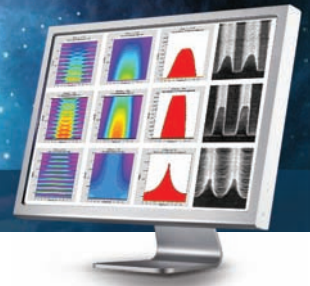


# Optolith

## Advanced 2D Optical Lithography Simulator

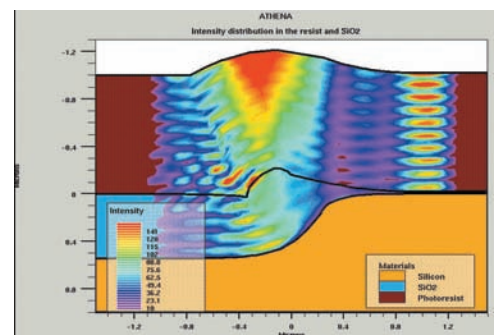


Optolith is a powerful non-planar 2D lithography simulator that models all aspects of modern deep sub-micron lithography: imaging, exposure, photoresist bake, development and reflow. Optolith provides a fast and accurate alternative to experimental evaluation of mask printability and process control. Optolith simulates both projection imaging and proximity printing with large mask-to-resist gap. Optolith is fully interfaced to all commercial IC layout tools conforming to GDSII and CIF formats, as well as to a special proprietary format used by MaskViews. As part of the Athena process simulation framework, Optolith provides seamless integration with diffusion, oxidation, implantation, etching and deposition simulation capabilities. This simulation environment allows the analysis of complex lithography effects in multilayer non-planar structures generated by oxidation, deposition and etching. It also provides unique opportunity to investigate and optimize implantation and etching process steps with real photoresist mask shapes taken into account.

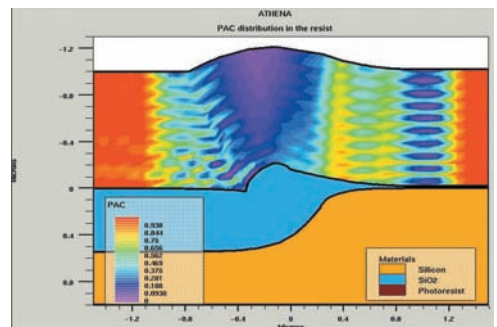
### Optolith Features and Models

- Projection imaging
- Proximity printing with broadband illumination
- Flexible illumination sources: shape (circular, square, gaussian, anti-gaussian, SHRINC/Quest, annular, on/off axis) and wavelength (g,h,i, DUV and broad line)
- Optical models for defocus, aberration (up to ninth order), spatial filtering, partial coherence, and large numerical aperture(NA)
- Layout mask features can be specified either by layout statements in DeckBuild or by using special layout files generated by MaskViews
- Rectangular, triangular, and circular features could be specified in the layout statement
- MaskViews handles both GDSII and CIF formats as well as layouts generated by user within MaskViews
- The mask transmittance and phase shift can be specified in MaskViews for either the whole mask layer or for each individual mask feature
- Simulation of combined image produced by sequential illumination of several mask layers
- The exposure process model based on the Beam Propagation Method (BPM) with explicit accounting for reflections and diffraction effects in non-planar structures
- Capability to take into account local modifications of material optical properties with the absorbed dose during exposure process
- 2D simulation of photo-active compound (PAC) diffusion during post-exposure bake
- Six advanced development models (Mack, Kim, Dill, Trefonas, Eib and Hirai)
- Viscous material flow model for simulation of photoresist reflow during post-development bake
- 2D and 3D visualization of aerial images in TonyPlot
- 2D visualization of intensity and PAC distributions as well as final photoresist profiles
- Extraction capabilities within DeckBuild provide powerful post process analysis including estimation of image irregularities, image contour proximity, critical dimensions (CDs), thicknesses and slopes of photoresist features, etc.
- Extraction capabilities combined with multiple loop simulation using DBInternal functionality of DeckBuild provide convenient tools for multi-variable process split analysis including Smile Plots and ED Trees.
- Automated large-scale experimentation capabilities are available within the Virtual Wafer Fab

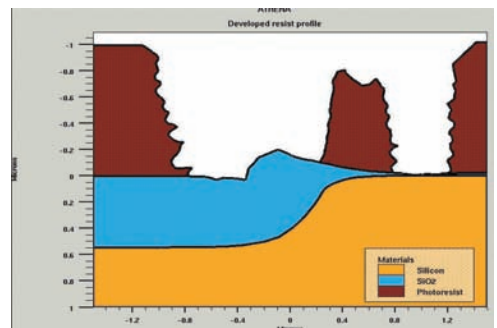
### Complete Photolithography Process



Intensity distribution



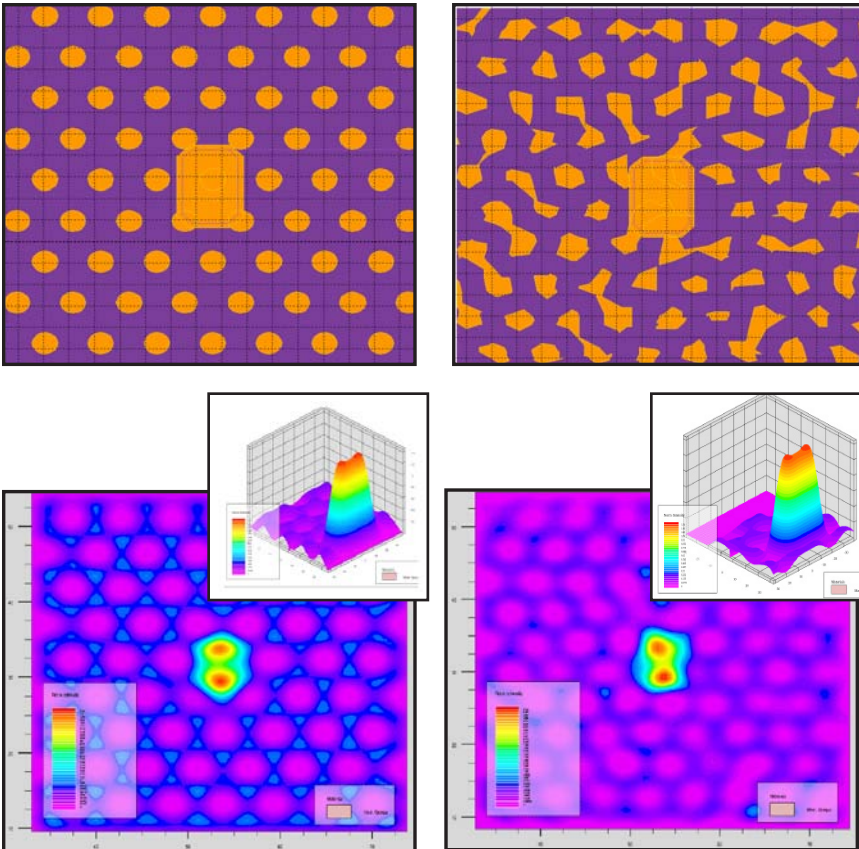
PAC distribution



Development profile

**SILVACO**

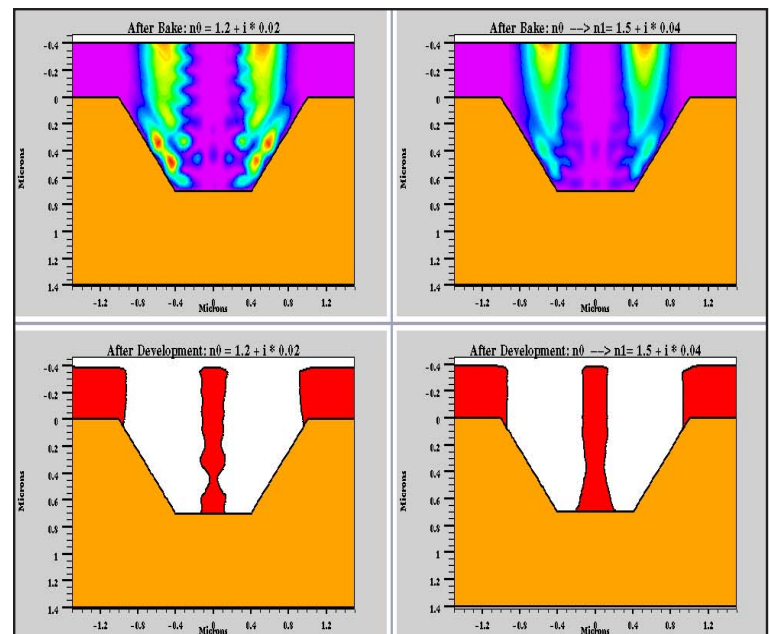
## Imaging of Complex Masks with Various Transparencies and Phase Shifts



The two upper plots show MaskViews visualization of GDSII layouts with regular (hexagons) and irregular shapes. These are test layouts for an LCD application. The Optolith interface with MaskViews allows specification of variable transmittance and phase shift. In this case, the central octagons have 100% transmittance while small regular and irregular spots are of 19% transmittance and 45 degrees phase shifts. The two lower plots show corresponding 2D aerial images calculated by projection imaging module of Optolith (insets are 3D views of the central octagonal spot).

## Exposure and Development Simulation in Non-Planar Structures

Optolith has a great advantage in comparison with other commercial lithography simulators because it can accurately handle non-planar structures. First of all, seamless integration with the SSuprem 4 and Elite modules allows the use of representative non-planar substrate geometries. Secondly, simulation of resist planarization using reflow process gives realistic shapes of resist layer. Thirdly, the Beam Propagation Method (BPM) accurately accounts for diffraction and multiple reflection effects in all non-planar resist layers with arbitrary shapes. Moreover, BPM takes into consideration local changes of resist refraction properties with absorbed light energy. This example demonstrates these non-planar capabilities and particularly the effect of exposure dose on the resist optical properties. The figures above show intensity distributions in a non-planar structure (two upper plots) and corresponding developed resist profiles (two lower plots). The two figures on the left correspond to the case of constant photoresist refraction index. The two figures on the right correspond to the photoresist with refraction index varying linearly with the accumulated dose during exposure process. The comparison of final structures shows that the dose effect could be very pronounced and should be taken into account. The strong reflection from the sloped walls with subsequent undercut during development may even result in complete removal of the resist feature.

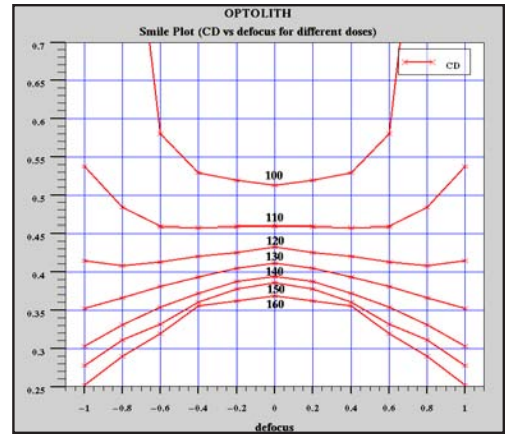
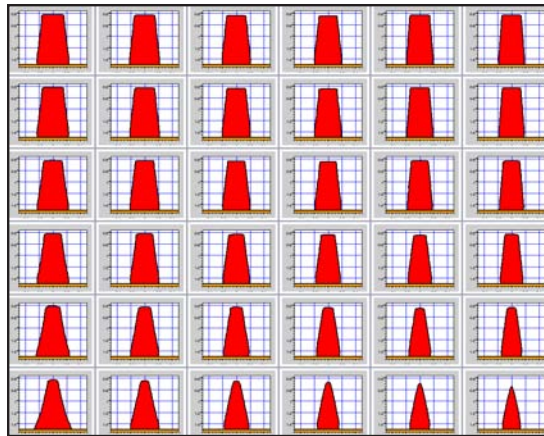




## Process Control - Smile Plots

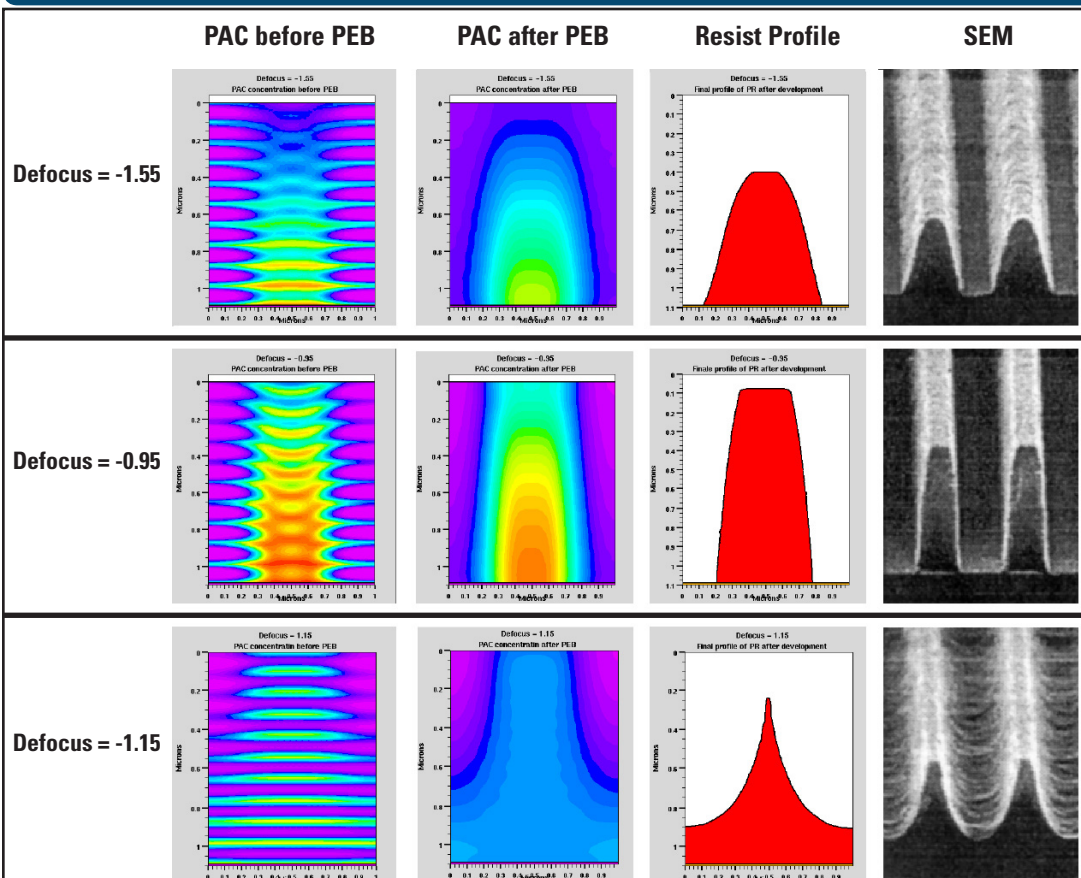
```
Deckbuild V3.32.1.R - smile.in, dir: /home/mrshat/brochures_Oct200
File View Edit Main Control Commands Tools
go internal
load infile=smile_tmpl.in
sweep parameter=dose type=linear range="100,160,7"
parameter=defocus type=linear range="-1,1,11"
save type=cd outfiles=smile.dat
tonyplot smile.dat -set smile-set
quit

##### Content of smile_tmpl.in file #####
# go internal
# set defocus=0
# set dose=110
# projection mag=52
# illumination lline
# illum.filter clear.dl circle sigma=0.5
# projection mag=52
# pupil.filter clear.dl circle
# layout lay.clear x.low=-0.2 x.high=0.2 z.high=0.5
#
# line x.loc=-0.5 space=0.01
# line x.loc=0 space=0.05
# line x.loc=5 space=0.01
# line y.loc=1.5 space=1.0
# line y.loc=2.5 space=1.0
#
# init dilcon
# deposit photoresist name=resist=OR32 thick=97 div=40 min.space=0.01
# rate.develop name=resist= OR32 lline=dill=0.027
# image win.x.lo=-4 win.x.hi=0 win.z.hi=0 dx=0.5
# defocus=-$defocus clear once.dlm
# expose dose=$dose num.ref=10
# bake diff.length=0.055
# develop mack time=75 steps=4 substeps=20
#
# extract names="cd_in_A" thickness material="OR32" mat.oceno=1\
# y.val=1.48
# extract names="CD" lline=495"cd_in_A"
```



Complete lithography simulation from imaging to resist development is the only practical methodology of process control. One of the key elements of process reproducibility is the depth of focus (DOF) control. Even after resist planarization the DOF could be different in various areas of the layout due to topological variations of the preceding process steps. In some cases even small changes in DOF or other process parameters may result in unacceptable violations of critical dimensions (CDs). The main controlling parameter for this CD vs. DOF effect is the exposure dose. Therefore, the only way to characterize the process response is to vary simultaneously defocus and exposure dose and extract corresponding CDs. Optolith together with Silvaco Interactive Tools provides an ideal environment for lithography process control. The image of DeckBuild in the upper left corner shows a very simple setting for the DBInternal module. It consists of the nested loop over “dose” and “defocus” parameters of the Optolith template input deck below. DeckBuild automatically runs the Optolith simulation 77 times with the defocus parameter varying between  $-1$  and  $1$ , and the exposure dose parameter varying between  $100$  and  $160$ . All final resist profiles are saved. Also, the extracted dose-exposure matrix of CD values is stored in the ASCII file “smile.dat”. Just 36 out of 77 resist profiles are shown in the “matrix” plot above. It is clear that the second row, which corresponds to the dose= $120$  mJ/cm<sup>2</sup> and defocus from  $0$  to  $1$  micron, demonstrates the smallest CD variation. TonyPlot can be used for visualization of the data stored in the “smile.dat” file. The corresponding smile (or Bossung) plot is shown in the figure to the right.

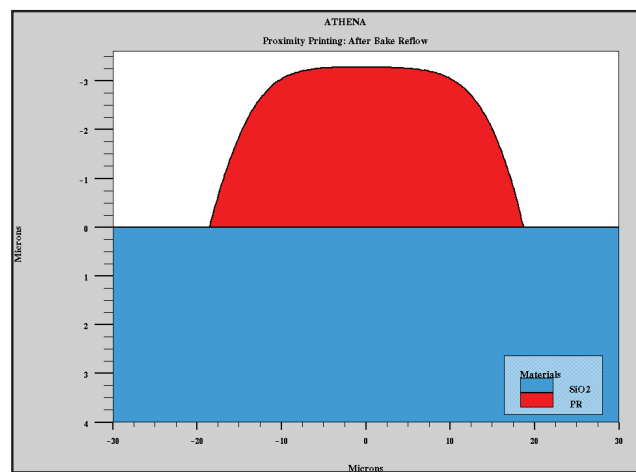
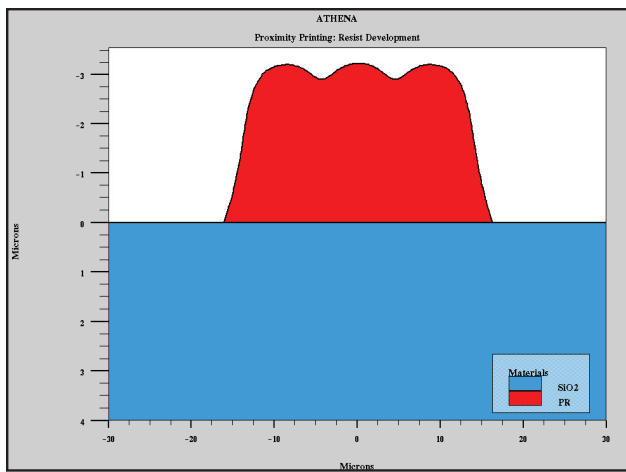
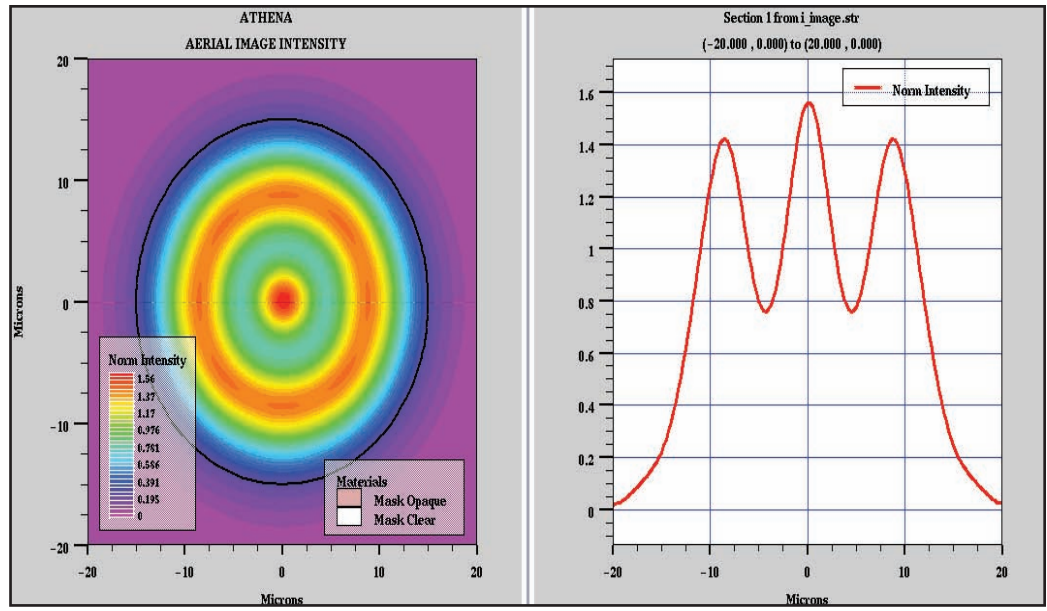
## Full Lithography Process Simulation



These pictures show the effect of defocus on CD variation and resist shape in comparison with measured resist profiles (SEM pictures were provided by LG Semiconductor). Several process parameters including bake diffusion coefficient and Dill's development coefficient have been calibrated. It is clearly seen that complex CD extraction, which takes into account characteristics of the resist shape is necessary to achieve accurate calibration and optimization of the complete lithography process.

## Proximity Printing

Proximity printing or imaging without any reduction lens regained its popularity recently because it appeared to be a very cost effective solution for active-matrix liquid crystal display (AMLCD) technology. The accurate simulation of proximity printing could not be achieved by simplification of "standard" projection technology methods. Therefore, a separate proximity printing module is implemented in Optolith. It is seamlessly integrated with other lithography simulation modules as well as with MaskViews.



The picture at the top of the page demonstrates proximity printing image of circular feature with radius 15 microns. This is a typical feature size for AMLCD. This image is calculated for the distance (gap) of 150 microns between mask and resist film. The single i-line illumination was used. The multi-image and multi-exposure capabilities of Optolith allows the approximation of broadband illumination by combining results of several image/exposure simulations for main lines of the white spectrum. The variation in intensity is typical for proximity imaging. In the case of broadband illumination these variations slightly decrease. The lower plots show results of subsequent lithography steps: after exposure and bake the negative resist has been developed. The developed resist demonstrates a typical "ripple" pattern (plot on the left). The postdevelopment bake/rewflow removes the pattern (plot on the right).

# SILVACO

### HEADQUARTERS

4701 Patrick Henry Drive, Bldg. 2

Santa Clara, CA 95054 USA

Phone: 408-567-1000

Fax: 408-496-6080

### CALIFORNIA

sales@silvaco.com

408-567-1000

### MASSACHUSETTS

masales@silvaco.com

978-323-7901

### TEXAS

txsales@silvaco.com

512-418-2929

### JAPAN

jpsales@silvaco.com

### EUROPE

eusales@silvaco.com

### KOREA

krsales@silvaco.com

### TAIWAN

twsales@silvaco.com

### SINGAPORE

sgsales@silvaco.com



WWW.SILVACO.COM

Rev. 090413\_08