REDUCTION OF PROXIMITY INDUCED CORNER ARTIFACTS BY SIMULATION SUPPORTED PROCESS OPTIMIZATION

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ABSTRACT

Reducing proximity artifacts is the most common challenge occurring in mask aligner lithography especially when exposing substrates at larger proximity gaps. Typically, proximity artifacts are most prominent at positions where the symmetry of the structures that should be produced is broken, i.e. line ends or corners. The tests presented here focused on various process parameters expected to influence the occurrence of proximity induced corner artifacts, including geometrical design of the mask structures, as well as exposure optics, gap and dose. It could be shown, that the artifacts can greatly be reduced by a combined optimization of the parameters stated before.

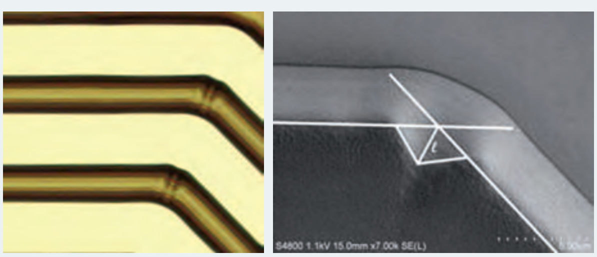

Figure 1. Optical microscopy image (left) of resist structures on top of a copper metallization. The resist structures serve as etch mask for producing conductor lines (bright: conductor path, dark resist structure). The resist structures at the inner corners of the conductor paths present a diffraction induced resist abrasion, visible as darkening in the resist lines, that reaches through the complete resist width. In the SEM image (right) it can clearly be seen, that the proximity artifact is strongest at the resist surface. The lines drawn into the SEM image illustrate the construction of the quantifying number ℓ that was used to control the influence of the process optimization. The drawn lines follow the strongest contrast along the main resist profile. Protrusions in the close vicinity of the eroded area were disregarded.

DESCRIPTION OF ISSUE AND DEFINITION OF TARGET OF THE STUDY

The process under investigation in this study worked on a 7 µm thick film of AZ P4620, but similar phenomena were reported in other resist film thicknesses and resists. The size of the features under observation was about 20 µm. Before the process optimization the wafer was exposed with Large Gap Optics (LGO) at an exposure gap of 50 µm. The exposure dose at the beginning of the study was reported to be around 800 mJ/cm², well above the dose recommended by the resist manufacturer.

Figure 1 illustrates the artifacts as observed in the baseline process. In the optical microscopy image the artifacts are clearly visible as darkening protruding into the resist (amber colored regions) at the inner corners of conductor paths (bright yellow area, i.e. regions free of resist). The artifacts reach far into the resist structure and even change the geometry of the conductor path. Also in the electron microscopy image on the right side the defect is clearly visible as a resist abrasion. As can be seen from the SEM image, the proximity artifact is the strongest at the resist surface. In the following the extent ℓ of the artifact at the resist surface will be used to quantify the defect.

DOE AND SIMULATION

To optimize the process the influence of a wide range of process parameters was investigated by process simulation and experiment. However, due to the amount of the performed tests not all results can be reported in full detail in this article. Therefore, the report will mainly focus on the three individual parameters exposure gap, exposure optics and exposure dose and on the parameter space of geometrical variations of the mask. The influence of soft baking conditions was investigated in the first part of the study. The influence of soft bake temperature T_{SB} and time t_{SB} were found to be of minor

importance, as long as they were kept within a reasonable process window (90°C<T_{SB}<110°C, 90s<t_{SB}<180s). The film thickness variation caused by the varying baking conditions were tracked but could not be assigned as relevant influence on the results in the following tests. A byproduct of the test was the result that the development medium has a noticeable influence on the resist abrasion. The KOH based developer showed a reduced artifact in comparison to the TMAH based developer. However, as in most fabs TMAH based developers are used, the following tests focused on those.
Main parameters for the exposure process tests were the exposure gap, the optics configuration and geometrical variations of the mask design. Besides these three parameters the exposure dose was also assessed, as influence of the dose has to be expected. However, due to other process restrictions the dose of the process is not always adjustable at customer sites. The complete DOE performed in experiments spanned 168 parameter configurations. Additionally, geometrical variations were evaluated in simulation calculations. At this end the influence of line width, edge angles and the radius of corner roundings (fillets) were reviewed. A list of the varied parameters and the respective value range can be found in table 1.
For process simulation the software LayoutLab from GenISys GmbH was used. For a detailed introduction to this software please refer to the article "Simulation for Advanced Mask Aligner Lithography" in the same issue of the SUSSreport.

RESULTS

DOSE

Variation of dose had a clear influence on the length ℓ of the artifact area in the conductor path edges. As can be seen in Figure 2, the artifact area length was reduced by lowering the exposure dose.
Measurements resulted in a length of 5 µm when exposing the resist with 800 mJ/cm² and of 3.5 µm when exposing with 510 mJ/cm². In order to understand the underlying effects a threshold simulation was performed with the LayoutLab software. By performing a threshold simulation it is easily possible to compare the influence of relative dose changes on the exposure result even without a precise calibration of the used resist media and development process conditions.

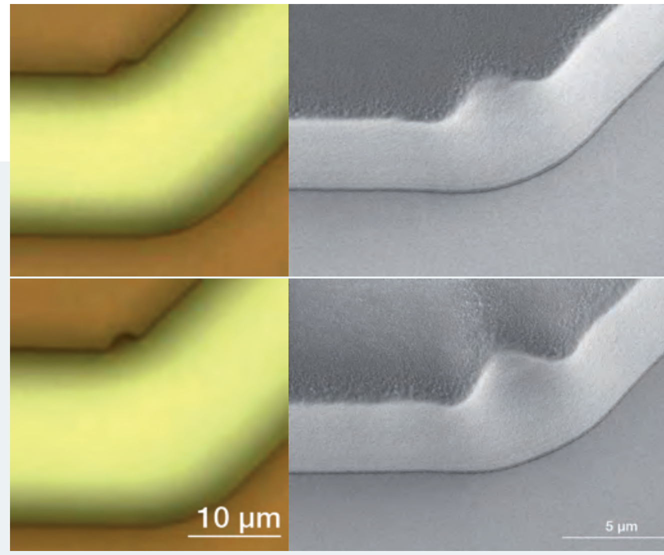

Figure 2. Optical (left) and electron (right) microscopy images of the corner artifact induced by a dose of 510 mJ/cm² (top) and 800 mJ/cm² (bottom). The erosion zone is larger with a higher dose

Figure 3 shows the result of the simulation. The color coding represents the different doses that are reached in different areas of the simulated area, red showing the highest dose, blue the lowest. From the graphics it can be understood that the areas affected by the proximity artifact are exposed with significantly lower intensities than the main area of the conductor paths. An easy model for the behavior of photolithographic resists is that of a simple threshold, meaning that resist is either developed, if the threshold dose is reached, or stays on the wafer untouched, if the actual dose is smaller than the threshold. From this model it can be easily understood, that an increase in total dose will bring even areas with lower intensities over the threshold of the resist, worsen the proximity artifact in the structure corner, analogous to the changing shape of the iso-intensity-lines in the simulation.

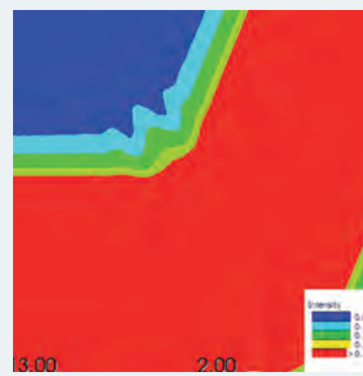

Figure 3. Iso-intensity-lines simulated for the same structure as in figure 2. The different colors represent areas exposed by at least the referenced intensity. Increasing exposure time, i.e. increasing doses, will lift the more corrugated areas of lower intensities over the dose threshold of the resist.

Parameter, Unit	T_{SB}, °C	t_{SB}, s	Dose, mJ/cm²	Gap, µm	Line width, µm	Fillet radius, µm	Corner angle, deg	Optics configuration
Min value	90	90	510	30	15	0	90	LGO
Max value	110	180	800	50	50	33	157.5	HR optics

Table 1: Parameters and their respective extremal values as used in experiments and simulation (middle blue). For most parameters more than 2 different values had to be used in the DOE due to the nonlinear response of the results on the input values.

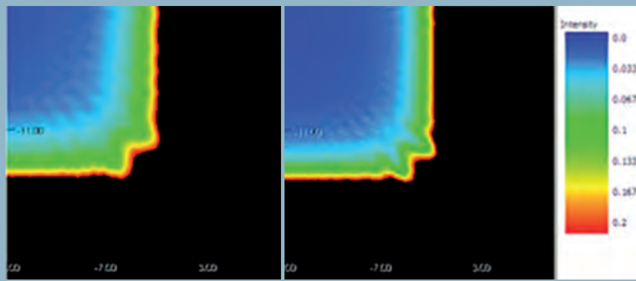

Figure 4. Images of the simulation results for a sharp 90 deg corner. The left image represents the situation at 50 µm, the right image at 30 µm gap. In 50 µm gap the corrugation has a longer wavelength, a slightly bigger amplitude and a stronger attenuation.

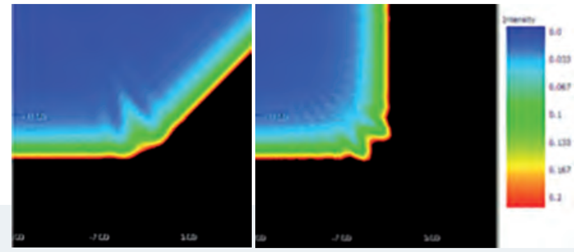

Figure 5. Images of the simulation results for a 90 deg and a 135 deg corner calculated for LGO optics and an exposure gap of 30 µm.

EXPOSURE GAP

Experiments to evaluate the influence of the exposure gap onto the size of the abrasion area were not conclusive in the range of exposure gaps relevant for the processes under examination. Whereas at higher doses an influence of the gap could not be excluded, at lower doses no significant influence could be observed in the experimental results. Also simulation calculations could not clearly prove an influence on the length of the artifact area. Figure 4 shows the result of the simulation for large gap optics. The figure represents simulation results for a 90 deg sharp corner in 50 µm gap (left) and 30 µm gap (right).

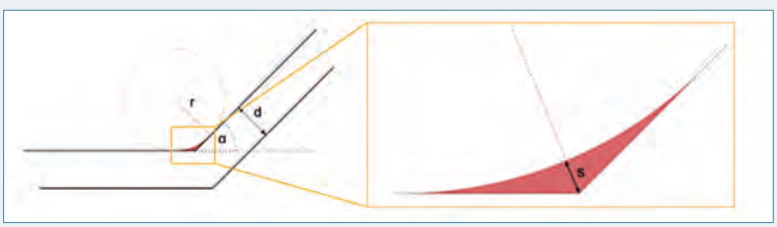

Figure 6. Schematic drawing of the geometrical parameters defining the fillet. With increasing radius r and decreasing corner angle the fillet distance s increases.

No decrease in length of the artifact area could be measured in the simulation results. Additionally, in the same time the artifact area widens. However, the level of the corrugation, i.e. the slope of the intensity at the edge as well as the ratio between corrugation period and depth was decreased by increasing the gap. Whether these results are beneficial for the actual process has to be decided on a case-by-case basis.

GEOMETRICAL VARIATIONS, LINE WIDTH, EDGE ANGLE AND FILLETS

The line width of the conductor paths was assessed in simulations only. For all line widths which were analyzed the simulation results predicted the same corner artifacts. This result can also intuitively be understood, as at line widths of 15 µm and more at the scrutinized gaps no influence of the opposite edge is expected.

In contrast, the variation of the corner angles showed a reasonable influence on the corner artifacts in the simulations. Also this can be understood intuitively, as the distance between two points that have the same distance from the corner origin will be bigger for bigger corner angles. Therefore, also the interference of the diffraction pattern will be reduced. Figure 5 shows images of corner angles of 90 deg and 135 deg, simulated with LGO optics at an exposure gap of 30 µm. For the 90 deg angle amplitude, frequency and number of visible undulations is higher than for the 135 deg angle.

As third geometrical parameter the use and size of a fillet, i.e. a rounding of the inner corner, was determined. Fillets were simulated for curvature radii ranging from 2.5 µm up to 33 µm. However, the maximum reasonable curvature radius depends on the length ℓ of the artifact area and on the angle of the corner. The fillet distance s should not exceed the length ℓ of the artifact area thus restricting the curvature radii of the fillets to 20 µm and smaller. Figure 7 shows a comparison between simulations performed for a corner without fillet and with a fillet of 5 µm curvature radius. The diffraction artifact is considerably reduced, most prominently visible for the 90 deg corner, where the corrugation visible at the structure without corner rounding is completely removed The experimental results shown in the optical microscopy image clearly support the results from the simulation. The length of the abrasion area ℓ at the resist surface was almost reduced to half the value without fillet.

EXPOSURE OPTICS

Even more then fillets, the choice of the exposure optics had a significant influence on the exposure result. Both, experimental data as well as simulation results proved, that by using HR optics the presence of corrugations can be drastically suppressed for all corner shapes, at all observed exposure gaps. In the optical

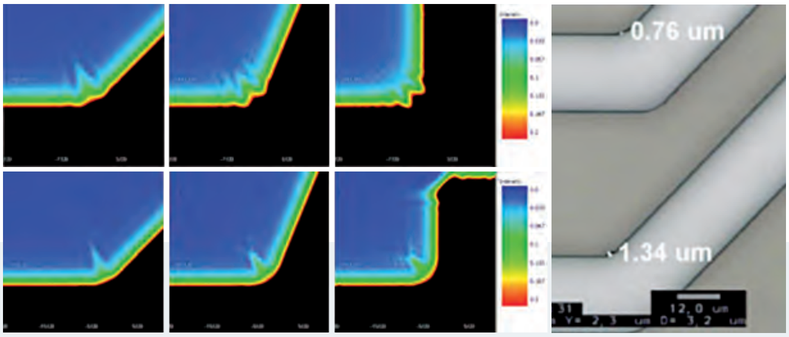

Figure 7. Comparison between the simulation results of a sharp corner (fillet radius 0, top row) and a corner smoothed with a filled of radius 5 µm (bottom row). This simulation was performed for LGO optics in 30 µm exposure gap. The optical microscopy image shows the results of consequential experiments with a mask having rounded corners (top conductor path) and sharp corners (bottom conductor path).

microscopy, which is depicted in Figure 8, distinct resist abrasion can be observed at the inner corner of the conductor paths created by LGO optics exposure (Figure 8 left). In this case the resist abrasion is strong enough to reach down to the bottom of the resist wall, changing the actual shape of the conductor path at the corner even at the wafer surface. Additionally, it is easily recognizable from the image that the artifact continues towards the resist surface, interfering with the designed structure throughout the complete resist thickness. In contrast to that, in the image of the conductor path, created with HR optics exposure, no resist abrasion is detectable at the wafer surface. Even on the top side of the resist hardly any proximity artifact can be distinguished. The results of simulation calculations affirm the experimental results.

Figure 9 represents the results of simulations done for LGO optics (left hand image) and HR optics (right hand image). While in the LGO result a strong corrugation of the edge is visible, the HR results show hardly any corrugation. These results identified the optics of one of the main parameters to reduce the proximity induced corner artifacts.

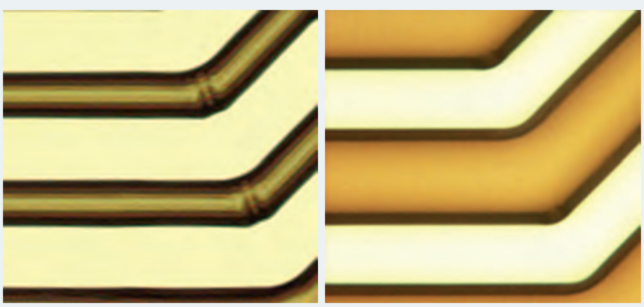
Figure 8. Optical microscopy images of corners in the conductor paths. The image on the left depicts the situation after exposure with LGO optics, the picture on the right after exposure with HR optics. The artifacts in the corner are significantly reduced.

CONCLUSIONS

From the results of the presented study three main claims can be made. First, the study proved the capability of the simulation software to support the process development by reducing the amount of experimental time and cost. By assessing the effect of corner fillets and the influence of the curvature radius the mask design could be optimized without the need to do several design iterations.

Second, the effect of fillets on the reduction of proximity induced corner artifacts could be proved and a quantitative support for the mask design could be derived. Third, the significant influence of the optics, selection on the reduction of diffraction phenomena could be visualized. The results emphasize the high importance for selecting the right optics configuration in order to keep unwanted proximity artifacts at the smallest possible level. In combination with the use of fillets the formation of proximity artifacts can be minimized.

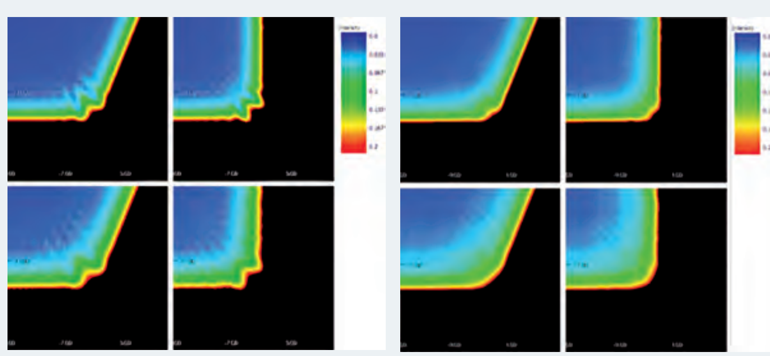
Figure 9. Images of simulation results calculated with LGO (left) and HR optics (right), at 30 µm (top) and 50 µm (bottom) gap, respectively. In the images calculated with LGO optics distinct corrugations can be seen for both gaps. The results obtained with HR optics show drastically reduced corrugations, with having slightly better results when exposing at 50 µm gap, where no corrugation but only a corner rounding can be observed.


Dr. Marc Hennemeyer is Application Scientist at SUSS MicroTec Lithography. He works on coaters and mask aligners and was responsible from SUSS MicroTec side for the evaluation of the LabView simulation software. Marc graduated in Physics at University of Munich where he also received his PhD working on micro fluidic systems for biological applications. He authored and co-authored several papers on various topics, including micro imprinting and lithography and lithography simulation.