Lithography Tool Package

6. Process effects and real life process examples

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Outline

1. Introduction
   - Process steps in UV lithography

2. Spin coating
   - Resist composition
   - Pre-treatment
   - Principle
   - Softbake
   - Spin curve

3. Exposure
   - Hardware
   - Process parameters
   - Resolution
   - Alignment

4. Development
   - Principle
   - Effects
   - Resist tone, photo-chemistry, and contrast

5. Post-processing and characterization
   - Post processing
   - Characterization methods

6. Process effects and examples
   - Process effects
   - Real life process examples
Processing: effects

- The following slides shows simplified, exaggerated representations of top-view and cross-section inspection of resist patterns, for a square design, tens of µm in size
- Effects of exposure mode, exposure dose, and development time are shown, first for positive tone resist, then for negative tone resist
- Some effects are also illustrated by OM inspections of a real life process

- Inspection example (bright field design, optimal conditions):

<table>
<thead>
<tr>
<th>Mask</th>
<th>Positive tone</th>
<th>Negative tone</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Mask Positive tone" /></td>
<td><img src="image2" alt="Positive tone" /></td>
<td><img src="image3" alt="Negative tone" /></td>
</tr>
</tbody>
</table>
Positive tone resist: exposure mode

<table>
<thead>
<tr>
<th>Mask</th>
<th>Contact</th>
<th>Proximity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bright field</strong></td>
<td><img src="image1" alt="Square" /></td>
<td><img src="image2" alt="Square" /></td>
</tr>
<tr>
<td><strong>Dark field</strong></td>
<td><img src="image4" alt="Square" /></td>
<td><img src="image5" alt="Square" /></td>
</tr>
</tbody>
</table>
### Positive tone resist: exposure dose

<table>
<thead>
<tr>
<th>Mask</th>
<th>Under-exposed</th>
<th>Over-exposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bright field</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dark field</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Bright field
- Under-exposed: A completely exposed area.
- Over-exposed: A partially exposed area.

#### Dark field
- Under-exposed: A completely unexposed area.
- Over-exposed: A partially unexposed area.
## Positive tone resist: development time

<table>
<thead>
<tr>
<th>Mask</th>
<th>Under-developed</th>
<th>Over-developed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bright field</td>
<td><img src="image" alt="Under-developed" /></td>
<td><img src="image" alt="Over-developed" /></td>
</tr>
<tr>
<td>Dark field</td>
<td><img src="image" alt="Under-developed" /></td>
<td><img src="image" alt="Over-developed" /></td>
</tr>
</tbody>
</table>
## AZ 5214E: real life process flow

<table>
<thead>
<tr>
<th>Step Header</th>
<th>Equipment</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Spin coat of AZ 5214E with HMDS priming</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| 1.1 Coat wafers | Spin Coater: Gamma UV | Resist: AZ 5214E (line 3)  
Spin: 30 s @ 4500 rpm (~1.5 µm)  
Softbake: 60 s @ 90 °C  
Sequence: DCH 100mm 5214E 1.5um HMDS  
Si substrate  
HMDS priming: 15 s @ 120°C |
| 2 Exposure | | |
| 2.1 Expose | Aligner: MA6 – 2 | Mask: Litho test  
Exposure mode: Hard contact  
Exposure dose: 72 mJ/cm²  
HC wait time: 10 s  
Exposure time: 5.5 s @ 13 mW/cm² |
| 3 Development | | |
| 3.1 Develop | Developer: TMAH UV-lithography | Development in AZ 726 MIF: single puddle, 60 s  
Sequence:  
DCH 100mm SP 60s |
| 4 Inspection | | |
| 4.1 Inspection | Optical microscope | Inspect: Line and dot patterns, bright field and dark field, using 20X objective |
AZ 5214E: exposure mode

Mask

Contact

Proximity (~2µm)

1.5µm 5214E, Hard contact, 72mJ/cm², 60s TMAH puddle
AZ 5214E: process window

Mask

Under-exposure (20%)

Under-development (50%)

Optimal

Over-exposure (50%)

Dark erosion <10nm

Over-development (100%)

1.5µm 5214E, Hard contact, 72mJ/cm², 60s TMAH puddle
Exercise: What went wrong?

1.5µm MiR 701, Hard contact, 169mJ/cm², PEB 60s @ 110°C, 60s TMAH puddle
Exercise: a clue...

Dirty mask!

Solution: clean mask and re-work

Immediate solution: try vacuum contact

1.5μm MiR 701, Vacuum contact, 169mJ/cm², PEB 60s @ 110°C, 60s TMAH puddle
## Negative tone resist: exposure mode

<table>
<thead>
<tr>
<th>Mask</th>
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<th>Proximity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bright field</strong></td>
<td><img src="image" alt="Bright field Contact" /></td>
<td><img src="image" alt="Bright field Proximity" /></td>
</tr>
<tr>
<td><strong>Dark field</strong></td>
<td><img src="image" alt="Dark field Contact" /></td>
<td><img src="image" alt="Dark field Proximity" /></td>
</tr>
</tbody>
</table>
## Negative tone resist: exposure dose

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<tr>
<th>Mask</th>
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</tr>
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<tbody>
<tr>
<td>Bright field</td>
<td><img src="image" alt="Diagram" /></td>
<td><img src="image" alt="Diagram" /></td>
</tr>
<tr>
<td>Dark field</td>
<td><img src="image" alt="Diagram" /></td>
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</table>
## Negative tone resist: development time

<table>
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<tr>
<th>Mask</th>
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<th>Over-developed</th>
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<tbody>
<tr>
<td><strong>Bright field</strong></td>
<td>![Under-developed]</td>
<td>![Over-developed]</td>
</tr>
<tr>
<td><strong>Dark field</strong></td>
<td>![Under-developed]</td>
<td>![Over-developed]</td>
</tr>
</tbody>
</table>
# AZ nLOF 2020: real life process flow

## Step 1: Spin coat of AZ nLOF 2020 with HMDS priming

<table>
<thead>
<tr>
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</thead>
</table>
| 1.1  | Coat wafers | Spin Track 1 + 2 | Resist: AZ nLOF 2020 (track 2)  
Spin: 30 s @ 6700 rpm (~1.5 μm)  
Softbake: 60 s @ 110 °C  
Flow: T2 nLOF 2020 2um with HMDS |
|      |         | Spin Track 1 + 2 | Si substrate |
|      |         | Si substrate | HMDS priming: 72 s @ 50°C |

## Step 2: UV Exposure

<table>
<thead>
<tr>
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<th>Comments</th>
</tr>
</thead>
</table>
| 2.1  | Exposure | Aligner: MA6 – 2 | Mask: Litho test  
Exposure mode: Hard contact  
Exposure dose: 104 mJ/cm² |
|      |         |            | HC wait time: 10 s  
Exposure time: 8.6 s @ 13 mW/cm² |

## Step 3: Post Exposure Bake

<table>
<thead>
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</tr>
</thead>
</table>
| 3.1  | Post Exposure Bake | Developer: TMAH UV-lithography | Post Exposure Bake: 60 s @ 110 °C  
Sequence: DCH 100mm PEB60s@110C+SP30s |
|      |         |           | PEB and development is done simultaneously |

## Step 4: Development

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</thead>
</table>
| 4.1  | Develop | Developer: TMAH UV-lithography | Development in AZ 726 MIF: single puddle, 30 s  
Sequence: DCH 100mm PEB60s@110C+SP30s |
|      |         |           | PEB and development is done simultaneously |

## Step 5: Inspection

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</thead>
<tbody>
<tr>
<td>5.1</td>
<td>Inspection</td>
<td>Optical microscope</td>
<td>Inspect: Line and dot patterns, bright field and dark field, using 20X objective</td>
</tr>
</tbody>
</table>
AZ nLOF 2020: exposure mode

1.5µm nLOF, Hard contact, 104mJ/cm², PEB 60s @ 110°C, 30s TMAH puddle
AZ nLOF 2020: process window

- Mask:
  - 4µm
  - 3µm
  - 2µm
  - 1µm

- Under-exposure (50%)
  - "Dark" erosion ~60nm

- Under-development (50%)
  - "Dark" erosion ~30nm
  - Sidewall angle ~15°

- Optimal
  - Sidewall angle ~5°

- Over-exposure (50%)
  - Over-development (100%)

1.5µm nLOF, Hard contact, 104mJ/cm², PEB 60s @ 110°C, 30s TMAH puddle
Processing effects: exercise

Consider a bright field design of two 30µm by 30µm squares corner to corner processed using a positive tone resist. Discuss in teams what process effect may have caused the result in A or B.

A

Proximity (~2µm)

Length = 29.75 µm

Length = 29.60 µm

B

Over-exposure (50%)

Length = 29.32 µm

Length = 29.24 µm
Processing effects: Newton’s rings

The dose is changed locally due to interference between light reflected by an air gap (of varying size) between mask and resist surface -probably due to a particle

Solution: increase exposure dose
Immediate solution: develop again

Process:
- 1.5 µm MiR 701
- Vacuum contact
- 156 mJ/cm²
- PEB 60 s @ 110°C
- 60 s TMAH puddle
Further reading

- MicroChemicals homepage
  - Downloads → Application notes
  - Notes on composition, processing, and use of photoresists
  - E.g. “Lithography Trouble-Shooter”

- LabAdviser
  - labadviser.danchip.dtu.dk
  - Information on machines, resists, and processes
    labadviser.danchip.dtu.dk/index.php/Specific_Process_Knowledge/Lithography/UVLithography
  - E.g. “Information on UV Exposure Dose”
    labadviser.danchip.dtu.dk/index.php/Specific_Process_Knowledge/Lithography/UVExposure_Dose
## AZ MiR 701: real life process flow

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<td>1</td>
<td>Spin coat of AZ MiR 701 with HMDS priming</td>
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</table>
| 1.1  | Coat wafers | Spin Track 1 + 2 | Resist: AZ MiR 701 (track 1)  
Spin: 30 s @ 5000 rpm (~1.5 µm)  
Softbake: 60 s @ 90 °C (1 mm proximity)  
Flow: T1 MiR 701 1,5um with HMDS | Si substrate  
HMDS priming: 72 s @ 50°C |
| 2    | UV Exposure | | |
| 2.1  | Exposure | Aligner: MA6 – 2 | Mask: Litho test  
Exposure mode: Vacuum contact  
Exposure dose: 169 mJ/cm² | Pre vac: 10 s; full vac: 10 s  
Exposure time: 13 s @ 13 mW/cm² |
| 3    | Post Exposure Bake | Developer: TMAH UV-lithography | Post Exposure Bake: 60 s @ 110 °C  
Sequences: DCH 100mm PEB60s@110C+SP60s | PEB and development is done simultaneously |
| 4    | Development | Developer: TMAH UV-lithography | Development in AZ 726 MIF: single puddle, 60s  
Sequences: DCH 100mm PEB60s@110C+SP60s | PEB and development is done simultaneously |
| 5    | Inspection | Optical microscope | Inspect: Line and dot patterns, bright field and dark field, using 20X objective |
AZ MiR 701: exposure mode

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<tr>
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<th>Proximity (~2µm)</th>
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<tbody>
<tr>
<td>4µm</td>
<td>1µm</td>
<td>1.5µm MiR, Vacuum contact, 169mJ/cm², PEB 60s @ 110°C, 60s TMAH puddle</td>
</tr>
<tr>
<td>3µm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2µm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1µm</td>
<td></td>
<td></td>
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</tbody>
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1µm MiR, Vacuum contact, 169mJ/cm², PEB 60s @ 110°C, 60s TMAH puddle
AZ MiR 701: process window

1.5µm MiR, Vacuum contact, 169mJ/cm², PEB 60s @ 110°C, 60s TMAH puddle