Reduction of LWR by Advanced Polymer bound PAG based EUV resist

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Outline

1. Background
2. Acid diffusion study
3. LWR improvement by advanced PAG polymer
4. Image contrast enhancement
5. Smoothing process
6. Summary
Background

Key Gap for 22 nm Patterning

- Key Gaps for 22 nm HP Patterning
  1. LWR
  2. Collapse
  3. Sensitivity
  4. Resolution
  5. Defect (bridge/scum)
  6. Pattern transfer with thin resist

Goal: 22 nm HP 10mJ/cm² 1.4 nm

Kyoungyong Cho, EUV Symposium, Kobe 2010
Photon comparison ArF vs. EUV

Fig. 1 - A comparison of photon counting at ArF and EUV in a volume when absorbance coefficient and dose are constant across wavelength. About 14X fewer photons are absorbed at EUV vs. ArF.

\[ \text{ArF, } 10 \text{ mJ/cm}^2, \alpha = 4/\text{um} \]
\[ n_{\text{absorbed}} = 366528, \ E_{\text{absorbed}} = 2354 \text{ keV} \]

\[ \text{EUV, } 10 \text{ mJ/cm}^2, \alpha = 4/\text{um} \]
\[ n_{\text{absorbed}} = 25328, \ E_{\text{absorbed}} = 2326 \text{ keV} \]

X1/14 fewer photons at EUV

John J. Biafore, SPIE 2009, Vol.7273, 727343
Shot noise impact on LWR

Fig. 7 - Simulation of photon absorption and the acid shot noise image, at EUV, 30 nm lines, 2-beam imaging, Esize. Simulated quantum efficiency is 1.74. Acid 'clumps' are visible about photon absorption sites.

\[
\Phi = \frac{33116 \text{ acids}}{19059 \text{ abs. photons}}
\]

\[
\Phi = 1.74
\]

\[
\text{avg. dist. between acids} = 4 \text{nm}
\]

John J. Biafore, SPIE 2009, Vol.7273, 727343
Acid diffusion impact on LWR

Shorter acid diffusion and smaller LWR with low temperature PEB

Trade off sensitivity

Roel Gronheid, SPIE 2011, Vol.7969, 796904
ADI surface roughness dependence on acid diffusion length

Experimental

Acid contained TC
Resist Polymer
Si

Bake 60sec + Develop

Polymer
Si

Roughness Increases as the acid diffusion increases.
This result indicates that the acid diffuses heterogeneously.

Shorten the acid diffusion should achieve better LWR.

Surface Roughness on AFM Image

RMS 3.6nm
RMS 10.0nm

Film Loss (Å)

Bake Temp (°C)

85 90 95 100 105
Surface roughness comparison between PAG blend and bound

Bound PAG shows better roughness than that of blend at the same film loss. This result indicates that acid diffusion in bound PAG polymer film is more homogeneous, and result in better LWR.
PAG Bound Polymer Characteristics

EUV interferometric exposure at PSI

<table>
<thead>
<tr>
<th>PAG Type</th>
<th>$p$ (nm)</th>
<th>$\lambda$ (nm)</th>
<th>$\nu$ (s$^{-1}$)</th>
<th>$E_s$ (mJ/cm$^2$)</th>
<th>$d$ (nm)</th>
<th>EL</th>
<th>LWR (nm)</th>
<th>$L_d$ (nm)</th>
<th>$K_{LUP}$</th>
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<tr>
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<td>90</td>
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<td>0.11</td>
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<td>0.24</td>
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The shortest acid diffusion and lowest LWR can be attained with anion bound PAG.

Courtesy of IMEC
PAG Modification 1st step
Bulky anion

26nmLS

10.0mJ/cm²
LWR6.4nm

14.7mJ/cm²
LWR5.6nm

Bulky anion bound PAG acid diffusion length shows half of ref., which successfully reduces LWR.

EUV MET
NA0.3 0.36/0.68
Quadrupole
Resist FT 40nm

EUV Symposium 2012 in Brussels
PAG Modification 2nd Step
Bulky cation

10.0mJ/cm²
LWR6.4nm

11.24mJ/cm²
LWR4.7nm

Bulky cation bound PAG acid diffusion length reduces LWR.

Bulky cation reduces OOB effect and outgas

EUV MET
NA0.3 0.36/0.68
Quadrupole
Resist FT 40nm
PAG Modification 3\textsuperscript{rd} Step
Bulky anion / cation

<table>
<thead>
<tr>
<th>PAGx1.0</th>
<th>Qx1.0</th>
<th>26nmLS</th>
<th>24nmLS</th>
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<td>Dose 11.00mJ/cm\textsuperscript{2}</td>
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<td>LWR 6.4nm</td>
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<table>
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<td>LWR 4.5nm</td>
<td>LWR 5.4nm</td>
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Combination of bulky cation and bulky anion
Higher concentration of small diffusion PAG improves LWR.

EUV MET
NA0.3 0.36/0.68
Quadrupole
Resist FT 40nm
Higher sensitivity & better LWR design

Concept for advanced sensitizer design
1) Higher ionization efficiency
2) Improve LWR, prevent collapse

Phenolic sensitizer reduces swelling to improve collapse. Excess sensitizer causes film loss and collapse.

Prof. Kozawa and Tagawa SPIE Vol. 5753 (2005)
Hydrophobisity control for LWR improvement

Big polarity difference

Small polarity difference

Hydrophilic

Hydrophobic

Small polarity variation shows smaller LWR

Monomer cLogP

24nmLS

Dose 17.90mJ/cm²
LWR 4.5nm

Dose 18.90mJ/cm²
LWR 4.0nm

EUV MET
NA0.3 0.36/0.93
Quadrupole
Resist FT 40nm
ED window expansion by smaller LWR

**Resist A**
- 75nm FT
- 30nmLS

**Resist B**
- 75nm FT
- 30nmLS

**Resist C**
- 60nm FT
- 28nmLS

**TMAH development**
- DIW Rinse

**EUV MET**
- NA0.3 0.36/0.68 Quadrupole

**LWR**
- 5.2
- 4.8
- 3.8

**Minimum CD**
- 23.8nm

**ED window expansion by smaller LWR**

**Improved PW and collapse with smaller LWR**

*IBM®*
Image contrast enhancement

22nmLS

LWR 5.2nm

NA blocker
Design 22nmLS

EUV ADT
NA0.25
NA Blocker


Resolution enhancement & LWR improvement by high contrast optical image
Post development smoothing process

Summary

1. Bulky anion / bulky cation of small diffusion PAG with high loading to improve LWR. PAG is dominant for progress.
2. Sensitizer and polarity control to improve LWR.
3. PW expansion by LWR improvement.
4. High contrast images to improve LWR.
5. Post development smoothing process to reduction LWR.
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