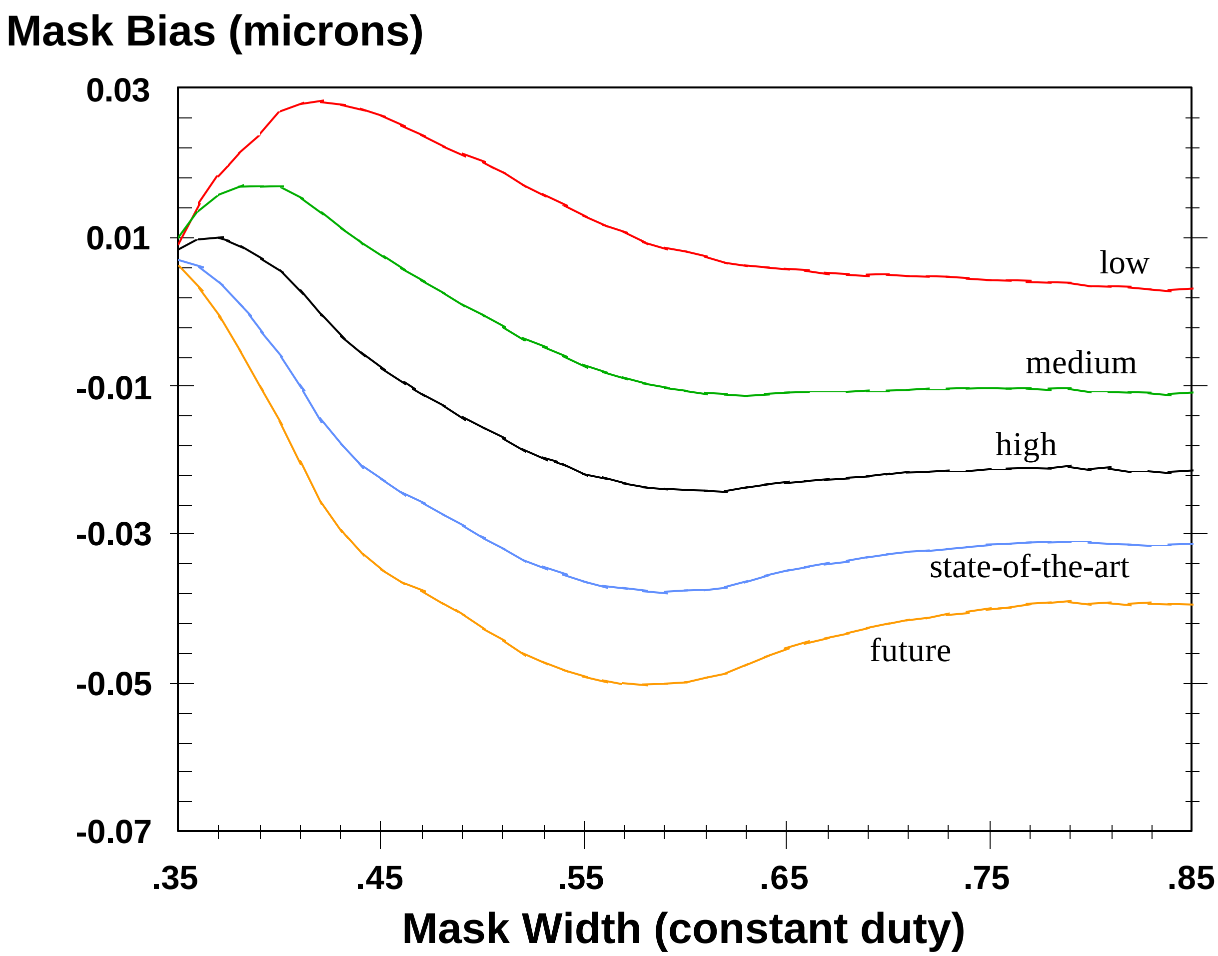

Figure 2b. Proximity correction design curves for spacewidth = 1.2*linewidth as a function of resist contrast (NA = 0.52, σ = 0.5, i-line). Curves were constrained to have zero correction at the 0.4μm equal lines and spaces.

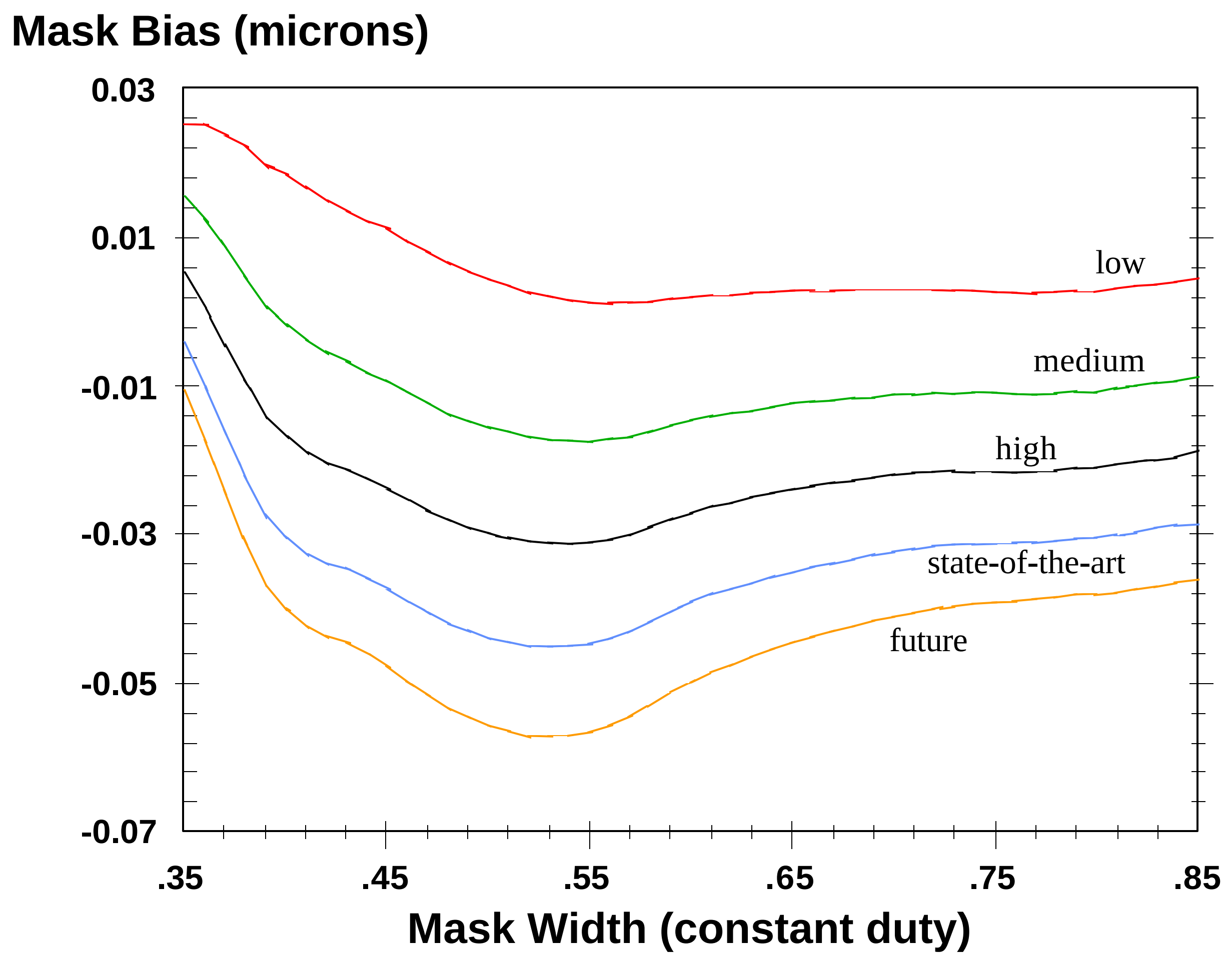

Figure 2c. Proximity correction design curves for spacewidth = 1.4*linewidth as a function of resist contrast (NA = 0.52, σ = 0.5, i-line). Curves were constrained to have zero correction at the 0.4μm equal lines and spaces.

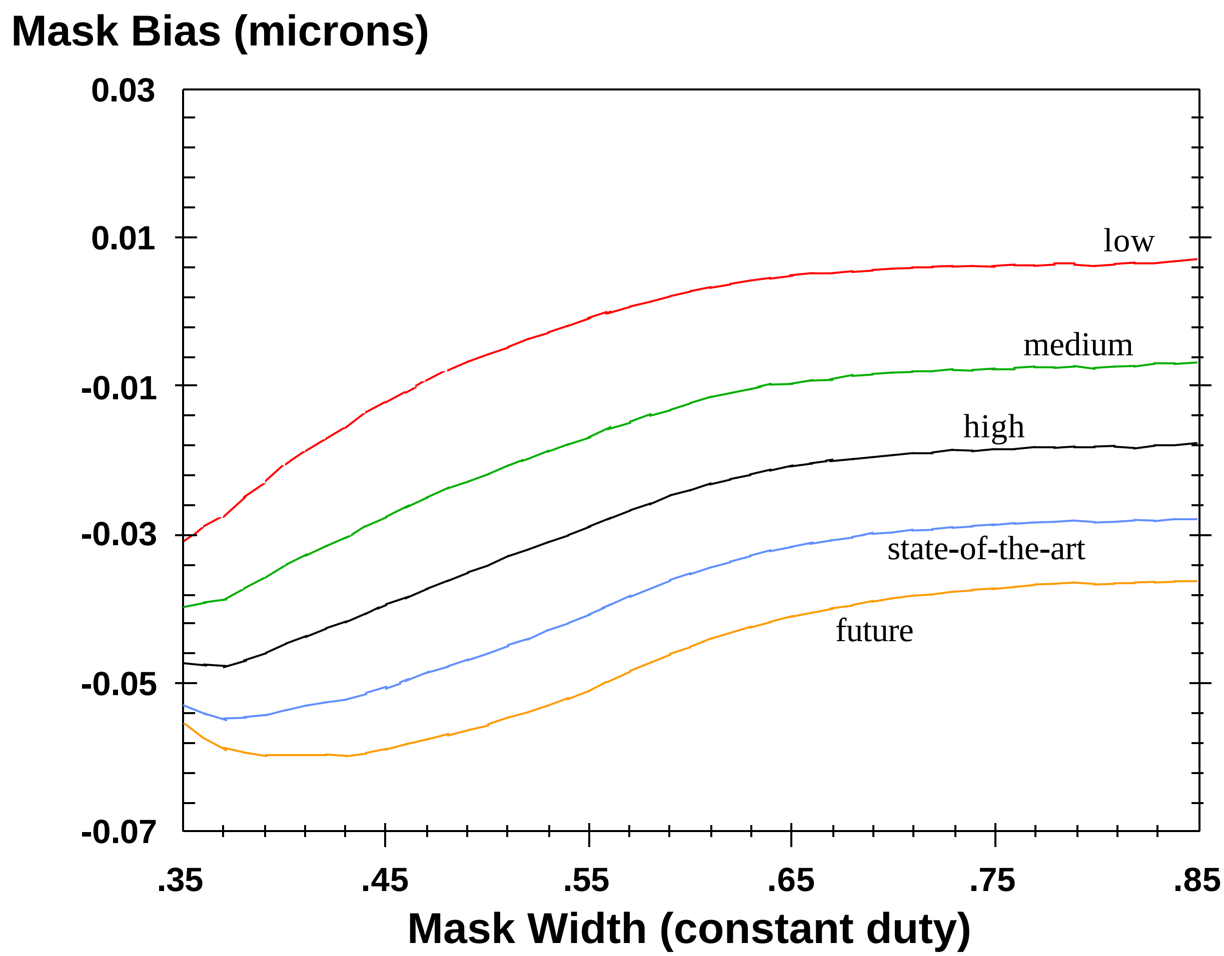

Figure 2d. Proximity correction design curves for isolated lines as a function of resist contrast (NA = 0.52, σ = 0.5, i-line). Curves were constrained to have zero correction at the 0.4μm equal lines and spaces.