OPC for Mask Aligner
Proximity Lithography = Shadow Printing

Source: Süss Microtech

Mask Aligner

Source: Hitachi High Tech

Flat Panel Display Proximity Printer:

Source: Hitachi High Tech
Litho Complexity

**Source**
- Wavelength (broadband)
- Collimation angle, Source Shape
- Tilt angle

**Mask**
- Layout feature sizes
- Transmission / Greyscale / Phase
- Diffraction effects

**Resist & stack**
- Material optical properties
- Thicknesses, Reflections

**Proximity gap**

\[ HP = \frac{3}{2} \cdot \sqrt{\frac{\lambda}{\exp.\ gap + \frac{\text{resist thickness}}{2}}} \]
The Litho Challenge

Design

Manufacturer

Mask

The Desired Pattern

The Result

Very time consuming and expensive -> DFM technology
Simulation Images

Layout → Aerial → Bulk Intensity → 3D Profile

First Principle (Physics) → Phenomenological
Mask Model

- Modelling of mask
  - Arbitrary 2D layout data
    - GDSII, DXF, CIF, or text based
  - Clear / Dark binary mask
  - Complex gray-tone mask
  - Phase sifting mask
3D imaging kernels calculate the aerial image

- Modelling of source
  - Broad band spectrum including peak width
  - Collimation angle, arbitrary source shape, tilted sources

- Fast and accurate calculation of aerial image at arbitrary gaps based on Kirchhoff Scalar Diffraction theory
  - „thin mask“, no vectorial (polarization) effects
  - Raleigh Sommerfeld integral is solved (better than paraxial approximation)
  - Image calculation at arbitrary distances from mask

- Limitation
  - Feature size should be > wavelength
  - Distance from mask should be > wavelength

Models are proven in IC manufacturing since > 20 years.
• The calculation of image intensity (aerial image / bulk image) is based on solid physics (optics) and mathematics.

• Accuracy of algorithms are proven by benchmarks with experiments and different rigorous methods and experiments

• Verification and optimization using intensity image provides a tremendous value

Bad intensity image will result in bad resist on wafer!
Optimum intensity image is the best base for good resist results!
• **Transfer Matrix Model (thin film algorithm)**
  - Light propagation and absorption in a stack of homogeneous layers of different material
  - Wavelength dependent $n$ and $k$
  - Reflection at material interface
  - Change of propagation angle at material interface

• **Bleaching:**
  - Change of $n$ & $k$ over during exposure
  - $n$ and $k$ of non-exposed and exposed resist is needed
  - Exposure is modelled in multiple steps
3D resist development model based on Dill (resist sensitivity) and Mack 4 (development rate) parameter:

- Bulk image intensities are converted in concentrations
- Concentrations define dissolution rate
- The 3D development front over is modeled over development time
Resist model parameter require fitting to experimental data (resist contrast curve, DRM, resist profiles) of actual resist process.

Layout LAB offers the Calibration module for fitting parameters to experimental data.
Mack Development Model

3D resist simulation vs. experiment after resist parameter calibration

Figure 4: Comparison of simulated ((a) and (c)) and experimentally observed ((b) and (d)) photoresist profiles.

Fit of experimental data with Mack model
Simulation is:

- Saving Time & Cost
  - No need to make masks, print wafer or inspect
  - No materials “burned”, no line occupation
  - Saves engineering resources

Simulation supports:

- Designer
  - Development of design rules
  - Layout verification, hot-spot detection
  - Layout optimization, OPC

- Process engineer

- Equipment, mask and material supplier

Cross (10µm line width) at 30µm proximity gap
Multiview for process window
• Artifacts known from projection printing appear in proximity printing as well...

Solution in high-end projection printing: pre-distortion of the mask geometry to restore image fidelity – OPC
• Typical OPC methods in high-end projection printing

iso-dense bias

mask biasing

subresolution features

line end shortening

serif

hammerhead

corner rounding

serif

mousebite

Will it work also for mask aligner litho?
• A simple example: patterning of 3 µm iso and dense lines

Process window analysis

Common dose latitude is much worse than the “single” dose latitudes!
• Modify the linewidths on mask (biasing)...

Common dose latitude vs. iso and dense lw on mask

prox. gap: 15 μm
target lw: 3 μm +/- 10%
pitch for dense line: 6 μm
• Patterning at 20 µm gap

Process window analysis

3 µm dense line on mask
target: 3 µm ± 10%

gap: 20 µm

3 µm iso line on mask
target: 3 µm ± 10%

gap: 20 µm

Common dose latitude is zero!

No chance to print both dense and iso lines within the given tolerance!
• Biasing for 20 µm gap

prox. gap: 20 µm
target lw: 3 µm +/- 10%
pitch for dense line: 6 µm
• Taking into account gap variations
• Mask layout

- original pattern, 3 μm x 3 μm
- with serif type #1
- with serif type #2
• Comparison simulation to experiment - dots
• Comparison simulation to experiment - holes
OPC Assist Features

Aerial image (simulation)

Mask pattern

OPC assist features
Sub-Resolution Features

Check Process Window: Gap/Dose variation

„Hot-Spot“ Detection

Optimize layout for increasing Process Window

„ OPC“
Optimize Layout

Mask Layout = Target
150μm gap

Simulation result without OPC

Intensity Image

Threshold at +/- 10% Dose avriation

3D profile for negative resist
Mask Layout = OPC

Simulation result with OPC

Threshold at +/- 10% Dose variation

3D profile for negative resist
For question and more information please contact

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