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Resist Diffusion Model for Fast and Accurate sub-20nm Lithography Simulation

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Abstract—**Simulation of advanced photolithography requires accurate modeling of acid diffusion in photoresist. In particular at sub-20nm technology nodes resist diffusion can have a strong impact on the final printed patterns. We demonstrate good accuracy and excellent numerical efficiency of a simple diffusion model for resist modeling especially when applied to gridded designs, generally used at sub-20nm nodes. Unlike previous technology nodes where complex 2D layouts required the use of complex emprirical resist models, a simple mathematically concise diffusion model appears to work well with gridded designs. Calibration to SEM data shows that good accuracy is obtained with diffusion lengths ~15-20nm.**

Keywords: ***lithography simulation, DFM, resist diffusion, resist modeling***

I. INTRODUCTION

Accurate simulation of lithographic patterning relies on calibrated models capturing complex photochemical processes in the resist under UV exposure. Relevant physical effects include acid diffusion leading to resist blur and reduction of resolution. Conventional resist models use complex multi-parameter expressions designed to capture various line pitches and patterns [1]. However, at the limit of optical lithography with 193nm immersion scanners, severely restricted design styles are expected such as gridded designs and multiple patterning [2,3].

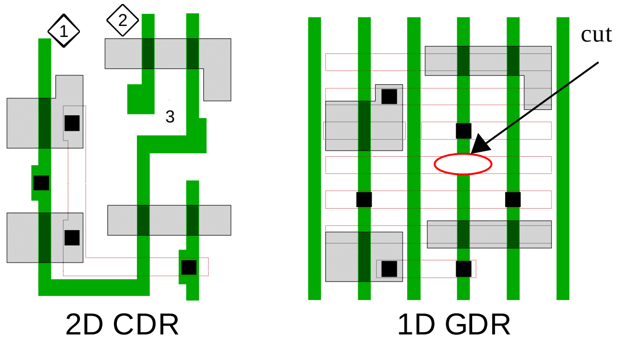
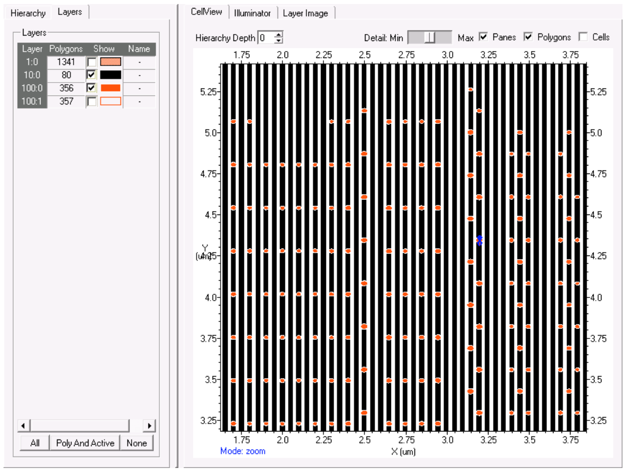


Figure 1. Conventional 2D design style 2D CDR (left, potential problem areas are highlighted) versus Gridded Design 1D GDR style (right, the critical layer consists of identical cut patterns such as the one shown)

For gridded designs (GDR – Gridded Design Rules) the critical layer consists of a large number of identical cut patterns, similar to the contact/via layer. The geometric complexity of conventional 2D design styles, which necessitated complex empirical resist models, is no longer present in GDR.

We found that in case of GDR a more physical and at the same time mathematically concise diffusion model produces the best match to experimental data. As shown in a larger example layout Fig. 2, cut patterns in 1D-GDR designs are relatively sparse and repetitive. Diffusion effects are strongest in isolated island-type patterns, which is why a simple diffusion model appears to work well in this case. Our model shows excellent accuracy for 20nm, 18nm, 16nm designs demonstrated by comparisons of simulation to SEM images. At the same time our resist model requires little additional CPU time over a basic aerial image calculation in our simulator.



Layers

Layer	Polygons	Show	Name
1:0	1341	☐	-
10:0	80	☑	-
100:0	356	☑	-
100:1	357	☐	-

Hierarchy Depth 0
☑ Panes ☑ Polygons ☐ Cells

Figure 2. Example 1D-GDR design showing vertical lines and a large number of identical cuts. Relative sparsity of cut patterns eases modeling of resist diffusion due to similar environment of each cut.

II. RESIST DIFFUSION MODEL

Acid diffusion in photoresist introduces additional image blur on top of the intrinsic contrast limitations of the aerial image. To model this effect, a classical diffusion operator is

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applied to the calculated aerial image intensity distribution. The diffusion length is a function of acid chemistry and must be calibrated to measured data to reflect process specifics.

Two different sets of data were used to calibrate the diffusion model. RMS CD error versus diffusion length is shown in Fig. 3 for a general set of test patterns, and Fig. 4 for 20nm design rule 1D GDR cuts [4]. In both cases the optimal values of diffusion length are in the range 15-20nm. It is interesting to note that overall smaller CD error values are observed when calibrating to cut patterns than for general patterns. This indicates that our model is particularly well suited for 1D GDR cut patterns [2,3,4] due to their relatively repetitive nature and relative sparseness.

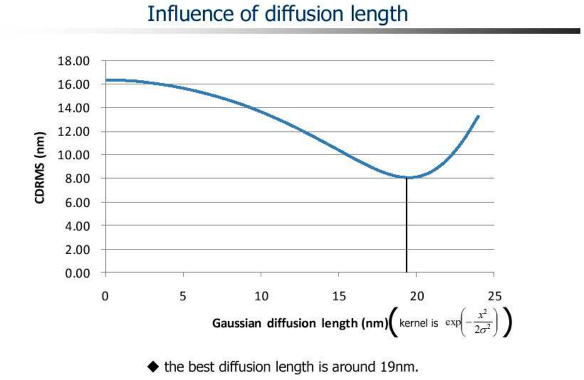


Figure 3. Calibration of diffusion length for the resist diffusion model using general patterns. A value around 15-20nm appears to best match experimental data, best fit is at ~19nm.

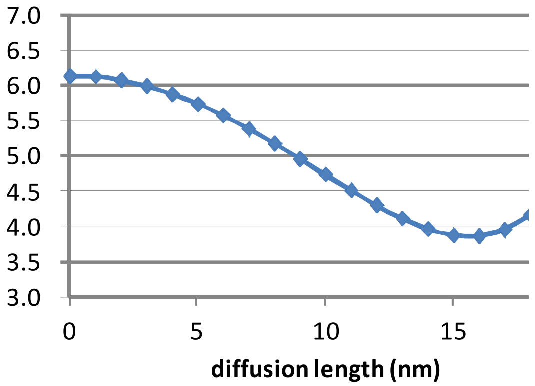


Figure 4. Calibration of diffusion length for the resist diffusion model using 1D-GDR patterns Best fit is at ~16nm, in comparison to general patterns smaller CD errors ar seen for all values of diffusion length.

III. APPLICATION TO 1D-GDR CUTS

In 1D-GDR designs are composed of regular periodic lines pattern and a number of identical cuts patterns. The number of cuts is in general large and their proximity varies, although the intent of 1D-GDR is to keep their density uniform and low. Examples are shown in Figs. 5, 6.

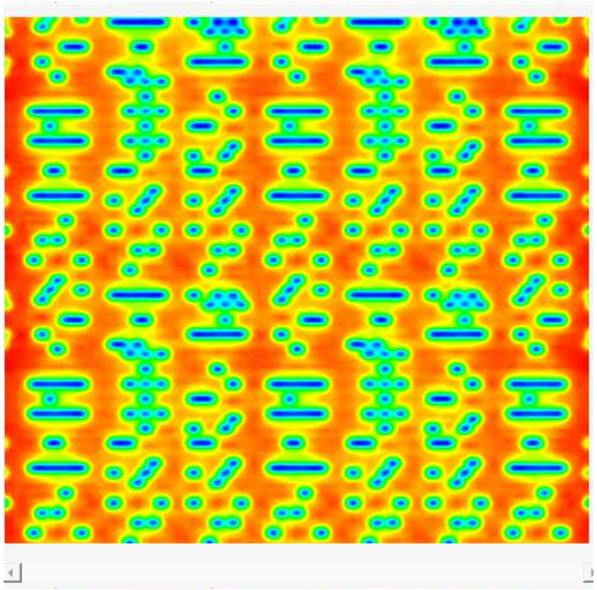


Figure 5. Aerial image of the cuts layer in a standard cell design at the 20nm node.

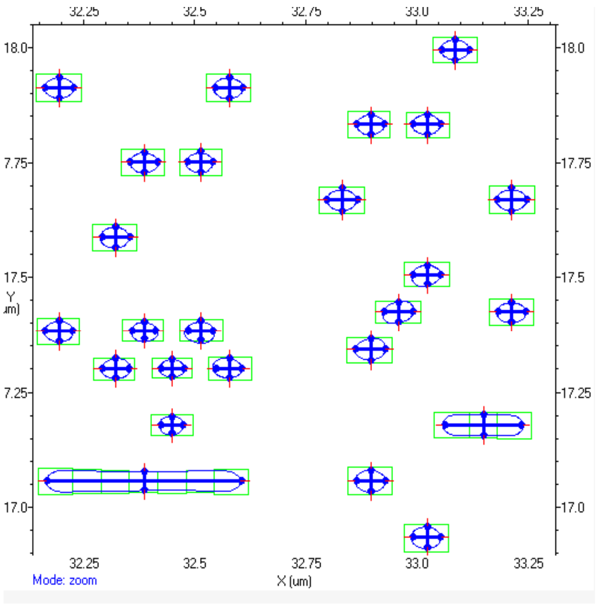


Figure 6. Cut patterns for a portion of the image shown in Fig. 3 using a resist diffusion length of 15nm.

IV. MODEL VALIDATION

The above diffusion resist model was implemented in our lithography simulation and OPC tool. Predictions of the tool were validated against experimental data at various technology nodes using 1D-GDR standard cell and memory layouts [3,4]. In such designs the cuts layer is the critical one with the tightest pitch and highest demands on lithography resolution. In particular, poly and Metal-1 cuts layers were therefore

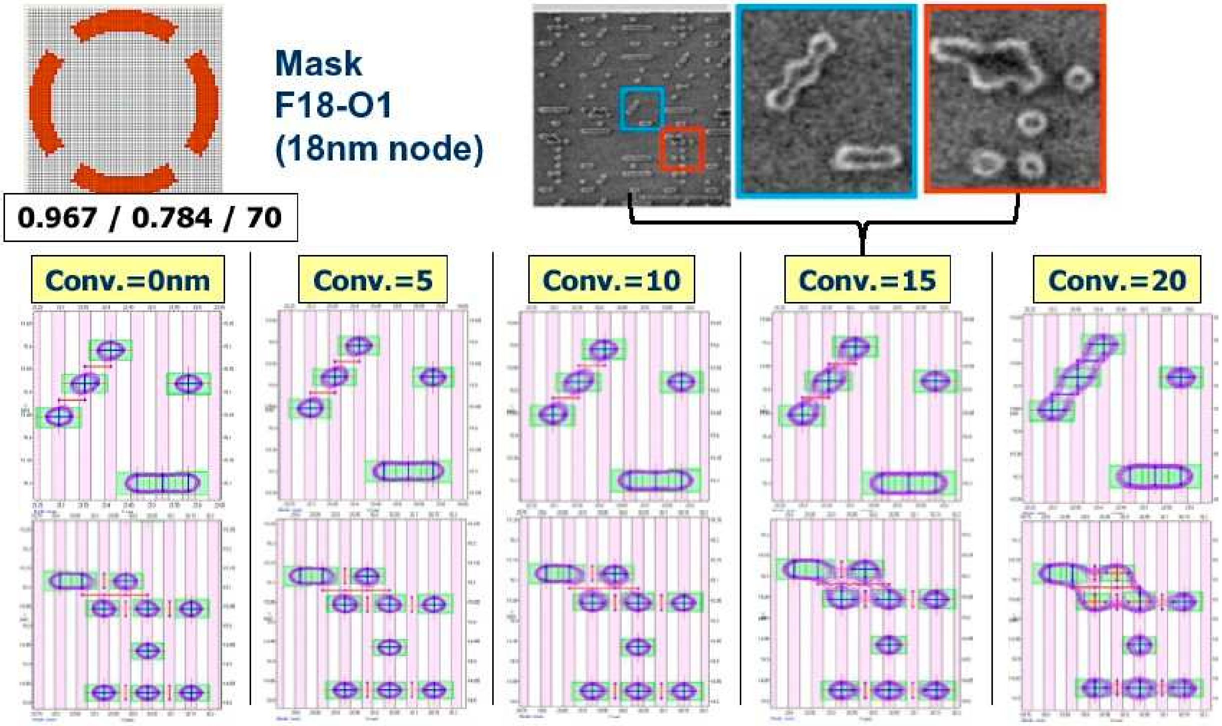
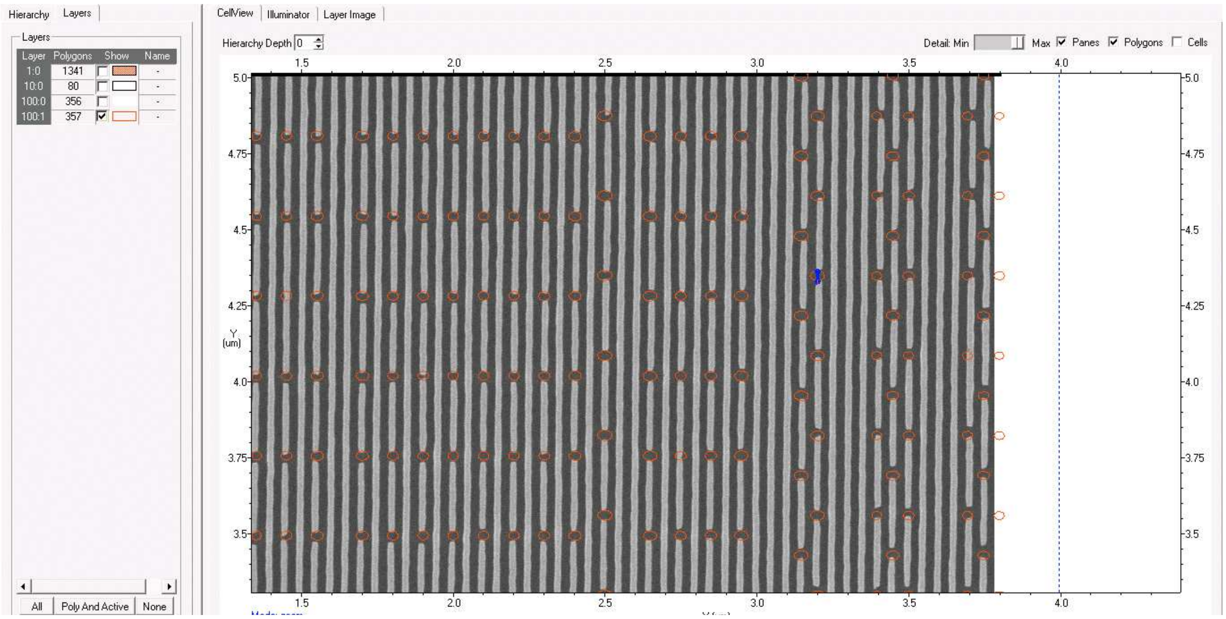


Figure 7. Metal-1 cuts at the 18nm node: simuilated patterns at different resist diffusion lengths and SEM images



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100:1	357	☑	-

Hierarchy Depth 0

Detail: Min Max ☑ Panes ☑ Polygons ☐ Cells

Figure 8. SEM image (grayscale) and overlaid simulation results (red circles) for the Metal-1 cut layer in 18nm technology [4]. A good match between simulation and experiment is seen.

considered. The relative simplicity of the cuts layers in comparison to conventional 2D layouts allows the use of a mathematically concise diffusion model with few empirical parameters – only one in our case (diffusion length) as compared to typically 7-9 for conventional models used for 2D layouts [1].

Results for Metal-1 cuts at the 18nm node [4] are shown in Fig. 7. The selected scanner illuminator is shown at the top left, portions of the SEM image are shown at the top right. Simulation results for various values of the resist diffusion length are shown in the bottom part of Fig. 7. With increasing diffusion length progressively stronger image blur can be seen, at ~15nm we see the best match to SEM data, as expected from our calibration curves in Figure 4. Finally, Fig. 8 shows an overlay of the SEM image and simulation results of the Metal-1 cut layer using the calbrated resist diffusion length. A good match between SEM data and simulation is seen.

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