Simulation Tools for Advanced Mask Aligner Lithography (AMALITH)

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Diffraction affects the printing results:

+ Intensity depends on the Gap
+ Normalized Image log-slope (NILS) depends on the Gap
+ Resolution is limited
+ $W$ on the wafer can be different than on the mask
Resolution Enhancement Technologies

+ Optimization of the mask pattern shape (Optical Proximity Correction, OPC)

+ Optimization of angles of incoming light (off-axis illumination, OAI)
MO Exposure Optics

**MO Exposure Optics**

**1st Köhler Integrator**
- Ellipsoidal Reflector

**1st Field Lens**
- First Fourier Lens
  - $f_{FL}$

**2nd Köhler Integrator**
- Second Fourier Lens
  - $f_{FL}$

**Illumination Filter Plate (IFP)**

**Mask**
- Wafer

**Proximity Gap**

**Precise modeling for simulations**

**Preselection Illumination**

**Uniformity** in Angular Spectrum and Irradiance

**Determination of Angular Spectrum**

**SUSS MicroOptics**
Simulations

+ **Manufacturing Tool**
  Reduction of the number of experimental test, troubleshooting of problems in the fab

+ **Research Tool**
  Improvement in lithography based on simulation results (PSM and Off axis illumination)

+ **Process Development Tool**
  Development of new lithographic process or equipment (top bottom antireflection coatings)

+ **Learning Tool**
  Possibility to see intermediate parts of imaging sequence, like aerial image and latent images
Lithography Simulation: LayoutLab

RESULTS

Input

Mask

Exposure

Output

NILS; contrast, DoF

INTERMEDIATE RESULTS

Aerial Image

Output

Resist profile; CD; Sidewall slope

RESISTS

Resist Concentration

3D Resist View

Output

ANALYSIS VALUE

Export; Metrology

Process Window

Export

Process Window CD vs Gap/Dose
Source Optimization

Simulation and experimental setting

+ Photomask: 10 µm x 10 µm
+ 1.2 µm thick photoresist (AZ1518)
+ 100 µm Exposure Gap
Source Optimization

**Simulation setting**
- Photomask: cross shape
- 0.1 µm thick photoresist (AZ1518)
- 0, 20, 50, 100, 200 µm Exposure Gap

Simulated Resist Profile (LayoutLAB, GenISys):

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>Contact</th>
<th>20 µm</th>
<th>50 µm</th>
<th>100 µm</th>
<th>200 µm</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-IFP</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
</tr>
<tr>
<td>MALT-IFP 0°</td>
<td><img src="image6.png" alt="Image" /></td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
</tr>
</tbody>
</table>
Source Mask Optimization (SMO)

Simulation setting
- Photomask: cross shape and OPC mask
- 0.1 µm thick photoresist (AZ1518)
- 100 µm Exposure Gap

SOURCE OPTIMIZATION + OPC = SMO

MALT-IFP 0°
Fresnel type mask optimization

Simulation setting
+ Photomask: Fresnel Zone Plate (FZP)
+ 5 μm thick photoresist (AZ1518)
+ 800 μm Exposure Gap

OPC Structure (Fresnel-type)

2D Aerial Image

DoF
Square IFP

Simulation and experimental setting
+ Photomask: Fresnel Zone Plate (FZP)
+ 5 µm thick photoresist (AZ1518)
+ 800 µm Exposure Gap

Illumination Filter Plates (IFP)

OPC Structure (Fresnel-type)

Resulting Aerial Image

11µm via at 800 µm proximity gap

Side view

Top view
Talbot Effect

Near-field **diffraction effect** observed when a plane wave is transmitted through a grating or other periodic structure.

At multiples of a certain defined distance the structure is replicated. At smaller regular fractions of this gap, sub-images can also be observed.

This distance is known as the **Talbot Length** and is found by these formulas:

- \( Z_T = \frac{2d^2}{\lambda} \) [Quadratic array]
- \( Z_T = \frac{3d^2}{2\lambda} \) [Hexagonal array]

Exactly halfway between these locations, the structures with half the spatial period of the original structure are reproduced.
Talbot Effect in Proximity Lithography

Hexagonal Array \( Z_T = \frac{3d^2}{2\lambda} \) \( Z_T \approx 102 \, \mu\text{m} \) (\( d = 5 \, \mu\text{m}; \lambda = 365 \, \mu\text{m} \))

Aerial Image for Gap between 0\( \mu\text{m} \) and 2\( Z_T \) (Cross Section)

Aerial Image, Gaps: \( Z_T \pm 3 \, \mu\text{m} \)

Simulation Setting
+ Photomask: Hexagonal Array (\( d = 5 \, \mu\text{m}; \text{size} = 4 \, \mu\text{m} \))
+ 102\( \mu\text{m} \pm 3 \mu\text{m} \) Exposure Gap

DoF > 6\( \mu\text{m} \)
Comparison between Simulation and Experiment

Simulation 3D Resist Structure
(LayoutLab, GenISys)

Simulation and experimental setting
- Photomask: Fresnel Zone Plate (FZP)
- 5 µm thick photoresist (AZ1518)
- 102 µm Exposure Gap

Printed resist structures

2 µm
MO Talbot Lithography (Periodic Structures/PSS)

- Flowers: 4 µm
- Pitch: 6 µm
- Resist: 2 µm thick
- Etching: RIE (Bosch, Si)
- Proximity Gap: 102 µm
- Mask Aligner: MA8/BA6

Flowers 4 µm
Pitch 6 µm
Resist 2 µm thick
Etching RIE (Bosch, Si)
Proximity Gap 102 µm
Mask Aligner MA8/BA6

0.8 µm
Conclusion

- Two simulation tools LayoutLab [GenISys] and Dr.LITHO [Fraunhofer IISB] were presented
- MO Exposure Optics allows the employment of simulation
- Simulations allow to find the most promising illumination and mask setting
- Experimental results and simulations correspond well

Outlook

- Resist model parameter require fitting experimental data with actual resist process
- More accurate physical description at the molecular level is needed to allow a rigorous and improved photoresist modeling