Lecture 18 –
Optical Lithography 3 - Resist

EECS 598-002 Winter 2006
Nanophotonics and Nano-scale Fabrication
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Photoresist

- The most commonly used photoresist nowadays is a two-component system which consists of the novolac resin and the diazonaphthoquinone photoactive compound (PAC; a dissolution inhibitor).

<table>
<thead>
<tr>
<th>novalac</th>
<th>PAC</th>
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</thead>
<tbody>
<tr>
<td>1. Inert to photochemistry</td>
<td>1. Responsible for photochemistry</td>
</tr>
<tr>
<td>2. For film-forming</td>
<td>2. Quantum efficiency:</td>
</tr>
<tr>
<td>3. For adhesion</td>
<td>( \phi = \frac{\text{# of molecules transformed}}{\text{# of photons absorbed}} )</td>
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<tr>
<td>4. For chemical resistance</td>
<td></td>
</tr>
<tr>
<td>5. For thermal resistance</td>
<td>Not the total intensity!</td>
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</table>
Chemically amplified DUV resist

- Since the quantum efficiency of a regular resist is ~ 100 fold smaller at the DUV wavelength, chemical amplification is used.
- Instead of optically destroying the dissolution inhibitors, chemically amplified DUV resist creates acid by photochemical reactions. Acid then destroys the inhibitor at an elevated temperature (PEB). Each acid molecule can trigger the catalysis event to destroy several inhibitors → amplification.

Resist process overview

- Adhesion promotion or BARC coating
- Resist coating
- Softbake (SB)
- Exposure
- Post-exposure bake (PEB)
- Resist development
- Rinse and dry
- Metrology (CD & REG)
  - bad
  - good
- Resist/BARC removal
- Etch
Resist process environment control

- Resist process happens in a controlled environment (track).

From TEL

Exposure module
Adhesion promotion

- The most common adhesion promoter is HMDS (hexamethylenedisiloxane). Applied in vapor phase (100-160 °C).
Spin coating

Resist thickness \[ t = \frac{KC^\beta \eta^\gamma}{\omega^\alpha} \]

\( \omega \) = spin angular speed
\( C \) = resist concentration
\( \eta \) = molecular weight

1. Low spin speed results in a thicker resist toward the edge of the wafer
2. High spin speed results in opposite thickness profile as well as random variation in thickness due to thermal effects.
Edge bead removal (EBR)

- The resist on the edge of the wafer is often removed (EBR) to reduce potential contamination sources and help the vacuum chuck to hold the wafer.
- TEBR: use chemicals to remove the edge bead
- OEBR: use optical source to expose the edge bead

Thickness variation and spill over to the back
Softbake (SB)

- Purpose: To remove the residual solvent and anneal the stress. Note some resists do require some solvent to remain in order to improve the photochemical reaction speed.

From *Introduction to Microlithography*

*Figure 28.* Dissolution rate of a typical commercial positive photoresist (DNO-novolac) as a function of prebake temperature.
Exposure (Dill’s model)

- Concentration of dissolution inhibitor = \( M(z,t) \)

\[
\alpha = AM(z,t) + B \quad \rightarrow \quad \text{As } M(z,t) \text{ reduces, the absorption will be bleached.}
\]

\[
I(z,t) = e^{-\alpha z}
\]

\[
\frac{\partial M(z,t)}{\partial t} = -I(z,t)M(z,t)C
\]

It is very important for bleaching to happen. Otherwise, there will be no light that can reach the bottom of the resist to clear. This is the main reason that photoresist used for G- or I-line does not work well at the DUV wavelength.
Resist characteristics

Normalized resist thickness after development

The slope determines the contrast and dose sensitivity.

Dose to clear

log(dose)

0 1
Swing curve

- Swing curve plots the “dose to clear” vs film (e.g. resist) thickness.
Post exposure bake (PEB)

- PEB is different from the “hardbake” before an etching process.
- PEB is used to induce the diffusion of photogenerated compound in order to smooth out the interference effect on the resist profile.
PEB temperature vs CD

From Future-Fab International, issue 12.
Reactions with airborne molecules, such as ammonia or amines, neutralize acid near the top of the resist film, forming a mushroom cap.

Reactions with certain substrates, such as TiN, neutralize acid near the bottom of the resist, forming a foot.

From Future-Fab International, issue 12.
Development time vs resist profile

Figure 57. Cross-sectional view of MRS resist profiles as a function of development time. (Reproduced with permission. Copyright 1982 Institute of Electrical and Electronics Engineers, Inc.)

From *Introduction to Microlithography*
Focus-Exposure Matrix (FEM)

Bossung plot:

- Focus window
- Exposure latitude
Metrology

- Registration: overlay measurement
- CD
Resist profile by top-down measurement

Sloped profile

X-section

Top-down SEM

LER (line edge roughness)

1. Line edge roughness is playing an increasing role in determining pattern-and performance-limited yield entitlements. It is a fact of life for 193 nm lithography, which now must carry the industry for at least three generations with the aid of immersion technology. LER’s increasing importance will demand innovation in CD-SEM imaging, measurement and analysis. (Source: KLA-Tencor)