Molecular resists for EUV lithography

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Molecular Resist - xMT

Molecular resin

Crosslinker

PAG
### Acid Diffusion Resistance

<table>
<thead>
<tr>
<th>Acid Concentration (mC/cm²)</th>
<th>PHOST Diameter (nm)</th>
<th>PBOCST Diameter (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>104 pC/cm²</td>
<td>21.2 nm</td>
<td>16.7 nm</td>
</tr>
<tr>
<td>117 pC/cm²</td>
<td>21.0 nm</td>
<td>16.8 nm</td>
</tr>
<tr>
<td>133 pC/cm²</td>
<td>20.4 nm</td>
<td>15.9 nm</td>
</tr>
<tr>
<td>150 pC/cm²</td>
<td>20.7 nm</td>
<td>17.3 nm</td>
</tr>
<tr>
<td>169 pC/cm²</td>
<td>24.9 nm</td>
<td>17.1 nm</td>
</tr>
<tr>
<td>191 pC/cm²</td>
<td></td>
<td>18.1 nm</td>
</tr>
<tr>
<td>216 pC/cm²</td>
<td></td>
<td>20.3 nm</td>
</tr>
</tbody>
</table>

(a) and (b) show images of acid diffusion resistance tests with corresponding measurements in μC/cm² and nanometers.
Proposed Two Step Scheme

Chemical reactions and molecular structures are depicted in the image, illustrating a proposed two-step scheme for a chemical process.
xMT-110

Molecular resin

Crosslinker

PAG

Quencher

Non-nucleophilic base
30 kV Electron Beam Exposure

**IM-Resist IM-xMT-110**
Resist without quencher added

- **Pitch:** 50nm
  - **Lines:** 19.5nm
  - **Dose:** 195 pC/cm
  - **LWR:** 3.5nm

- **Pitch:** 46nm
  - **Lines:** 18.5nm
  - **Dose:** 214 pC/cm
  - **LWR:** 3.2nm

- **Pitch:** 38nm
  - **Lines:** 17.8nm
  - **Dose:** 214 pC/cm
  - **LWR:** 4.0nm
193nm Contrast Curve

**IM-EUV-XMT-110 Photospeed Curve**

**DOW PROCESS CONDITIONS**

|                |  
|----------------|---
| **BARC**       | DOW BARC  
| **RESIST THICKNESS (Å)** | 400  
| **SOFT BAKE (SB)** | 105 deg / 180 s  
| **POST EXPOSURE BAKE (PEB)** | 90 deg / 60s  
| **DEVELOPER** | NBA  
| **DEVELOPER PUDDLE TIME** | 60s  
| **COAT/DEVELOP TRACK** | TEL ACT8  
| **EXPOSURE TOOL** | ASM-1100  

\[ E_{50} : \quad 1.4 \text{ mJ/cm}^2 \]

\[ \text{Contrast:} \quad 2.86 \]
Molecular Resist – xMT-213

Molecular resin

Crosslinker

PAG

Quencher
30 kV Electron Beam Exposure

**IM-Resist IM-xMT-213** (lower sensitivity, higher resolution)

- p50nm dose 690 pC/cm, LWR 2.5nm
- p46nm, dose: 690 pC/cm, LWR 2.4nm
- p38nm, dose: 429pC/cm, LWR 2.5nm
- p32nm, dose: 354 pC/cm, LWR 2.4nm
- p28nm, dose: 311 pC/cm, LWR 3.0nm
- p26nm, dose: 311pC/cm, LWR 4.1nm
50 kV Electron Beam Exposure

IM-Resist IM-xMT-110  Dose 170pC/cm
100 kV Electron Beam Exposure

100 kV

(a) Pitch: 30 nm
CD: 13.8 nm

(b) Pitch: 28 nm
CD: 12.5 nm

200 nm
EUV - PSI - 16 nm hp

CD: 16.9 nm
Dose: ~30 mJ/cm²
LER: 2.15 nm
LWR: 2.94 nm

Exposure Latitude 17.4% in a separate test (LWR 3.1 nm)
Optimization of xMT

last year

13.9 nm, 8.07 nm LWR

13.9 nm, 3.56 nm LWR

11.9 nm, 5.9 nm LWR
Active Underlayer

18 nm hp

Bare silicon

Active underlayer
Quencher level

0% quencher
- CD: 14.2 nm
- Dose: 24.3 mJ/cm²
- LER: 6.27 nm

2% quencher
- CD: 14.0 nm
- Dose: 36.1 mJ/cm²
- LER: 3.26 nm

5% quencher
- CD: 14.1 nm
- Dose: 51.9 mJ/cm²
- LER: 3.01 nm
NXE3300 @imec

FT 32 nm, bare silicon

hp 22nm
Dose 32.0 mJ/cm²
CD 22.3 nm
LWR 4.04 nm
LER 3.55 nm

hp20
Dose 33.5 mJ/cm²
CD 21.7 nm
LWR 4.97 nm
LER 3.70 nm

hp19nm
Dose 33.5 mJ/cm²
CD 20.1 nm
LWR 4.34 nm
LER 3.31 nm
Metal Resists

- Fullerene 2.0 - metal complex
- Hybrid Type I - blend
- Hybrid Type II - bound
Limitations of chemical amplification

Shot Noise

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

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

J.J. Biafore et al, doi: 10.1117/12.813551
Fullerene - Metal Complex - Increasing Cross-section

Data from CXRO
Fulleropyrrolididene-Bipyridine-Platinum Complex

\[ \text{Fulleropyrrolididene-Bipyridine-Platinum Complex} \]
Sensitivity Improvement

EUV response curves (PSI Open Frame)

C$_{60}$-Bpy (control)

C$_{60}$-Bpy-Pt

C$_{60}$-Bpy: 1121 mJ/cm$^2$
C$_{60}$-Bpy-Pt: 694 mJ/cm$^2$
Metal Complex Resist - EUV
One Pt atom is good – two must be better

$C_{60}$-BisBpy

$C_{60}$-BisBpy-Pt
EUV Exposure

![Graph showing normalized retained film thickness versus dose for different materials.](image-url)
EBL Exposure

![Graph showing EBL Exposure]

- Normalized Retained Film Thickness vs. Dose (mC/cm²)
- Different curves represent different materials:
  - $C_{60}$-Bpy
  - $C_{60}$-Bpy-Pt
  - $C_{60}$-BisBpy
  - $C_{60}$-BisBpy-Pt

Cylindrical Condenser Lens (CCL)
## Sensitivities and Contrasts

<table>
<thead>
<tr>
<th></th>
<th>$E_{50%}$</th>
<th>$\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EUV</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C_{60}$-Bpy</td>
<td>1122</td>
<td>6.5</td>
</tr>
<tr>
<td>$C_{60}$-Bpy-Pt</td>
<td>694</td>
<td>4.2</td>
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<tr>
<td>$C_{60}$-BisBpy</td>
<td>738</td>
<td>5.1</td>
</tr>
<tr>
<td>$C_{60}$-BisBpy-Pt</td>
<td>697</td>
<td>6.4</td>
</tr>
<tr>
<td><strong>EBL</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C_{60}$-Bpy</td>
<td>9</td>
<td>4.3</td>
</tr>
<tr>
<td>$C_{60}$-Bpy-Pt</td>
<td>4</td>
<td>2.3</td>
</tr>
<tr>
<td>$C_{60}$-BisBpy</td>
<td>6</td>
<td>3.9</td>
</tr>
<tr>
<td>$C_{60}$-BisBpy-Pt</td>
<td>6</td>
<td>9.5</td>
</tr>
</tbody>
</table>
Electron Scattering

Inelastic Mean Free Path

Elastic Scattering Cross-sections

Data from http://www.ioffe.rssi.ru/ES/Elastic/
Inelastic Mean Free Path

Data from http://www.nims.go.jp/research/organization/hdfqf1000000isjt-att/hdfqf1000000ispa.pdf
Carbon, Rhenium, Platinum

Graphs showing the total cross-section (cm²) and mean free path (Å) for different electron energies (eV) for Carbon, Rhenium, and Platinum. The graphs indicate elastic and inelastic scattering.

- Elastic scattering
- Inelastic scattering
Rhenium Complex

Re Complex

Control

41.6 nC/cm

132.9 nC/cm
Bis Platinum Complex

Bis Pt Complex

Control

46 nC/cm

46 nC/cm

Bis-Pt P50 D46 F

Bis-control P50 D46
Metal Complex Material

Graph showing the relationship between dose and normalized thickness for ML568, ML356, and ML296. The figure includes chemical structures and images of the materials.

ML568
ML356
ML296

Graphic representations of the materials under examination.
SHIBL – C_{60}-bpy-Pt

hp 10 nm
Dose: 34 pC/cm

hp 7.5 nm
Dose: 55 pC/cm

hp 6.5 nm
Dose: 45 pC/cm
Metal Hybrid Resist

Hybrid Type I

Metal additive blended with xMT

Hybrid Type II

Metal bonded to xMT structure
Metal Hybrid Resist - Type I

Control Material

Improvement in performance

Hybrid-I A
hp: 14 nm
Dose: 23.3 mJ/cm²
CD: 16.3 nm
LER: 5.1 nm

Hybrid-I B1
hp: 14 nm
Dose: 23.1 mJ/cm²
CD: 14.9 nm
LER: 4.6 nm

Hybrid-I B2
hp: 14 nm
Dose: 19.4 mJ/cm²
CD: 14.4 nm
LER: 6.0 nm

Hybrid-I C
hp: 14 nm
Dose: 20.6 mJ/cm²
CD: 15.0 nm
LER: 6.7 nm

Reduction in performance

Hybrid-I D
hp: 14 nm
Dose: 23.4 mJ/cm²
CD: 16.3 nm
LER: 9.7 nm

Hybrid-I E
hp: 14 nm
Dose: 33.0 mJ/cm²
CD: 14.4 nm
LER: 4.57 nm
Metal Hybrid Resist - Type I

- Normalized Sensitivity
- Number of metal atoms in solution (E+17)

Graph showing the relationship between normalized sensitivity and the number of metal atoms in solution.
### Metal Hybrid Resist – Type I (+ve tone)

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Hybrid-I F</th>
<th>Hybrid-I G</th>
</tr>
</thead>
<tbody>
<tr>
<td>hp:</td>
<td>18 nm</td>
<td>18 nm</td>
<td>18 nm</td>
</tr>
<tr>
<td>Dose to mask:</td>
<td>290 mJ/cm²</td>
<td>183 mJ/cm²</td>
<td>-</td>
</tr>
<tr>
<td>Dose:</td>
<td>38 mJ/cm²</td>
<td>~24 mJ/cm²</td>
<td>19.3 mJ/cm²</td>
</tr>
<tr>
<td>CD:</td>
<td>17.7 nm</td>
<td>17.6 nm</td>
<td>17.4 nm</td>
</tr>
<tr>
<td>LER:</td>
<td>2.0 nm</td>
<td>3.2 nm</td>
<td>8.4 nm</td>
</tr>
</tbody>
</table>
Acknowledgements

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Any questions?

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