Negative Tone Imaging in EUV

Shinji Tarutani¹)
Takanobu Takeda¹), Wataru Nihashi¹), Shuuji Hirano²), Natsumi Yokokawa²), Hiroo Takizawa²)

Research & Development management headquarters
1) Electronic Materials Research Laboratories
2) Synthetic Organic Chemistry Laboratories

FUJIFILM Corporation
Outline

1. Motivation of this work
2. Advantage of negative tone imaging in EUV
3. Process and material strategy in EUV-NTI
4. Lithography performances
5. Summary
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Motivation of this work

NTI in ArF immersion

NA = 1.2, Immersion (Water), Y Oriented Polarization, Dipole Radius: 0.1
128 nm Pitch 1:3 Pattern Simulation

Bright Mask
Line: Posi Resist
Trench: Nega Resist

Dark Mask
Line: Nega Resist
Trench: Posi Resist

Wide white area
Enough intensity
Large contrast

Narrow white area
Weak intensity
Poor contrast

What will happen in EUV?
Motivation of this work

<table>
<thead>
<tr>
<th></th>
<th>EUV</th>
<th>ArF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>13.5 nm</td>
<td>193 nm</td>
</tr>
<tr>
<td>Total photon number</td>
<td>Large</td>
<td>Large</td>
</tr>
<tr>
<td>Flare</td>
<td>Large (~% order)</td>
<td>Small</td>
</tr>
<tr>
<td>Resist</td>
<td>PHS based</td>
<td>(Meth)acrylate based</td>
</tr>
</tbody>
</table>

Compared to PTI

Does NTI work well in EUV?
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Advantage of negative tone imaging in EUV

Simulations at 0.25NA (NXE:3100)

Simulator: Sentaurus Lithography version G-2012.06

Illumination: 0.25 NA, 0.81 σ, Conventional

Target feature, mask:

30 nm 1:1 C/H, Mask bias : 0 ~ 15 nm, 2.5 nm step
30 nm isolated C/H, Mask bias : 0 ~ 15 nm, 2.5 nm step
28 nm isolated trench, Mask bias : 0 ~ 12 nm, 2 nm step

Flare:

For NTI: 0 ~ 7%, 1% step
For PTI: 0 ~ 2%, 0.2% step

Output:

NILS, Max irradiance (sensitivity)
Advantage of negative tone imaging in EUV

Simulations at 0.25NA (NXE:3100), 30 nm 1:1 C/H
Parameter: flare and mask bias

- Larger flare
- Larger mask bias

- 5% flare
- 2% mask bias
- 0% mask bias

Max Irradiance vs. NILS graph
Advantage of negative tone imaging in EUV

Simulations at 0.25NA (NXE:3100), 30 nm isolated C/H
Parameter: flare and mask bias

Larger flare
Larger mask bias
Advantage of negative tone imaging in EUV

Simulations at 0.25NA (NXE:3100), 30 nm isolated C/H
Parameter: flare and mask bias

- 5% flare
- +7.5 nm mask bias
- +48% photons
- Larger mask bias
- Larger flare
Advantage of negative tone imaging in EUV

Simulations at 0.25NA (NXE:3100), 30 nm isolated trench
Parameter: flare and mask bias

Larger mask bias

Larger flare
**Advantage of negative tone imaging in EUV**

Simulations at 0.25NA (NXE:3100), 28 nm isolated trench

Parameter: flare and mask bias

- **5% flare**
- **+6 nm mask bias**
- **+53% photons**
- **Larger mask bias**
- **Larger flare**
Advantage of negative tone imaging in EUV

Short summary on simulations at 0.25NA (NXE:3100)

Dense C/H
- PTI can affords high NILS around 2.8, however, photon number is not sufficient.
- NTI affords 2.5 NILS under 5% flare, with good photon number.
- Lower flare gives much advantage to NTI.

Iso C/H and trench
- PTI can affords high NILS around 3.3, however, photon number is not sufficient.
- NTI affords NILS of 3.0 for C/H and 2.8 for trench, with good photon number (50% more than PTI).
- Lower flare gives much advantage to NTI.

Challenges in NTI:
- Resolution of resist (resolution at low NILS, not so critical)
- Optics (low flare, not so critical)

NTI has big advantage in photon number!!
Advantage of negative tone imaging in EUV
Simulations at 0.33NA (NXE:3300B)

Simulator: Sentaurus Lithography version G-2012.06
Illumination: 0.33 NA, 0.9 σ, Conventional
Target feature, mask:
   24 nm 1:1 C/H, Mask bias : 0 ~ 10 nm, 1 nm step
   24 nm isolated C/H, Mask bias : 0 ~ 10 nm, 1 nm step
Flare:  0 ~ 3%, 0.5% step
Output: NILS, Max irradiance (sensitivity)
Advantage of negative tone imaging in EUV

Simulations at 0.33NA (NXE:3300B), 24 nm 1:1 C/H
Parameter: flare and mask bias

- Larger flare
- Larger mask bias

Max Irradiance

Larger mask bias
3% 0%

PTI
NTI

0% 3%

NILS
2 3 4
Advantage of negative tone imaging in EUV

Simulations at 0.33NA (NXE:3300B), 24 nm isolated C/H
Parameter: flare and mask bias

Larger flare

Larger mask bias
Advantage of negative tone imaging in EUV

Simulations at 0.33NA (NXE:3300B), 24 nm isolated C/H

Parameter: flare and mask bias

- Larger flare
- Larger mask bias
- 3% flare
- +6 nm mask bias
- +38% photons
Advantage of negative tone imaging in EUV

Short summary on simulations at 0.33NA (NXE:3300B)

Dense C/H
- PTI can affords high NILS around 3.1, however, photon number is not sufficient.
- NTI affords 2.9 NILS under 3% flare, with good photon number.
- Lower flare gives much advantage to NTI.

Iso C/H
- PTI can affords high NILS around 3.1, however, photon number is not sufficient.
- NTI affords NILS of 2.9 for C/H, with good photon number (38% more than PTI).
- Lower flare gives much advantage to NTI.

Challenges in NTI:
- Resolution of resist (resolution at low NILS, not so critical)
- Optics (low flare, not so critical)

"NTI has still big advantage in photon number!!"
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Process and material strategy in EUV-NTI
Approaches to negative tone imaging (ArF)

1. **Negative tone resist materials**
   with conventional **alkaline development process**

2. **Negative tone development process**
   with conventional **ArF immersion resist materials**

**Mechanism of NTD process (ArF)**

- **Hydrophobic polymer**
  - Can dissolve in an organic solvent
  - Can not dissolve in an alkaline solution

- **Exposure & PEB**
  - **De-protection**
  - **Polarity change**

- **De-protected hydrophilic polymer**
  - Can not dissolve in an organic solvent
  - Can dissolve in an alkaline solution

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**Symposium on immersion lithography and extension (2007)**
S. Tarutani et al, FUJIFILM
Process and material strategy in EUV-NTI

Approaches to negative tone imaging (EUV)

*Polarity change at PEB step in resist material*

→ Hydrophobic to hydrophilic

Organic solvent type developer

![Graph showing cLogP values for EE-HS (EUV) and AD-MA (ArF)]

- ΔcLogP EE-HS (EUV)
- ΔcLogP AD-MA (ArF)

To keep short diffusion length
To prevent swelling at dev. step

New material design is needed!!

22% to ArF!!
Process and material strategy in EUV-NTI

Key point on material design

Large cLogP difference at de-protection reaction
Low activation energy for acid diffusion suppression

New material

Comparable cLogP difference
~5% activation energy
to conventional ester type blocking monomer

\[ \Delta \text{cLogP} \]

\[ \text{Ea} \]
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**2012 International Symposium on Extreme Ultraviolet Lithography**

**N1216A4, 1:1 CH**

NA 0.3  
Quad.#97@LBNL

**FT 60nm on org. UL**  
FN-DP001, 30sec,  
Mask bias : None  
21.3 mJ/cm²

<table>
<thead>
<tr>
<th>HP 26nm</th>
<th>HP 25nm</th>
<th>HP 24nm</th>
<th>HP 23nm</th>
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<tr>
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<td><img src="image3.png" alt="Image" /></td>
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<table>
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<th>HP 22nm</th>
<th>HP 21nm</th>
<th>HP 20nm</th>
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<td><img src="image7.png" alt="Image" /></td>
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</tbody>
</table>
2012 International Symposium on Extreme Ultraviolet Lithography

**N1223A4, 1:3 CH**

**FT 60nm on org. UL**

FN-DP001, 30sec, Mask bias : None

**13.8 mJ/cm²**

NA 0.3
Quad.#97@LBNL

26nm 25nm 24nm 23nm

22nm 21nm 20nm
N1223A4, 1:4 CH

FT 40nm on org. UL
FN-DP001, 30sec,
Mask bias : None
13.8 mJ/cm²

NA 0.3
Quad.#97@LBNL

26nm 25nm 24nm 23nm

22nm 21nm 20nm

N.D.
**N1223A4, 1:5 Trench**

- **NA 0.3**
- **Quad.#97@LBNL**

**FT 40nm on org. UL**
- **FN-DP001, 30sec,**
- **Mask bias : None**

**6.25 mJ/cm²**

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**Positive tone resist, P1807A**

**FT 40nm on org. UL**
- **TMAH 2.38%, 30sec, Manual Dev.**
- **Mask bias : None, 21.2 mJ/cm²**
N1216A3, 1:1 LS

FT 40nm on org. UL
FN-DP001, 30sec,
Mask bias : None
21.3 mJ/cm²

Resolution limit of this condition
N1216A3, 1:1 CH

FT 40nm on org.UL
FN-DP001, 30sec
Mask bias : ~40%

NXE:3100
NA 0.25, Conventional

32nm HP
CD 32.0nm
3σ LCDU 1.6nm
21.0 mJ/cm²

31nm HP
CD 31.0nm
3σ LCDU 1.8nm
21.0 mJ/cm²

30nm HP
CD 29.6nm
3σ LCDU 2.6nm
21.0 mJ/cm²

29nm HP
CD 28.6nm
3σ LCDU 3.6nm
20.5 mJ/cm²

28nm HP
20.0 mJ/cm²

27nm HP
20.0 mJ/cm²

26nm HP
20.0 mJ/cm²

25nm HP
19.5 mJ/cm²
Summary

• EUV NTI has good advantage in photon number.

• Challenges in NTI are resist material resolution and optics with low flare.

• New resist material was well designed and synthesized for NTI, which has low activation energy and big cLogP difference at de-protection reaction.

• FEVS-N1216A and N1223A series were evaluated with BMET, and showed 26nm dense C/H, 25nm isolated C/H resolution, 22nm isolated trench resolution. Dense L/S resolution is close to PTI resolution.

• FEVS-N1216A3 showed 30nm HP resolution with good CDU (3σ 2.6nm) at NXE:3100, conventional illumination.
Acknowledgement

NISSAN CHEMICAL INDUSTRIES, LTD.  Providing UL material

ASML  Useful discussions

SEAMATECH  EUV exposure slot arrangements

imec  EUV exposure experiments

BERKELEY LAB  EUV exposure experiments

FUJIFILM  FEUS, FEBE, FFEM
Logistics and experiments supporting
Thank you for your kind attention!!

We strengthen synergies among the wide and diverse range of technologies owned by the Group to create new businesses that shape the future.