SIMULATION FOR ADVANCED MASK ALIGNER LITHOGRAPHY

Ulrich Hofmann, Daniel Ritter, Balint Meliorisz, Nezih Unal
GenISys GmbH | Germany

Dr. Michael Hornung, Ralph Zoberbier
SUSS MicroTec Lithography GmbH | Germany

Published in the SUSS report 01/2012

SIMULATION FOR ADVANCED MASK ALIGNER LITHOGRAPHY

Ulrich Hofmann, Daniel Ritter, Balint Meliorisz, Nezih Unal, GenISys GmbH, Eschenstr. 66, 88024 Taufkirchen, Germany
Michael Hornung, Ralph Zoberbier, SUSS MicroTec Lithography GmbH, Schleissheimer Str. 90, 85748 Garching, Germany

1. INTRODUCTION

Lithography simulation has been a key enabler for IC manufacturing to keep track with Moore's law. 30 years ago, the end of optical lithography had been projected for feature sizes smaller than 1 µm. Just now, Intel announced[1] that they will still use optical lithography for the nodes down to 14 nm. Without lithography simulation and the simulation based source mask optimization technology this would never have been possible.

The history of lithography simulation starts in the 70 s when Rick Dill at IBM Yorktown Heights Research Center created the mathematical equations[2] that describe the basic steps of lithography processes. This was successfully applied to fight a "yield bust" at an IBM factory[3] and thereby became an important tool for understanding and improving lithography tools and processes in the 80 s. Simulation enabled sub-wavelength lithography in IC manufacturing through the introduction of OPC technologies, "source shaping" (off-axis, multi-pole, quasar,… illumination), introduction of phase-shift masks and recently the "source-mask-optimization" technique.

Mask Aligners in the past did not require lithography simulations since they were regarded as tools for "non-critical" applications. However, key differentiators such as cost advantage (e.g. low cost LED), the capability to print on large (e.g. displays) and non-planar (e.g. 3D packaging, MEMS) substrates require mask aligners to push the resolution limits. The application of simulation based resolution enhancement techniques will obviously enable extensions into markets that otherwise could not be served by mask aligners. SUSS MicroTec and GenISys offer mask aligner users the capability to apply techniques like OPC, source-shaping, source-mask-optimization, grey-tone or phase-shift technology to continue using cost effective mask aligner manufacturing beyond the limits of current processes.

The recent development of the MO Exposure Optics for SUSS mask aligner systems in combination with lithography simulation technology enables mask aligners to be used for critical applications with high demands on resolution, topography, large gaps and process window. SUSS mask aligners allow the ability to "shape" the illumination source, GenISys' simulation platform Layout LAB allows finding the optimum combination of source shape and mask layout to print the desired result on the wafer without producing masks, running experiments, and wasting material and time.

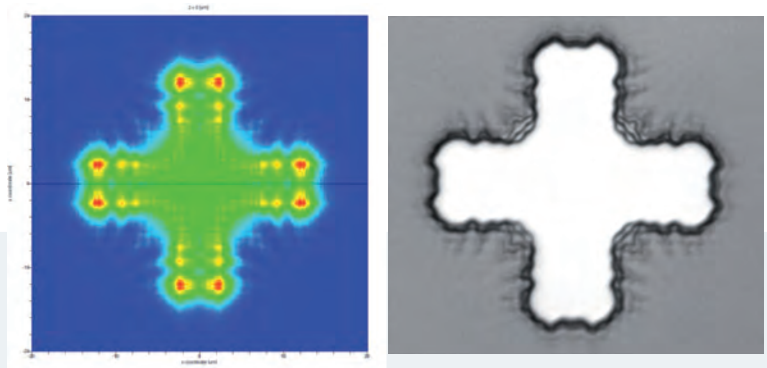


Figure 2. (left) Calculated intensity distribution of a cross-type mask pattern (10 µm line width) at a 30 µm proximity gap. (right) experimental verification (1 µm thick AZ 1518 photoresist on Si)

2. MASK ALIGNER SIMULATION SOFTWARE

2.1 SIMULATION SOFTWARE WITH ACCURATE MODELING OF SUSS MASK ALIGNER

GenISys started to develop the proximity lithography simulation software Layout LAB five years ago. A first market validation came from the flat panel display market, where Layout LAB software was successfully applied to advance the manufacturing of high resolution displays for smart phones by optimizing mask layouts (OPC) and process conditions.

Three years ago, SUSS MicroTec and GenISys joined forces to transfer this potential opportunity to mask aligner lithography applications. The accurate modeling of the SUSS mask aligner tools was developed and integrated as part of the joint project MALS[4,5] that included Fraunhofer IISB in Erlangen, FH Vorarlberg and OSRAM. As a result, the Layout LAB simulation software includes an accurate modeling of SUSS mask aligner exposure optics, including the simulation and optimization of the IFP design (illumination shape), and/or the mask layout in connection with the new MO Exposure Optics.

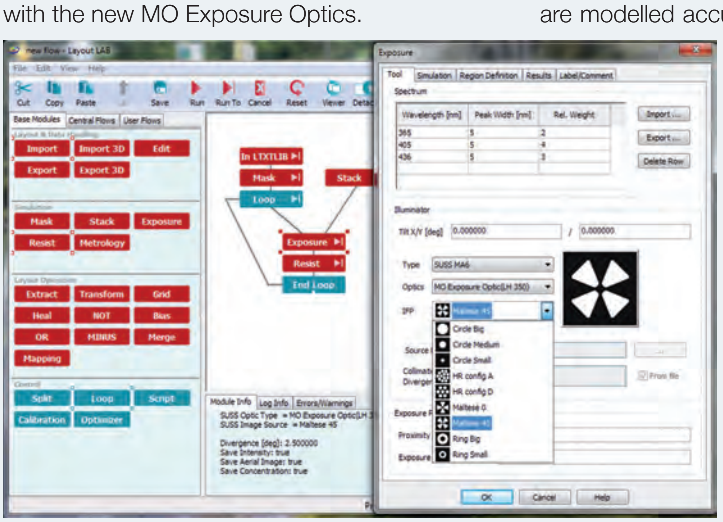


Figure 1. Layout LAB user interface showing the modeling of the SUSS Mask Aligner models with their different illumination types. Also included is the new MO Exposure Optics with the available IFP designs, and the capability to model and optimize customized source shapes.

2.2 SIMULATION OF INTENSITIES IN THE RESIST

The simulation software Layout LAB uses a fast algorithm for calculating the so called "aerial image" (the intensities in air at a given distance below the mask) based on Kirchhoff scalar diffraction theory. The model takes into account a broad band light source (e.g. spectrum of mercury lamp), and the source shape (either circular with collimation angle, or arbitrary, either loaded from a database of measured SUSS mask aligner source shapes, or custom designed). The mask is assumed to be a "thin mask" with the capability to model any transmission (grey tone) and phase-shift. The intensity image is calculated in "one shot" at an arbitrary gap, meaning the calculation time does not depend on the gap. The "aerial image" is transferred into the resist by the "Transfer Matrix Method", which models the light propagation in the resist and all material layers underneath the resist. All back-reflections from the substrate and the coatings are modelled accurately considering the refractivity and extinction of the materials (n and k values). Layout LAB is also able to model the "bleaching" of the resist (change of absorption coefficient during exposure). The accuracy of the algorithm has been validated by both benchmarking it with rigorous methods, and actual measurements and exposure tests at SUSS MicroTec and mask aligner users. The time for simulating the full 3D intensity image for a typical area of 100 x 100 µm is in the minute range, meaning that hundreds of simulations with

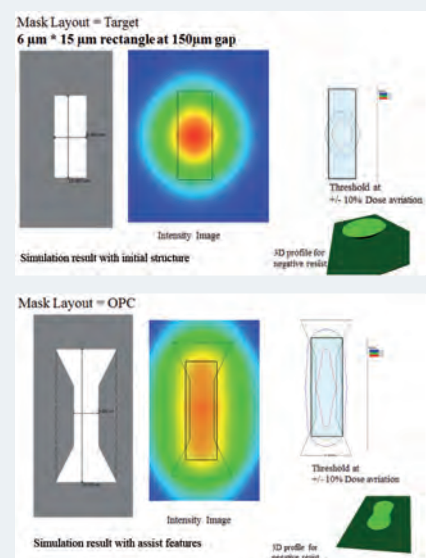


*Figure 3. Effect of assist features on figure fidelit The target shape (6 µm*15 µm rectangle) on th left cannot be printed at a 150 µm proximity gap whereas the OPC'd structure is much closer t the target.*

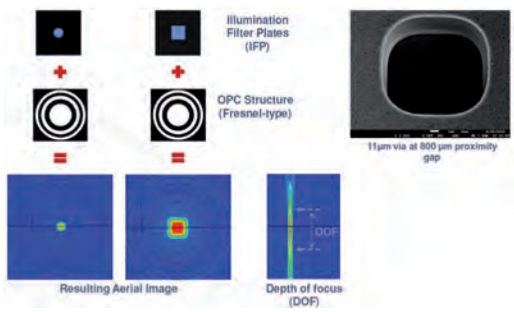


Figure 4. Creative use case for mask aligners – the Fresnel lens on the mask images the source shape directly onto the wafer

different conditions (gaps, source shapes, mask layouts,…) can be done in a few hours.

As the intensity image already contains most of the information on how the structure will print, optimizing mask layout (OPC), source shape (e.g. IFP design), gap and dose variation is typically done based on simulating the intensity image in the resist. The following example demonstrates the beneficial effect of assist features on feature fidelity – both size and position of the assist features were optimized using simulations.

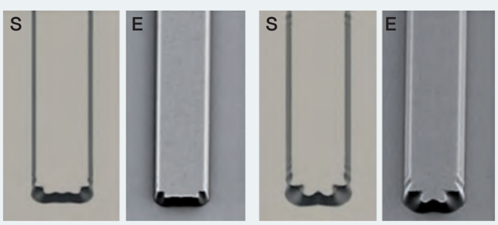


Figure 5. Comparison of simulated (S) and experimental (E) resist profiles for two different illumination settings. Large circular illumination (left) and small circular illumination (right)

Another example of creative use for mask aligners is the following through silicon via (TSV) application. The source shape is the contact to be printed, and on the mask are Fresnel lenses that focus the source shape onto the wafer. This results in a tremendous depth of focus (DOF), required for TSV applications.

2.3 SIMULATION OF 3D RESIST IMAGES

Layout LAB also includes the 3D simulation of the resist development process based on the Dill Model for transferring intensities to photo-active-compounds PAC concentration (depending on sensitivity of the resist) and the MACK4 model describing the removal of the resist during development. The MACK4 is an empirical model with four parameters, modelling the resist development rate depending on the PAC concentration. This parameter need to be calibrated using experimental data from DRM (development rate monitor) or contrast curve. The automated resist parameter calibration to experimental data is included in Layout LAB.

2.4 VIEWS AND ANALYSIS TOOLS

Just looking at a simulated image is a first step in validating printability, but typical questions to a simulation platform go way beyond that. In order to find out the optimum print conditions for a given layout, one will need qualitative and quantitative methods to help sort out various issues.

Qualitative methods include 2D image views as well as their 1D cross sections, and matrix views that allow visualizing the same structure at various process conditions. Matrix views can be collapsed into overlay views to allow a better comparison of the image slope at the target CS position. In order to also be able to make quantitative predictions, the graphs allow reading intensity values, slopes and log-slopes at all positions in the layout.Thereby allowing computing exposure latitude, an important factor for process stability.

From these matrix views, one can quickly generate an analysis view that shows trends and thereby allows the computation of sensitivity values. For example, one can derive the line width sensitivity to gap and collimation angle, which allows generating specs on how accurate the proximity gap needs to be set.

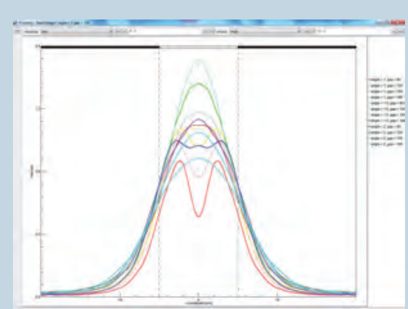


Figure 7. Overlay View (collapsed matrix view) for the same scenario

REFERENCES

[1] Mark LaPedus, "Intel Wants EUV but Keeps Lithography Options Open", Semiconductor Manufacturing and Design Newsletter, http://semimd.com/blog/2012/02/12/intel-wants-euv-but-firm-keeps-options-open/

[2] F. H. Dill, "Optical Lithography," IEEE Trans. Electron Devices, ED-22, No. 7 (1975) pp. 440-444.

[3] C. Mack, „30 years of Lithography Simulation", SPIE proceedings Vol. 5754, pp1-12

[4] MALS – Mask Aligner Lithography Simulation, Research project AZ-825-08 financed by the Bavarian Research Foundation

[5] K. Motzek et al, "Mask Aligner Lithography Simulation – From Lithography Simulation to Process Validation" Proceedings of the 37th International Conference on Micro and Nano Engineering, Berlin 2011, in Microelectronic Engineering (in press).

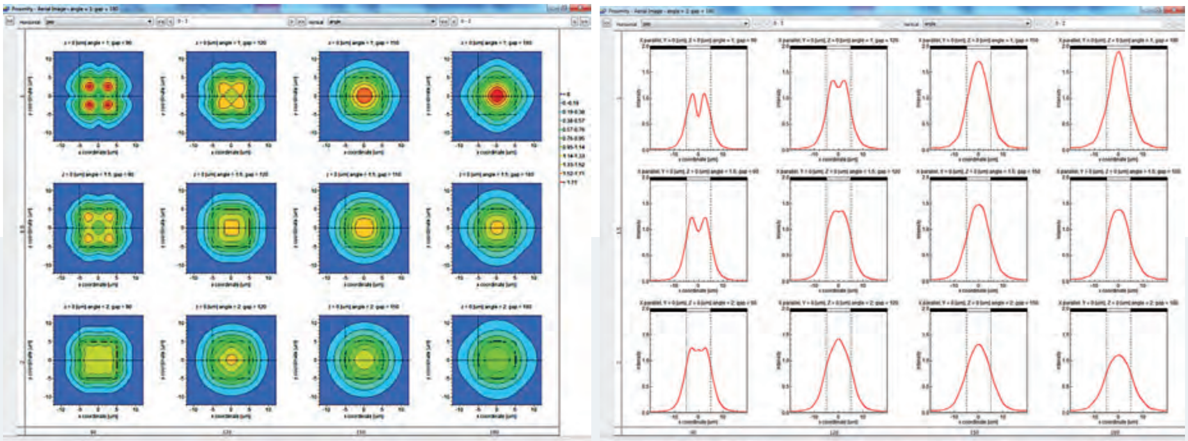


Figure 6. Matrix view for variation of 2 process parameters (gap and collimation angle) for a 15µm square to optimize the collimation angle for maximum proximity gap range

3. SUMMARY AND OUTLOOK

Lithography simulation enables the ability to transfer the benefits of mask aligners beyond the classical limits by resolution enhancement techniques such as layout optimization (OPC), source shaping, advanced mask technologies (grey-tone, phase shift), or combinations thereof such as source-mask-optimization.

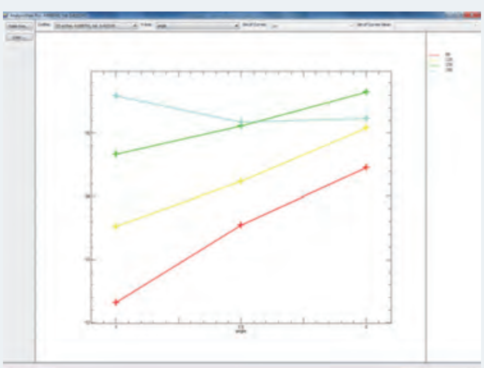


Figure 8. Analysis view showing the trends for the same process parameters gap and collimation angle.

Layout LAB is a dedicated simulation software including an accurate model for SUSS mask aligner, including the support of the new SUSS MO Exposure Optics. SUSS MicroTec is offering the simulation software Layout LAB to existing and new mask aligner user and provide in co-operation with GenISys training and support to apply the new technology to advance their products. GenISys and SUSS MicroTec will continue to enhance the combination of simulation, exposure tool and process in close cooperation with users, offering the highest value to the customer.

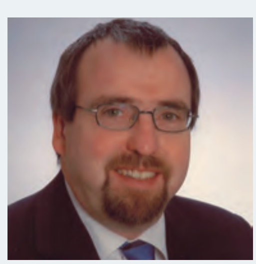
THE AUTHORS

As Vice President Marketing & Sales at GenISys GmbH in Munich, Germany, Nezih Unal is one of the company's key figures in creating unique solutions that make a difference. With over 25 years experience in various engineering and management positions in the semiconductor industry, Nezih worked on diverse technologies such as MEMS devices, optical lithography simulation software, and e-Beam lithography software.

Nezih Unal received his Diploma in Electronics Engineering at the University of Wuppertal in Germany in 1988, with a focus area on semiconductor technology. After his thesis on plasma and ion sources for micro-patterning processes he has started to work on the development of Reactive Ion Etching (RIE) processes for sub-micron IC manufacturing at Motorola. In 1992 he joined the new start-up microParts GmbH to develop and manufacture 3D MEMS devices using X-ray lithography (LIGA technology). Nezih joined SIGMA-C GmbH as director of Sales in 2003, and positioned the optical lithography simulation software SOLID as a strong #2 in the market. Early 2006, Nezih joined GenISys GmbH in his current role.

Ulrich Hofmann has more than 20 years experience in the semiconductor industry. Before founding GenISys, Ulrich worked in various technical and management positions on E-beam technologies as well as optical lithography technologies.

Ulrich Hofmann received his Diploma in Physics at the Technical University Munich in 1987. For the thesis in theoretical nuclear physics, he developed a new model on how to compute magnetic moments for nuclei. His first contact with the Semiconductor world was with Sigma-C in 1989, developing the first working hierarchy engine for E-beam lithography, data preparation and proximity effect correction, enabling full chip proximity effect correction on a single desktop computer. After joining Etec Systems in Hayward, CA in 1996, Ulrich pioneered technologies such as real-time proximity effect correction, hierarchical data processing, and ultra-high bandwidth datapath for massive parallel E-Beam direct write, and later became responsible for the commercial development and factory integration of the RSB next generation mask lithography tool. In 2005, he founded GenISys GmbH, a software house providing solutions for the optimization of microstructure fabrication processes for R&D, semiconductor manufacturers and equipment suppliers throughout the world.



Michael Hornung is Technical Marketing Manager at SUSS MicroTec Lithography based in Garching, Germany. During his career at SUSS MicroTec he passed further functions. So he was project manager in R&D responsible for the (nano) imprint technology and other new technologies for mask aligners. He also worked as application engineer for a while and lead the application group at SUSS MicroTec for two years.

Before he joined SUSS MicroTec he was project manager at CERN in Geneva, Switzerland, working at the inner detector for the ATLAS project.

Michael Hornung holds a Ph.D. degree in Natural Science from the University of Freiburg, Germany and an MBA from the University of Applied Science of Ludwigsburg, Germany.