ALTERNATIVE EUV MATERIALS STATUS AT IMEC

Resist TWG meeting EUV Resists / Alternative Materials
Maastricht Oct 4th, 2015
Danilo De Simone
CONTENT

» EUV: where we are today
  - RLS & NXE requirements
  - The Universe of EUV resists today

» The introduction to the imec Lab-to-Fab concept
  - EUV photo materials vs the imec pathfinding

» Summary
At the last EUVL symposium, resist RLS has been ranked as 2nd critical item after source power in terms of critical items (last year it was ranked 4th).

Key challenges today:

i) Have an high Resolution resist with high Sensitivity, excellent LER and Etch Resistance

ii) Have a resist platform with high extendibility to the next nodes
### EUV AND ASML REQUIREMENTS

#### Lithographic options for <10nm patterning

- EUV, the choice for wafer manufacturing

<table>
<thead>
<tr>
<th>Resolution [nm]</th>
<th>32</th>
<th>27</th>
<th>22</th>
<th>16</th>
<th>13</th>
<th>10</th>
<th>7</th>
<th>&lt;7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength [nm]</td>
<td>0.25</td>
<td>0.33</td>
<td>0.33NA DPT</td>
<td>0.33NA DPT</td>
<td>0.33NA DPT</td>
<td>0.33NA DPT</td>
<td>0.33NA DPT</td>
<td>0.33NA DPT</td>
</tr>
<tr>
<td>NA</td>
<td>0.25</td>
<td>0.33</td>
<td>0.33NA DPT</td>
<td>0.33NA DPT</td>
<td>0.33NA DPT</td>
<td>0.33NA DPT</td>
<td>0.33NA DPT</td>
<td>0.33NA DPT</td>
</tr>
<tr>
<td>Lens flare</td>
<td>8%</td>
<td>6%</td>
<td>4%</td>
<td>4%</td>
<td>4%</td>
<td>4%</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td>Illumination coherence</td>
<td>α=0.5</td>
<td>α=0.8</td>
<td>α=0.2-0.9</td>
<td>Flex-OAI</td>
<td>Extended Flex-OAI</td>
<td>reduced pupil fill ratio</td>
<td>reduced pupil fill ratio</td>
<td>reduced pupil fill ratio</td>
</tr>
<tr>
<td>Imaging CDU [nm]</td>
<td>-</td>
<td>2.0</td>
<td>1.7</td>
<td>1.3</td>
<td>1.1</td>
<td>1.0</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>DCO [nm]</td>
<td>7</td>
<td>4.0</td>
<td>3.0</td>
<td>1.5</td>
<td>1.4</td>
<td>1.2</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>MMO [nm]</td>
<td>-</td>
<td>7.0</td>
<td>5.0</td>
<td>2.5</td>
<td>2.0</td>
<td>1.7</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Dose [mJ/cm²]</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>TPT (300mm)</td>
<td>3</td>
<td>10 - 105</td>
<td>80 - 250</td>
<td>250</td>
<td>250</td>
<td>50</td>
<td>165</td>
<td>165</td>
</tr>
<tr>
<td>Power [W]</td>
<td>-</td>
<td>6 - 60</td>
<td>50 - 125</td>
<td>125</td>
<td>125</td>
<td>125</td>
<td>125</td>
<td>125</td>
</tr>
<tr>
<td>Throughput [W/hr]</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Source: Alex Chen Photopolymer Conference, Chiba JP 2015

- High sensitivity resist is still required and still an issue for the RLS triangle
- at imec: ASML NXE:3300 and TEL Lithius Pro Z EUV (since July’15)
THE UNIVERSE OF EUV RESISTS TODAY IS NOT CAR-PTD ONLY

Research focus increased significantly in the last years on alternative resists by various groups

The resist development has to deal with multiple challenges:

- Blur effect
- Low Mechanical strength
- Resist non-homogeneity
- Stochastic effects
- Low Photons Absorption
- Fast Dissolution rate
- Poor Etch resistance

MCR = Metal containing Resist
THE UNIVERSE OF EUV RESISTS TODAY

Research focus increased significantly in the last years on alternative resists by various groups

Molecular Resist

Ancillary Materials:
(LEF, smoothing post process, DDRM,..)

MCR = Metal containing Resist

conventional resists

not conventional resists

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• Blur effect
• Low Mechanical strength
• Resist non-homogeneity
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• Poor Etch resistance

EUVL

CAR PTD

CAR NTD

Photo Condensable Resist MCR

Sensitizer Resist MCR

Nano Particles MCR

NT Resist

CONVENTIONAL RESISTS

ALTERNATIVE MATERIALS (e.g., HEF, smoothing post process, DDRM,..)

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The resist development has to deal with multiple challenges:

- Blur effect
- Low Mechanical strength
- Resist non-homogeneity
- Stochastic effects
- Low Photons Absorption
- Fast Dissolution rate
- Poor Etch resistance

The large and complex landscape of EUV resist requires a new approach to Develop, Evaluate, Optimize and Integrate novel EUV resist into a Manufacturing Flow (that is not screening only).

Research focus increased significantly in the last years on alternative resists by various groups.
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THE IMEC PATH FINDING FOR EUV PHOTO MATERIALS

not at imec

- Lab - Phase 0
  - Concept and Explore

- Novel Resists

at imec

- Lab-to-Fab - Phase I
  - Manufacturing Compatibility

- Lab-to-Fab - Phase II
  - Patterning

- Fab - Phase III
  - Integration in a Module

Novel Resists + Conventional Resists

Complexity, Maturity and Time
COMPLEXITY OF EACH PHASE

Phase I – Lab-to-Fab
- Aging
- Rework feasibility
- Defectivity exploration
- Process flow definition
- Cleanroom compatibility
- Incoming material check
- Contamination Studies (metals) at tool level

Phase II – Lab-to-Fab
- Resolution
- Defectivity
- Sensitivity
- Roughness
- Process Window
- Fundamentals
- Modeling
- Patterning on full field EUV scanner

Phase III - Fab
- Contamination schemes
- New patterning methods
- Integration in a module
- Integration in a process flow
- Rework
- Wet etch
- Dry etch
- Contamination at wafer level
- Applications
KEY STEPS FOR INITIAL MATERIAL PERFORMANCE CHECK

Phase I – Lab-to-Fab
- Incoming material check
- Contamination Studies (metals..) at tool level
- Cleanroom compatibility
- Outgassing Hydrides
- Process flow definition
- Defectivity exploration
- Aging
- Rework feasibility
- Defectivity

Phase II – Lab-to-Fab
- Resolution
- Defectivity
- Sensitivity
- Roughness
- Patterning on full field EUV scanner
- Modeling
- Process Window

Phase III - Fab
- Contamination schemes
- New patterning schemes
- Integration in a module
- Dry etch
- Wet etch
- Rework
- Integration in a process flow
- Contamination at wafer level
- Applications
MCR - CROSS CONTAMINATION AT TOOL LEVEL

- 6 different metal containing materials tested at imec at level 1 or 2
- Possible risk of contamination at HVM level demonstrated
- For RD activities cross contamination always within the imec warning limit spec (1E10 at/cm²).

Now:
- For RD purpose cross contam test is not required if:
  - Metal resist is compatible with existing track configuration
  - Metal type is 1 or 2 compliant.
- However:
  - X-contam. test is recommended to increase knowledge and confidence.
  - It is mandatory for metal with level 3 or higher classification
  - It is mandatory for selected samples that move to the integration phase, marathon test included.

IMEC has created the conditions to safely address and speed up the evaluation of novel metal resists.

Mendeleev Table
Imec contamination risk by element:
Level 5 = highest risk
White = not assessed yet.
**MCR – OUTGAS & NEW RISK ASSESSMENT**

**OUTGAS** Spec before Mar2015: $\text{CC} \leq 10\text{nm (NXE3300)}$  \hspace{1cm} $\text{NCC} \leq 0.16\% (\text{NXE3300})$

- **2015 spec conv. CAR:** No testing required
- **2015 spec novel materials:** Waiver for limited NXE exposures can be obtained from ASML

**HYDRIDES:** New risk assessment is required that mimics optics contamination in scanner environment

[N. Harned, IEUVI Resist TWG, Feb'2015]

- MCRs present a metal contamination risk in the scanner environment where H2 is present due to the potential formation of metal hydrides ($\text{Mx-Hy}$)

ASML targets a response to the material supplier within 1 month

See Session 2 today TWG meeting

Outgassing of CAR and Alternative Resists: The way forward (Gijsbert Rispens, ASML)
LEADING EDGE EUV RESISTS VS RESOLUTION

Key issue today is the resist sensitivity: Dose is >>20mJ
Some textual content is not displayed in the image.
LEADING EDGE EUV RESISTS VS FILM THICKNESS

Resist Thickness (nm) - ITRS

- N10
- N7
- N5
- N3

Pattern transfer has to be proven

Metal can improve the etch resistance

Novel process module integration schemes should support the development of very thin resist.
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SUMMARY

Status-of-the art lithography tools are available at imec to explore EUV photo materials at leading edge technology.

IMEC has initiated the exploratory work and has introduced the Lab-to-Fab concept with focus on EUV materials.

**Novel Materials** are under investigation at different stages today.

**MCR** are showing **promising imaging results** comparable to CAR.

**RLS** targets, manufacturing compatibility for MCR and demonstration of integration into a real device are the challenges today.
ACKNOWLEDGEMENTS

▸ ALL THE MATERIAL SUPPLIERS AT IMEC (INPRIA, TOK, JSR, FFEM, NISSAN CHEMICAL, MERCK, BREWER SCIENCE) FOR CONTINUOUS COLLABORATION ON THE DEVELOPMENT OF NOVEL EUV PHOTO MATERIALS.

▸ ALL THE EQUIPMENT SUPPLIERS AT IMEC (ASML, SCREEN AND TEL) FOR CONTINUOUS COLLABORATION AND SUPPORT.

▸ MY COLLEAGUES AT IMEC: IVAN POLLENTIER, PHILIPPE FOUBERT, MIEKE GOETHALS, NADIA VANDENBROECK, CONTAMINATION GROUP, ERIC HENDRICKX, GEERT VANDENBERGHE, KURT RONSE, GREG McINTYRE
Thank-you for Your Attention

Q&A