Scattering Bars

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Resolution enhancement technologies refer to techniques that extend the usable resolution of an imaging system that don't involve decreasing the wavelength of light or increasing the numerical aperture of the imaging tool. The three most popular approaches are phase shifting masks, off-axis illumination, and optical proximity correction (see this column in *Microlithography World*, May 2003). In general, these three techniques do not work in isolation and the most aggressive mainstream lithography approaches use all three. In fact, off-axis illumination and phase shifting masks are essentially useless for typical chip manufacturing applications unless accompanied by optical proximity correction (OPC). While the most common and straightforward application of OPC is to simply move the absorber edges on the mask to better position the photoresist edges on the wafer (a task more easily said than done), an interesting and important additional technique is the use of scattering bars.

Scattering bars, also called sub-resolution assist features (SRAFs), are narrow lines or spaces placed adjacent to a primary feature in order to make a relatively isolated primary line behave lithographically more like a dense line. The problem being solved is generically describe as the problem of iso-dense bias. Isolated features will almost always print at a feature size significantly different than the same mask feature surrounded by other features. The "pitch curves" of printed critical dimension (CD) versus pitch for various nominal mask dimensions show the problem (see Figure 1 and this column from Autumn, 1996). While sizing the mask to give the correct CD on the wafer for all pitches certainly can work (this is the conventional OPC approach), there is another isolated versus dense difference that is not addressed by this bias OPC.

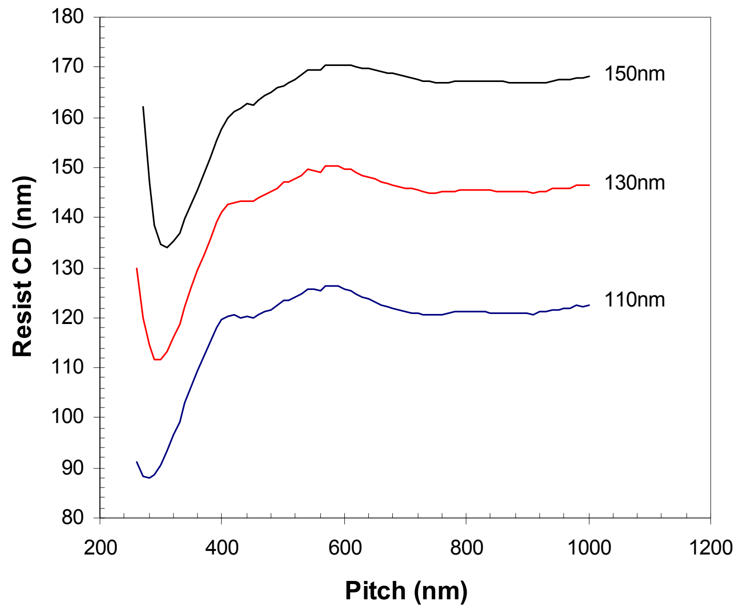
The response of an isolated feature to focus and exposure errors is significantly different than the same sized dense line. Figure 2 shows example focus-exposure matrices for dense and isolated lines after the isolated line has been sized to give the proper CD at the best focus and exposure needed by the dense features. The different shapes of the Bossung curves produce different shapes for the process windows, which limits the overlapping depth of focus even when the features nominally have the same best exposure dose.

Scattering bars are designed to reduce the difference in the focus response of an isolated feature compared to a dense feature by making the isolated feature seem more "dense". This becomes especially important when on off-axis illumination scheme is optimized for greatest depth of focus (DOF) of the dense features. The impact of quadrupole illumination, for example, on isolated features is to reduce an already small DOF by increasing the isofocal bias (as evidenced by the uniform curvature of the isolated line Bossung curves in Figure 2a). The overlapping process window for the dense and isolated lines of Figure 2 are shown in Figure 3a. The curvature of the isolated process window severely limits the useable, overlapping DOF.

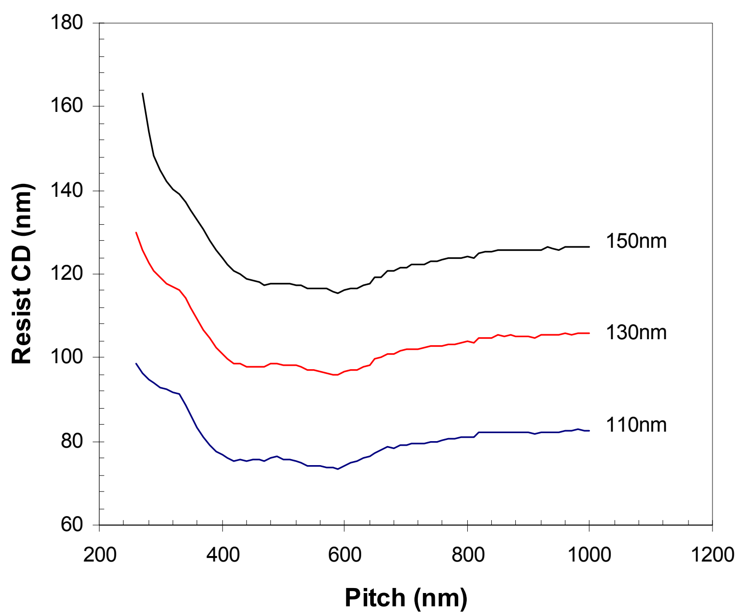
An SRAF, as the name implies, is a sub-resolution feature that is not meant to print. In fact, it must be carefully adjusted in size so that it never prints over the needed process window. This determines the most important trade-off in scattering bar design: make the assist features as large as possible in order to create a more dense-like mask pattern, but not so large as to print. Generally, these assist features are centered on the same pitch for which the off-axis illumination was optimized. As a result, the use of assist features allows the lithographer to design an off-axis illumination process optimized for dense patterns that can also be used to print more isolated features.

The assist bars used in Figure 3b were 50nm in size (wafer dimensions), and resulted in an increase in the overlapping DOF from 0.3µm, when only bias OPC was used, to 0.4µm. Further improvement can be obtained by using "double" scattering bars, where a second set of scattering bars are placed further away to create an effective five bar pattern. Of course, this requires enough free space around the primary feature to actually be able to fit these extra assist features.

While the concept of using scattering bars to improve the DOF of isolated features is a simple one, its practical implementation is anything but simple. Unlike the idealized case of an isolated line, real patterns contain lines with a variety of pitches (i.e., nearby patterns), each of which must be outfitted with an optimum assist feature, if one can fit. Bias OPC must be used on the intermediate cases where the space between two lines is not large enough to accommodate an assist feature. And then, of course, there is the problem of what to do with line ends and corners. These issues can be resolved, however, and sub-resolution assist features are becoming commonly used in many chip designs. Polysilicon gate and contact levels, in particular, have seen benefits from using SRAFs.

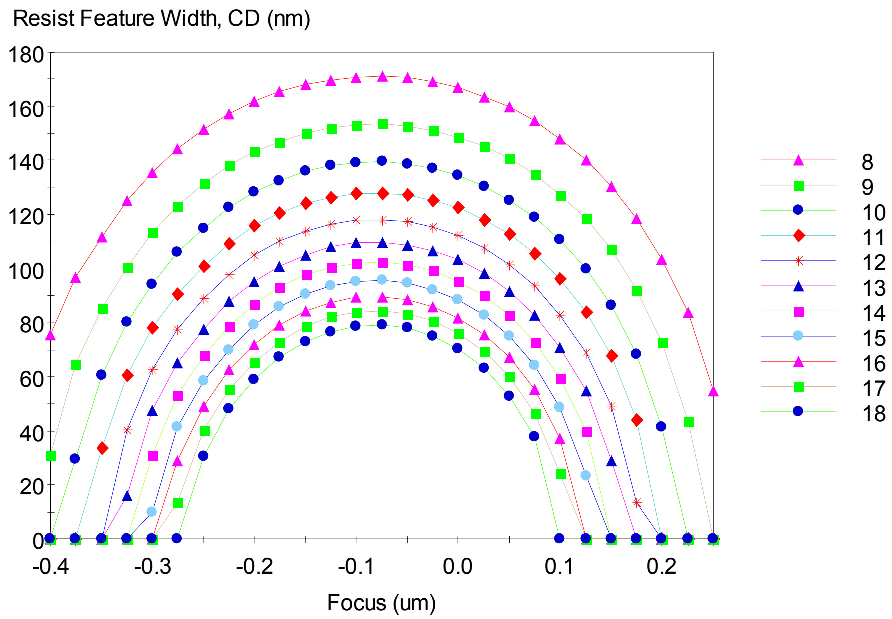


(a)

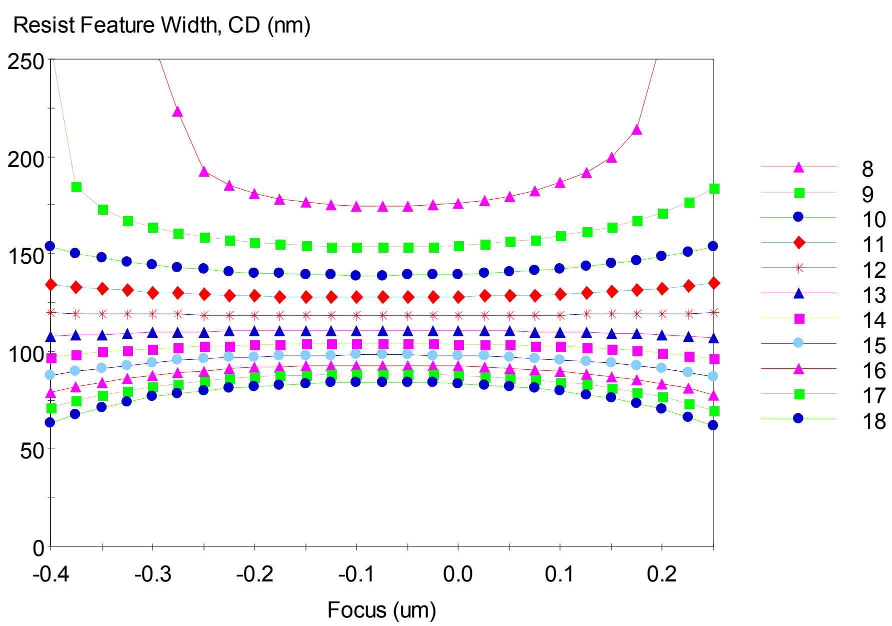


(b)

Figure 1. CD pitch curves (nominal mask CDs of 110nm, 130nm, and 150nm, NA = 0.85, λ = 248nm) with a) conventional illumination, σ = 0.5, and b) annular illumination with σ = 0.533/0.8.

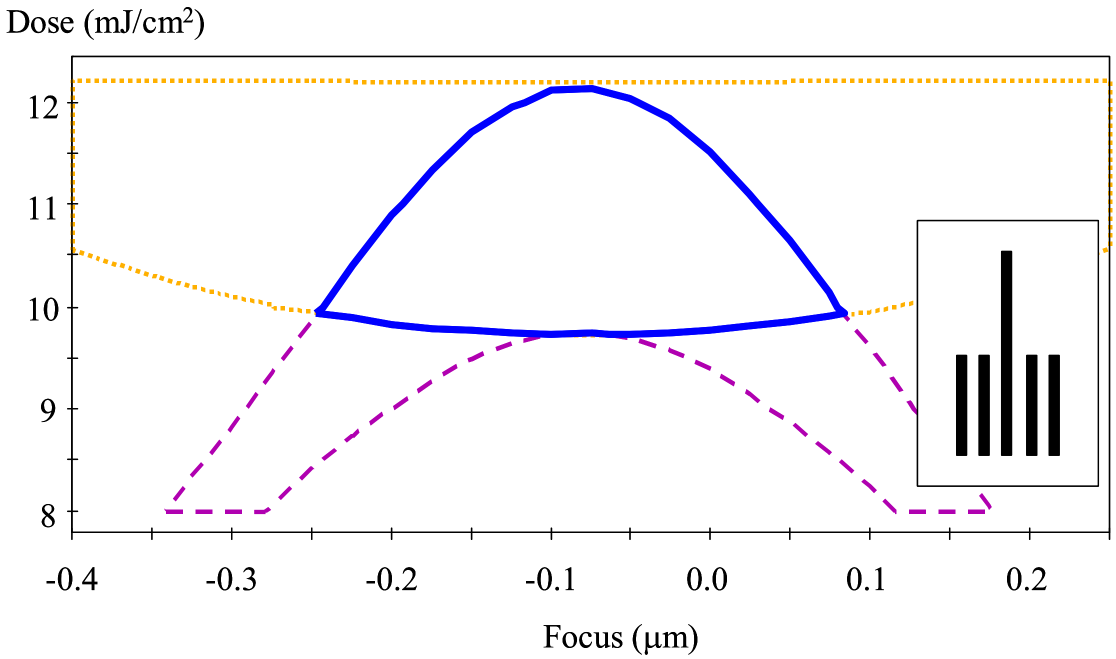


(a)

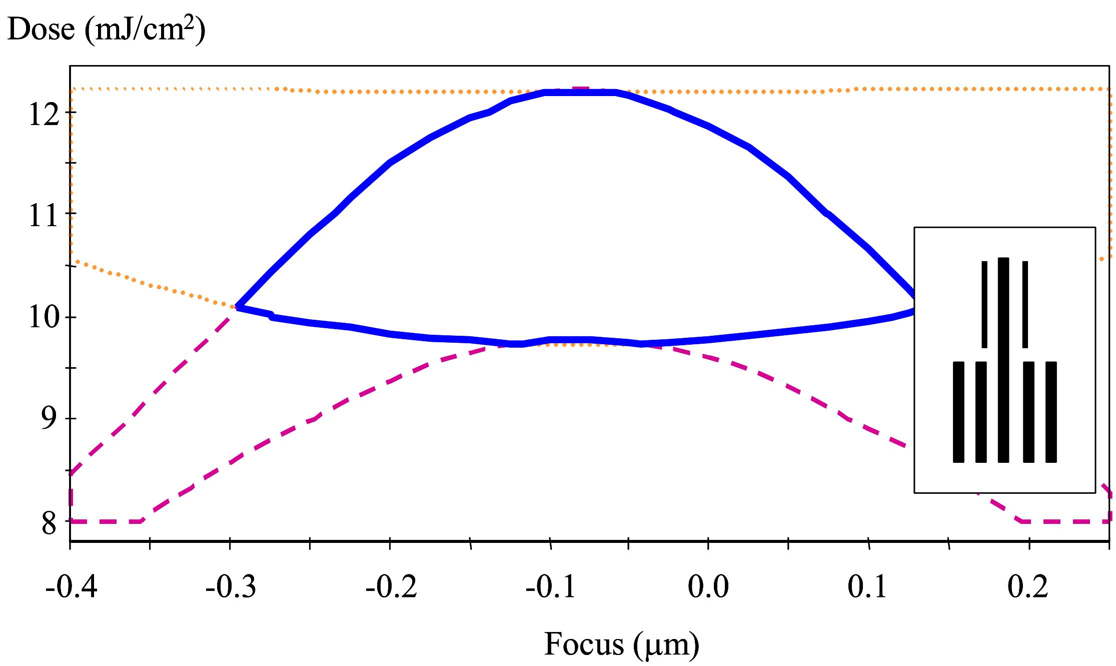


(b)

Figure 2. Focus-exposure matrices (Bossung curves) for a) isolated and b) dense 130nm features (isolated lines biased to give the proper linewidth at the best focus and exposure of the dense lines, λ = 248nm, NA = 0.85, quadrupole illumination optimized for a 260nm pitch).



(a)



(b)

Figure 3. Overlapping process windows generated from the focus-exposure matrices of dense and isolated lines for a) isolated lines with bias OPC (overlapping DOF = 0.3μm) and b) isolated lines with scattering bars (overlapping DOF = 0.4μm)