Simple Method for Rim Shifter Design: The Biased Self-Aligned Rim Shifter

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Abstract

A new, simple approach is given for the design of phase shifting masks using self-aligned rim shifters. First, a series of *design curves* are generated, which show all the combinations of rim width and chrome width which print a certain feature for a given process. Second, based on performance criteria for the critical feature(s) on the mask, a rim width is chosen. Finally, the design curves are used with the desired rim width to generate a *bias rule* which determines the needed chrome mask bias as a function of feature size and type. The result is an easy-to-fabricate self-aligned rim shifter mask with nearly the same performance benefits of a complicated two-level sized rim shifter mask. This technique is called the *Biased Self-Aligned Rim Shifter*.

I. Introduction

Phase shifting masks have shown great potential for improving lithographic performance, including resolution and depth-of-focus. However, several issues have so far prevented widespread manufacturing application of phase shifting techniques. In particular, the fabrication of the mask (including inspection and repair) and the design of the phase structures present many problems which have not yet been adequately addressed. Obviously, one would like a phase-shifting mask technique which is easy to design and fabricate, and which gives significant performance advantages. Unfortunately, these three criterion are usually conflicting. The best performance is obtained with complicated and difficult to fabricate designs, whereas simple designs give less than optimum performance.

The simple rim shifter technique is a good example of a method which is relatively easy to design and fabricate, but only gives modest performance improvements in general. First introduced by Nitayama et al. of Toshiba [1], a chrome structure is completely surrounded by a "rim" of 180° phase shifter of constant width. The simplicity of the structure enables the mask to be fabricated in a "self-aligned" process, i.e., only one lithography step is required when patterning the mask. Many possible fabrication techniques have been proposed [1,2] for such a self-aligned structure. Due to its simplicity, rim shifters were one of the first techniques to be used in the fabrication of actual devices, such as a 64Mb DRAM [3].

There are some problems associated with the simple self-aligned rim shifter. First, small dense features (such as equal lines and spaces near 0.5λ/NA in size) show only small improvement using a rim shifter. Second, isolated features show poor mask linearity when a constant rim width is used [4]. Further, optimum performance for the rim shifter requires different rim widths for different feature sizes and types [5]. Of course, sizing the rim width differently for different features requires a two write-level mask making process, removing the primary advantage of the self-aligned rim shifter.

In this paper I will propose a new self-aligned rim shifter design technique which gives near optimum performance, near perfect mask linearity, and the simplicity of the self-aligned mask making process. This technique is called the *Biased Self-Aligned Rim Shifter*.

II. Design Curves

A fundamental design constraint for any single photolithographic step is that all of the features on the mask must be imaged at the same exposure dose. This requirement may seem so obvious as to be hardly worth mentioning, yet when designing phase-shifting mask (PSM) patterns it is easy to forget. If one designs a PSM structure to give an optimum 0.35 μm isolated line, and another to give an optimum 0.45 μm line/space array, chances are that they will not print properly at the same exposure energy. If these two features reside on the same mask, this fact constrains the design of the PSM structure.

A rim PSM has two variables which can be adjusted: the chrome width (or non-shifted glass width for a space) and the rim width. The constraint of one exposure dose essentially takes away one degree of freedom. The remaining degree of freedom can be used to optimize performance. The constraint does not fix the chrome width, or the rim width, but rather it fixes the combination of the two to produce an aerial image which will print the properly sized photoresist feature at the given exposure dose. Thus, there will be a range of chrome/rim width combinations which satisfy this constraint. A plot of chrome width versus rim width for these acceptable combinations produces a *Design Curve* for that feature and the given exposure dose.

Figure 1 shows an example of two design curves for a rim shifted 0.5 μm isolated line. Each curve shows all possible combinations of chrome width and rim width (in wafer dimensions) which print a 0.5 μm line in photoresist at the two stated exposure doses. For example, at 200mJ/cm^2 a rim width of 0.1 μm per side combined with a chrome width of 0.18 μm will give the proper linewidth. Although these design curves can be determined experimentally, an easier approach is to use simulation techniques. Figure 1 was generated with PROLITH/2 simulating a standard Shipley SPR500 resist process on silicon wafers using a 0.5 NA i-line stepper. For a given rim width, the chrome width was varied until the proper linewidth was obtained. Figure 2 shows other design curves for several different 0.35 μm features.

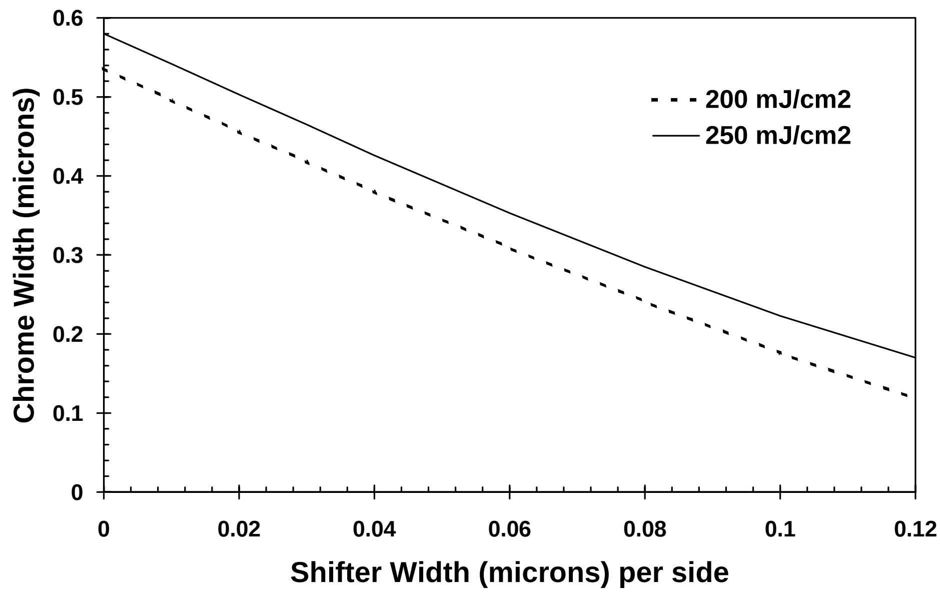

Figure 1: Design curves for a rim shifted 0.5 μm isolated line for the two listed exposure doses (i-line, NA = 0.5, σ = 0.4, SPR500 resist, bare Si wafer, simulated with PROLITH/2).

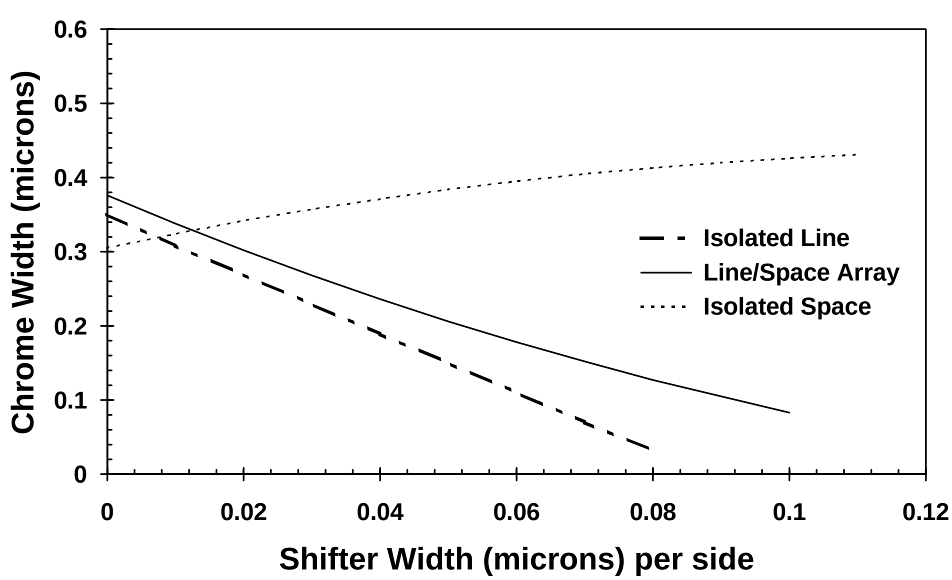

Figure 2: Design curves for rim shifted 0.35 μm features (i-line, NA = 0.5, σ = 0.4, SPR500 resist, bare Si wafer, 200 mJ/cm^2 exposure dose, simulated with PROLITH/2).

III. Optimizing the Design

The design curves in Figures 1 and 2 give the constraints on the design of a rim shifter, but do not give any clue as to the desirability of any given point on the curve. In order to optimize the performance of the rim shifter, one must evaluate points along the design curves using some metric or metrics for lithographic quality. The most realistic metric is the size of the focus-exposure process window. Experimentally determining numerous process windows can be difficult and expensive, so often intermediate metrics are used to indicate quality. For example, an aerial image can be judged by the slope of the logarithm of the image at the mask edge (the *log-slope*) [6]. The log-slope of an aerial image is directly proportional to the resulting exposure latitude of the resist features. The variation of this log-slope with focus is an indicator of how exposure latitude decreases with defocus and thus can be used to evaluate how imaging affects depth-of-focus.

Figures 3 - 5 show several log-slope defocus curves for different configurations of rim shifters. Figure 3 shows the effect on the log-slope defocus curve of adding a rim shifter to an isolated 0.35 μm line feature. The design curve from Figure 2 was used to give the required chrome width for each rim width and then aerial images were simulated using PROLITH/2 to generate the log-slope curves. Note that performance (higher log-slope) improves noticeably but not dramatically as the rim width increases. Figure 4 shows the results for an array of equal lines and spaces. As rim width increases, performance improves slightly until a rim width of 0.08 μm is used. After this point, larger rim widths give reduced performance. Finally, Figure 5 shows that an isolated space improves greatly as rim width increases. These figures clearly show what other workers have already stated: rim shifters are most effective for isolated structures, especially isolated spaces, and not very effective for small dense patterns. It is very important to note that the comparisons made here would not be possible without first generating the needed design curves. Beware of any comparisons of rim widths when the chrome or space width is held constant!

Although the log-slope is a good indicator of lithographic performance, including resist issues makes any simulation more realistic. The Lumped Parameter Model (LPM) is a simple model of resist exposure and development which allows focus-exposure process windows to be calculated on a Personal Computer in about a second [7]. Although the model is much simpler (and thus less accurate) than the primary parameter models used in simulators like PROLITH/2, its speed allows many different phase-shifting mask designs to be quickly compared and evaluated [8]. Figure 6 compares the process windows of 0.4 μm spaces with and without rim shifting. Over the indicated 0.8 μm focus range, the use of the rim shifter nearly doubles the available exposure latitude.

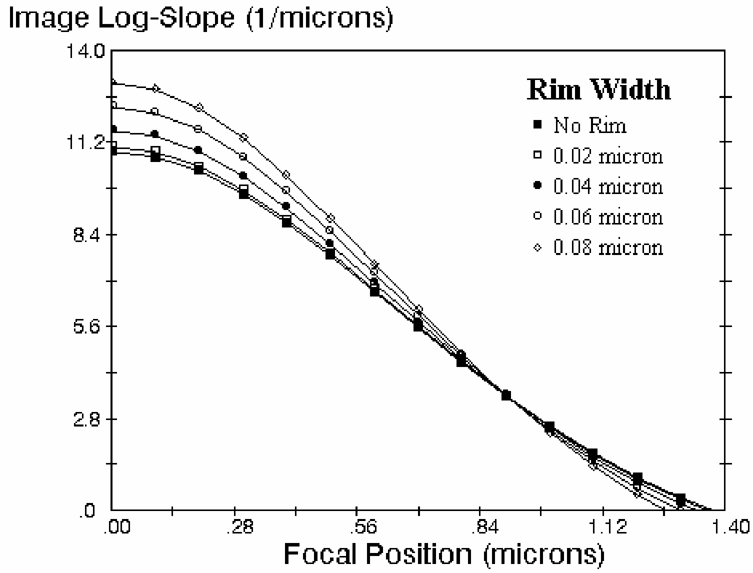

Figure 3. Log-slope defocus curves for a 0.35 μm isolated line for varying amounts of rim shifter width (i-line, NA = 0.5, σ = 0.4, using chrome width as determined from the design curves of Figure 2, simulated with PROLITH/2).

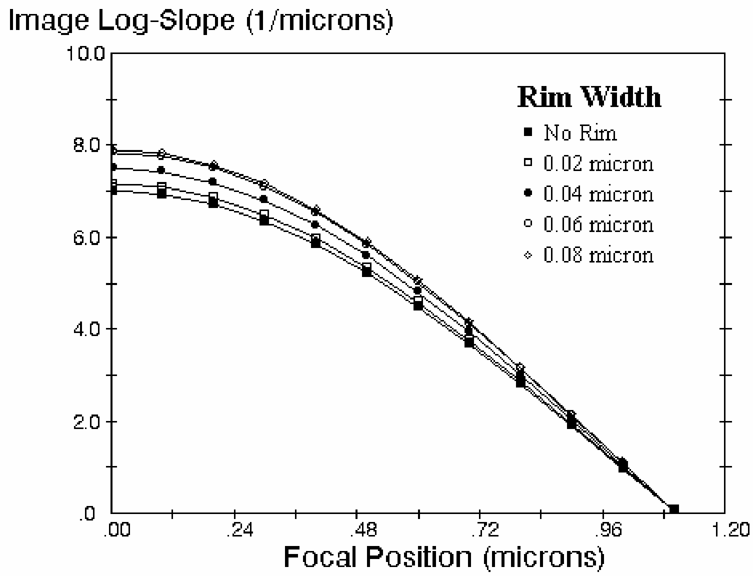

Figure 4. Log-slope defocus curves for a 0.35 μm line/space array for varying amounts of rim shifter width (i-line, NA = 0.5, σ = 0.4, using chrome width as determined from the design curves of Figure 2, simulated with PROLITH/2).

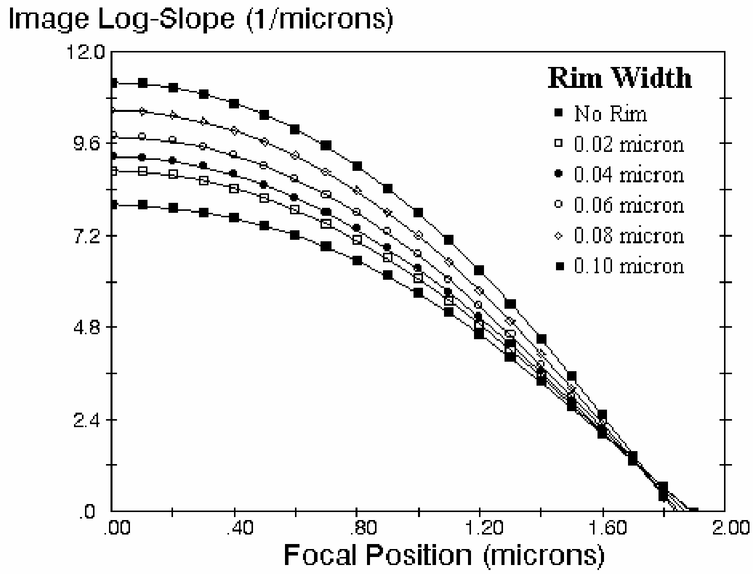

Figure 5. Log-slope defocus curves for a 0.35 μm isolated space for varying amounts of rim shifter width (i-line, NA = 0.5, σ = 0.4, using unshifted space widths as determined from the design curves of Figure 2, simulated with PROLITH/2).

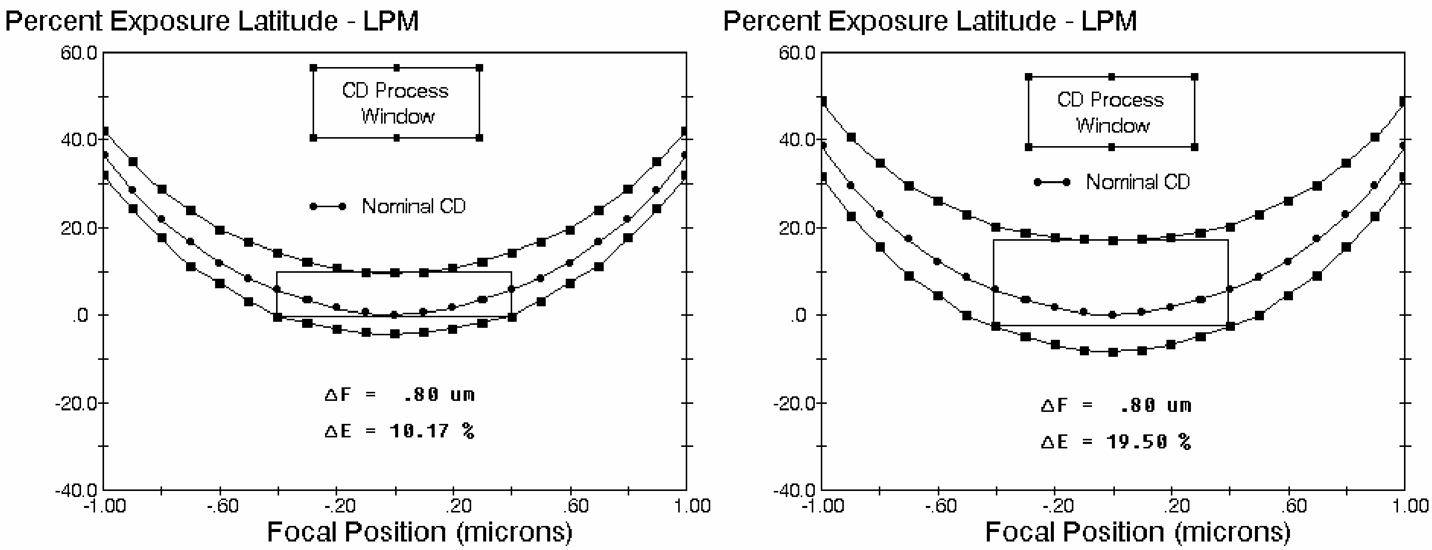

Figure 6. Comparison of process windows generated using the Lumped Parameter Model (LPM) for (a) no rim, and (b) a 0.1 μm rim for a nominal 0.4 μm isolated space (i-line, NA = 0.5, σ = 0.4, simulated with PROLITH/2)

IV. Completing the Design: Geometry-Dependent Bias

As discussed earlier, there is certainly a mask making advantage to using the same rim width for all features on the mask. If this design constraint is added, a self-aligned mask making process can be employed. Will this constraint significantly reduce the potential performance of rim shifters? Consider a mask which contains the three 0.35 μm features depicted in Figures 3-5. Optimum image quality is obtained when the isolated line has a rim width of 0.1 μm, the dense lines have a rim width of 0.08 μm and the isolated space has a rim width of greater than 0.1 μm. If all three features must reside on the same mask, a compromise rim width of 0.08 μm would give the greatest boost to the most difficult features, the dense lines, while giving close to the best performance to the other features. Thus, there is some sacrifice in imaging potential by picking this constant rim width, but the gain in mask making simplicity makes the compromise worth while in most applications.

Once a compromise rim width is chosen based on the critical features on a given mask level, the design curves are used to calculate the needed chrome widths for each feature. After including any mask making bias to these widths, the pattern layout necessary to produce the desired resist linewidths can be determined. The difference between the desired resist width and the required mask width is the overall mask bias needed for this biased self-aligned rim shifter design. The nature of the design approach virtually guarantees that isolated lines, dense lines and isolated spaces all require different amounts of bias, as will features of different sizes. The design approach given in this paper is thus a method of determining the required geometry-dependent biasing for a self-aligned rim shifting mask process.

Of course, determining the required geometry-dependent bias and implementing it are two very different things. An absolute necessity of the biased self-aligned rim shifter approach is the availability of an automated way of implementing a *geometry-dependent bias rule* (in the form of either an algorithm or a table). Such an automated software scheme is certainly within the capabilities of many of today's design and layout tools, but has not been widely accepted or used.

V. Conclusions

In this paper, a new, simple approach has been given for the design of self-aligned rim shifting masks. First, a series of *design curves* are generated, which show all the combinations of rim width and chrome width which properly print a certain feature for a given process. Second, based on performance criteria for the critical feature(s) on the mask, a rim width is chosen. Finally, the design curves are used with the desired rim width to generate a *bias rule* which determines the needed chrome mask bias as a function of feature size and type. The result is an easy-to-fabricate self-aligned rim shifter mask with nearly the same performance benefits of a complicated two-level sized rim shifter mask. This technique, called the *Biased Self-Aligned Rim Shifter*, is a practical approach to implementing a phase shifting mask technique without extensive mask redesign. One essential requirement, however, is the availability of an automated geometry-dependent biasing software tool as an add-on or an integral part of the mask layout tool.

References

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