Approaches to address the EUV resist challenges of image collapse, LWR, sensitivity, and resolution

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Outline

✓ Mechanism of resist collapse
✓ Technologies to fix resist collapse
✓ Discussion: trade-off relation, collapse and RLS
✓ Conclusions
Resist collapse

Capillary force

Mechanical Strength

Adhesion

Swelling

Collapse mode in present CAR

AR = 2.3

ادية

-adhesion

bend

break

peel

Resist collapse

Collapse mode in present CAR

AR = 2.3

ادية

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Resist collapse
Physics of capillary force

Capillary Pressure

\[ \Delta P = \frac{\gamma}{R} \]

\[ R = \frac{S}{2 \cos \theta} \]

\[ F_1 = \Delta P \times \Delta \text{Area} = \left( \frac{2 \gamma \cos \theta}{S} \right) \times H \times D \]

\( \Delta P \): Capillary pressure gradient
\( \gamma \): Surface tension
\( R \): Radius of curvature
\( S \): Spacing
\( \theta \): Contact angle of rinse liquid on resist surface

Balanced with:

Young’s modulus
(Mechanical strength)

Adhesion strength

\( \): Rinse liquid
\( \): Resist material
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Super critical CO₂ development for collapse issue

High mechanical strength / low capillary force are promising for collapse

Conventional dry

60nm 1:1 L/S Thickness: 250nm (aspect ratio > 4)

Tr = 250 nm

Supercritical dry

70nm 1:1 L/S Thickness: 250nm (aspect ratio = 3.6)

Tr = 250 nm

TMAH Development, X-linking type negative tone EB resist
FIRM process for collapse issue

K. Tanaka et. al.,

Fig. 12 Surface tension and contact angle to surfactant concentration
(surfactant: sample D, 248nm ESCAP type resist/Barc, 130nm L/S, Aspect ratio: 3.96)
Swelling would also cause collapse

22 nm hp patterns

Data courtesy of SEMATECH
Positive tone EUV resist

Deformation of pattern might be occur by “swelling”
Design principles for low swelling resists

**Design Principles**

- Increasing rate of (ii) + (iii)
  - (i) < (ii) + (iii)
- Increasing uniformity in development

**Development steps**

(i) Penetration of developer into film
- Hydrophilic surface (polymer)

(ii) Acid-base equilibrium
- High pKa acidic group (ionization degree)

\[
\text{OH} + \text{OH}^- \rightleftharpoons \text{O}^- + \text{H}_2\text{O}
\]

(iii) Solvation of polymer
- Hydrophilic polymer
- Low molecular weight polymer
- Weak intermolecular interaction polymer

(iv) Diffusion into solvent layer
Penetration speed control with developer molecular size

TMAH (0.26N) □ TBAH (0.26N)

Δfrequency, (Hz)

Development time, sec

TMAH
Diameter ~ 4.2 Å

TBAH
Diameter ~ 10.6 Å
Penetration speed control with polymer hydrophilicity

Variation of hydrophilic monomer ratio in co-polymer

Δfrequency, (Hz)

Development time, sec

Less hydrophilic

Much hydrophilic
Solvation speed control with polymer Mw

Small Mw
Less tangled
Easy to be solvated

Large Mw
Much tangled
Hard to be solvated

Small Mw

Development time, sec
0 mJ
9 mJ

Development time, sec
Development time, sec
0 mJ
9 mJ
4 mJ

Polymer Mw

Small
Large
Non-alkaline developer

**Design Principles**

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(iii) Solvation of polymer
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Low swelling property with solvent type developer

Low swelling character of negative tone development

QCM analysis result

Resist: FAiRS-9101A12
Negative Dev.
Low swelling character of negative tone development

- Negative development
- Negative development rinse
- Positive development
Non-uniform deprotection also causes swelling

Half-exposed area consists of mixture of polymers

HPLC

QCM

Fully exposed film (10 mJ)

Un exposed film

Half exposed film (5, 6 mJ)
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Trade-off relation between collapse and RLS

<table>
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<th>Addressing to collapse</th>
<th>Controlled property</th>
<th>Trade-off relation</th>
<th>Remark</th>
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<tbody>
<tr>
<td>scCO2 development</td>
<td>Surface tension</td>
<td>N      N    N</td>
<td></td>
</tr>
<tr>
<td>FIRM rinse</td>
<td>Surface tension</td>
<td>N      N    N</td>
<td></td>
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<tr>
<td></td>
<td>CA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrophobic resist</td>
<td>CA</td>
<td>N      (N) N</td>
<td>Un-uniform dissolution property</td>
</tr>
<tr>
<td></td>
<td>Swelling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TBAH developer</td>
<td>Swelling</td>
<td>N      N    N</td>
<td></td>
</tr>
<tr>
<td>Small Mw polymer</td>
<td>Swelling</td>
<td>(N)    N    N</td>
<td>Smaller Tg</td>
</tr>
<tr>
<td>Organic developer</td>
<td>Swelling</td>
<td>(N)    N    N</td>
<td>Smaller dissolution contrast</td>
</tr>
<tr>
<td>Uniform de-protection</td>
<td>Swelling</td>
<td>N      N    N</td>
<td></td>
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Basically, there’s no trade-off relation between collapse and RLS.
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Conclusions

✓ Capillary force is a major factor in collapse.

Reducing surface tension, increasing contact angle, and suppressing swelling property are effective to fix collapse.

✓ Basically, there would be no trade-off relation between collapse and RLS performance.