Lithography Tool Package

4. Development

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Outline

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   - Process steps in UV lithography

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   - Pre-treatment
   - Principle
   - Softbake
   - Spin curve

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

4. Development
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   - 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
Development

developer

rinse (H₂O)

spin drying

Robot developer

Manual developer

Semi-manual developer

Spin dryer
Development: principle

- **Resin**: Monomers or polymer chains of varying length (solid at RT)
- **Photo-active component** (PAC): Reacts with UV-light during exposure and changes the resin
- **Solvent** (∼70%): Dissolves the resin in order to enable coating

- In the exposure, light activates the photo-active compound which changes the solubility of the resist in the developer in the exposed areas
- In some resists, the photo-chemistry is a catalytic process, which is activated/assisted thermally in a so-called **Post-Exposure Bake** (PEB)

**Methods**
- Submersion: the substrate is submerged in a bath of developer
- Puddle: developer is dispensed onto the surface of the substrate, and held there by surface tension
- Spray: developer is sprayed onto the substrate
Development: resist tone

Positive tone

Coating
Exposure
Post-exposure bake
Development
Pattern

Negative tone
Photoresist: tone

Positive tone
- Exposed resist becomes soluble in developer
- Polarity change or chain scission
- Bleaching during exposure enables straight sidewalls even for thick resist

Negative tone
- Exposed resist becomes insoluble in developer
- Polarity change or cross-linking (usually requires PEB)
- Special case: no bleaching (AZ nLOF 2020) → always negative sidewalls
**Photoresist: special categories**

- **Image reversal resist (AZ 5214E)**
  - Positive resist changed to negative by additional process steps
  - Cross-linker (NH$_3$) is added, activated by the *image reversal bake*
  - The temperature of the image reversal bake is a critical parameter
  - Requires flood exposure before development

- **Chemically amplified resists**
  - Photo-initiation is catalytic
  - Requires PEB
  - Dose = light + heat → higher throughput
Developers at DTU Danchip

- **AZ 351B**
  - NaOH in water (base)
  - buffer additive (for submersion)
- **AZ 726 MIF**
  - TetraMethylAmmonium Hydroxide (TMAH) in water (base)
  - wetting agent (for puddle)
- **mr-Dev 600**
  - PGMEA for SU-8 development (solvent)

<table>
<thead>
<tr>
<th>UV Resist</th>
<th>MiR 701</th>
<th>nLOF 2020</th>
<th>5214E</th>
<th>4562</th>
<th>SU-8</th>
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<tr>
<td>Thickness</td>
<td>1.5–4 µm</td>
<td>1.5–4 µm</td>
<td>1.5–4 µm</td>
<td>5–10 µm</td>
<td>4–200 µm</td>
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<tr>
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<td>(x)</td>
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<td>AZ 726 MIF</td>
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<td>Positive</td>
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<tr>
<td>Negative</td>
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</table>
Photoresist: photo-chemistry

- AZ 5214E, AZ 4562, and AZ MiR 701 have diazonaphtho-quinone-sulphonate (DNQ) as the photo-active component, or photo-initiator.

- DNQ lowers the solubility of the resin in the developer, while the carboxylic acid increases the solubility → positive tone resist.

Courtesy of MicroChemicals GmbH

DNQ

Carboxylic acid
Photoresist: photo-chemistry, consequences

- After softbake, the resist has to rehydrate in order to enable exposure
  - 1µm rehydrates in 10s
  - 10µm requires at least 10 minutes
  - Thicker films may require hours to rehydrate
  - Insufficient rehydration leads to under-development and/or non-straight sidewalls

- After exposure, the N₂ has to outgas before any thermal process in order to prevent bubbles from forming
  - Before image reversal bake (5214E), and possibly PEB (MiR 701)
    - 1µm outgasses in ~1 minute, 3µm in ~10 minutes, while a 10µm film may require hours to outgas
    - Thick resist should be exposed in intervals with delays in between

- AZ nLOF 2020 and SU-8 both have a different PAC, and do not require rehydration or outgassing
Development: effects

- **Under-development**: resist remaining between pattern
  - Increase development time
  - Increase exposure dose (positive tone)

- **Dark erosion**: pattern attacked by the developer
  - The resist becomes thinner
  - Resist lines become narrower; gaps become wider
  - Minimize development time
  - Optimize softbake parameters (positive) / increase dose (negative)

- **Scumming**: resist residues left behind on the substrate
  - Substrate and developer dependent

- **Forgetting PEB** leads to
  - under-development of positive tone resist
  - full development (no pattern) for negative tone resist

Under-developed resist

Scumming on SiO₂. Courtesy of Sonny Massahi
Sidewall angle in negative resist

- In a cross-linking, negative tone resist, erosion of the exposed resist in the developer depends on the density of cross-links in the resist.
- Due to absorption during exposure, the cross-link density is often lower at the substrate, compared to at the top of the resist film (especially for AZ nLOF which doesn’t bleach).
- This gives rise to a higher erosion rate of the resist near the substrate, resulting in a sloped resist sidewall, or negative resist profile, after development.

- Sidewall angle usually limits the resolution in contact printing of negative tone resist.

\[ R = 2z \tan \alpha (+c) \]
Photoresist: contrast

• Ideally, at least for high resolution, the response of a resist to exposure should be a step function, i.e. no development below a threshold dose; full development above the threshold dose.

• In reality, development starts at a dose, $D_0$, but finishes at a higher dose, $D_C$ (dose to clear), leading to the definition of contrast, $\gamma$, as the slope of the transition:

$$\gamma = \frac{1}{\log\left(\frac{D_C}{D_0}\right)}$$

• What does the contrast curve look like for a negative tone resist?

![Contrast Curve](image-url)
Photoresist: contrast

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$$\gamma = \frac{1}{\log \left( \frac{D_C}{D_0} \right)}$$

• For a positive tone resist.

• For a negative resist, the curve is reversed.

• Complete development stops at a dose, $D_0$, and development stops a higher dose, $D_i$ (“fully insoluble dose”), leading to:

$$\gamma = \frac{1}{\log \left( \frac{D_0}{D_i} \right)}$$

• For a negative tone resist.

Courtesy of MicroChemicals GmbH
Photoresist: contrast, low vs. high

- Contrast determines how the image from the exposure transfers to the resist pattern
- In most cases, e.g. for dry etch, a high contrast is desired

- Contrast depends on many factors:
  - Developer chemistry, concentration, and temperature
  - Resist type and thickness
  - Softbake parameters (due to dark erosion)
  - etc.

Courtesy of MicroChemicals GmbH