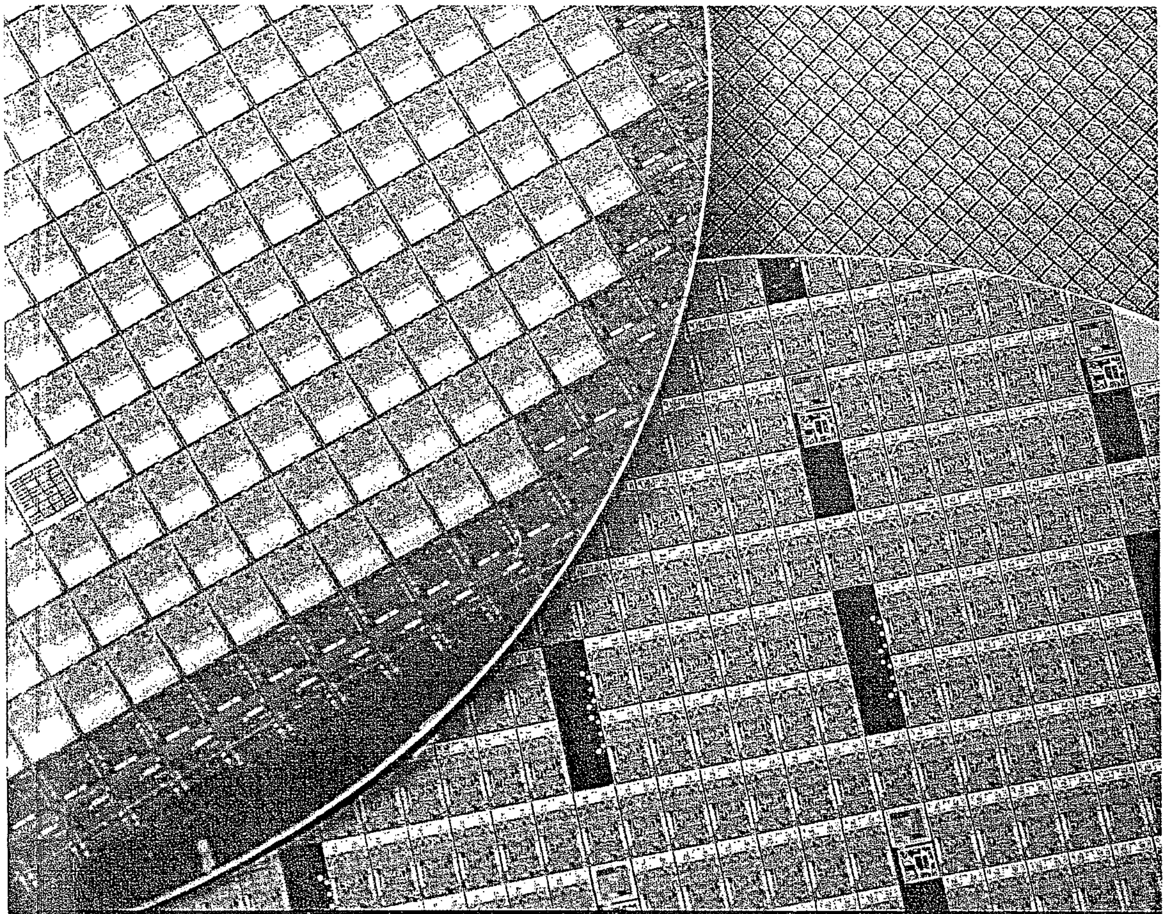
EXHIBIT B



Fundamental Principles of Optical Lithography

THE SCIENCE OF MICROFABRICATION

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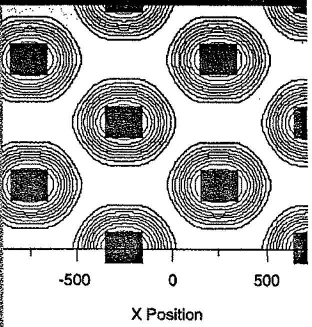
WILEY



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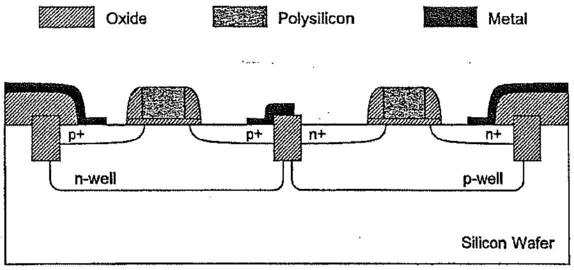


Figure 1.5 *Cross section of a pair of CMOS transistors showing most of the layers through metal 1*

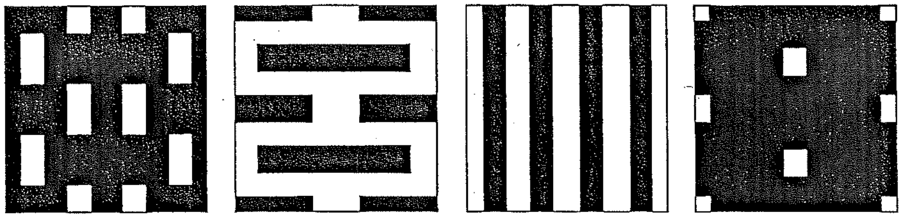

(a) Storage (b) Isolation (c) Wordline (d) Bitline Contact

Figure 1.6 *Critical mask level patterns for a 1-Gb DRAM chip*[2]*. Each pattern repeats in both* x *and* y *many times to create the DRAM array*

circuit and the final metal layer will provide connections to the external pins of the device package.

Many lithographic levels are required to fabricate an IC, but about 1/3 of these levels are considered 'critical', meaning that those levels have challenging lithographic requirements. Which levels are critical depends on the process technology (CMOS logic, DRAM, BiCMOS, etc.). The most common critical levels of a CMOS process are active area, shallow trench isolation (STI), polysilicon gate, contact (between metal 1 and poly) and via (between metal layers), and metal 1 (the first or bottom most metal layer). For a large logic chip with 10 layers of metal, the first three will be '1×', meaning the dimensions are at or nearly at the minimum metal 1 dimensions. The next three metal layers will be '2×', with dimensions about twice as big as the 1× metal levels. The next few metal levels will be 4×, with the last few levels as large as 10×. For a DRAM device, some of the critical levels are known as storage, isolation, wordline and bitline contact (see Figure 1.6 for example design patterns for these four levels).

1.2 Moore's Law and the Semiconductor Industry

The impact of semiconductor ICs on modern life is hard to overstate. From computers to communication, entertainment to education, the growth of electronics technology, fueled

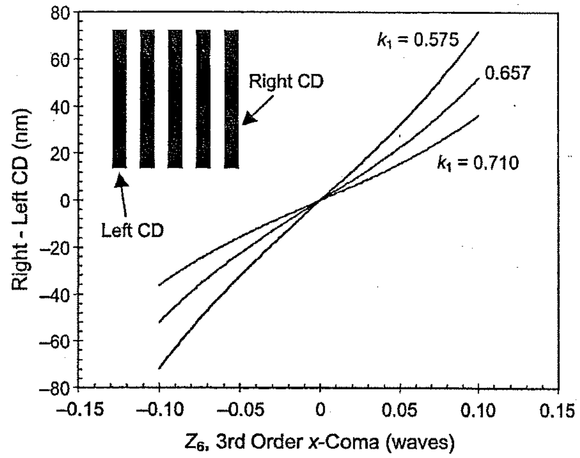


Figure 3.10 *The impact of coma on the difference in linewidth between the rightmost and leftmost lines of a five bar pattern (simulated for i-line,* NA *= 0.6, sigma = 0.5). Note that the y-oriented lines used here are most affected by x-coma. Feature sizes (350, 400 and 450 nm) are expressed as* k_1 *= linewidth* *NA/λ

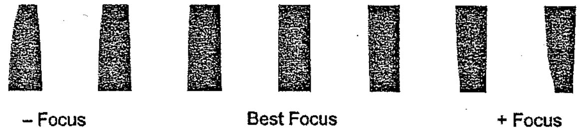


Figure 3.11 *Variation of the resist profile shape through focus in the presence of coma*

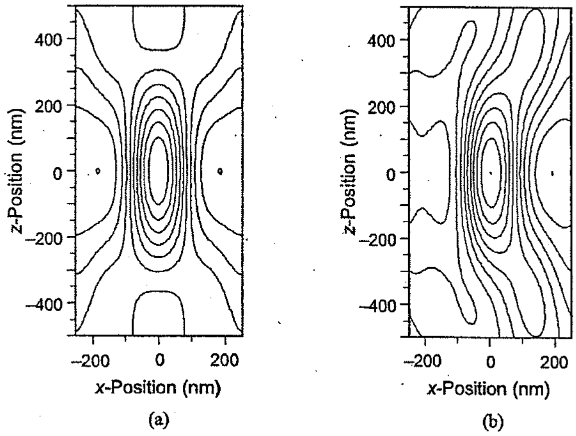


Figure 3.12 *Examples of isophotes (contours of constant intensity through focus and horizontal position) for (a) no aberrations, and (b) 100 mλ of 3rd order coma. (*NA *= 0.85, λ = 248 nm, σ = 0.5, 150-nm space on a 500-nm pitch)*

the end of the line and the edge of the nearby perpendicular line, or between two butting line ends. But this gap alone does not tell the whole story. Changes in the process (such as focus and exposure) will affect the gap width as well as the width of the isolated line.

An interesting approach to normalizing the relationship between linewidth and line-end shortening is to plot the gap width from a structure like that in Figure 8.38 as a function of the resist linewidth over a range of processing conditions. Based on the simple behavior of a pattern of lines and spaces where the resist linewidth plus the spacewidth will always be equal to the pitch, one can establish the ideal, linear imaging result for this case. For the pattern in Figure 8.38, the ideal result should be a straight line with equation *linewidth* + *gapwidth* = 500 nm, where the designed linewidth and gap width are both 250 nm. As an example, the data from a focus–exposure matrix are plotted in Figure 8.39 using this technique. Interestingly, all of the data essentially follow a straight line which is offset from the ideal, no line-end shortening result. The vertical offset between the ideal line and a parallel line going through the data can be considered the effective line-end shortening over the range of processing conditions considered. Although not perfect, this result shows that the variables of focus and exposure do not influence the effective LES to first order. The fact that the data form a line which is not exactly parallel to the ideal line simply indicates that, to second order, the LES does not exhibit the same process response to these variables as does the linewidth.

The gap width-versus-linewidth approach to characterizing the effective line-end shortening still ignores the three-dimensional nature of line-end effects. Processing changes, especially focus, can alter the shape as well as the size of a photoresist feature. For the

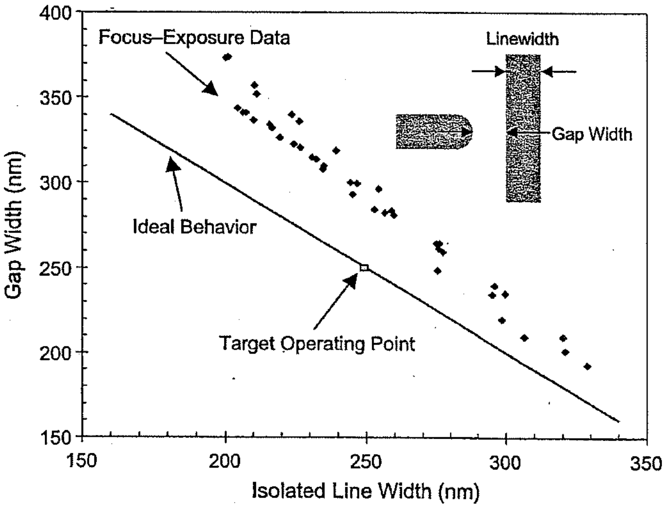


Figure 8.39 *Line-end shortening can be characterized by plotting the gap width of a structure like that in the insert as a function of the isolated linewidth under a variety of conditions. As shown here, changes in focus and exposure produce a linear gap width versus linewidth behavior*

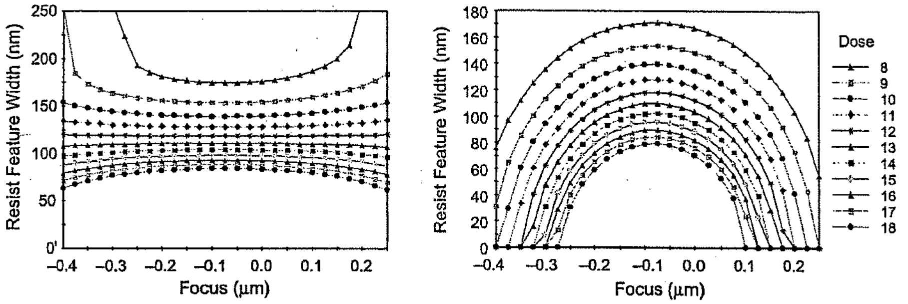
linear resolution (the smallest features that can be printed while still printing all larger features acceptably), it does not address the issue of process window, and thus the true manufacturable resolution. One important technique used with OPC that addresses process window as well as sizing issues is the *subresolution assist feature*, as described next.

10.2.4 Subresolution Assist Features (SRAFs)

Scattering bars, also called subresolution 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.[4] The problem being solved is generically described 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 CD versus pitch for various nominal mask dimensions show the problem (see Figure 10.7). While sizing the mask to give the correct CD on the wafer for all pitches certainly works (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 10.14 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 an off-axis illumination scheme is optimized for greatest depth of focus of the dense features (a topic that will be discussed extensively in section 10.3). The overlapping process window for the dense and isolated lines of Figure 10.14 is shown in Figure 10.15a. The curvature of the isolated process window severely limits the useable, overlapping DOF.



(a) (b)

Figure 10.14 *Focus–exposure matrices (Bossung curves) for (a) dense and (b) isolated 130-nm features (isolated lines biased to give the proper linewidth at the best focus and exposure of the dense lines,* $\lambda = 248\,\text{nm}$, *NA = 0.85, quadrupole illumination optimized for a 260-nm pitch)*