Effect of TMAH cleaning solution for removal of contaminants from EUV mask surface

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01 Introduction
- Issues on contaminants on EUV mask

02 Research Objective

03 Experimental Procedure

04 Results and Discussion
- Particle removal on EUV mask surface
- Carbon contamination removal on EUV mask surface

05 Summary
Scaling Scenario: Lithography

G. Chung, “Partnership to build a better future, and leading edge collaboration”, SPCC (2012)
Issues of EUV mask contamination

- **EUV mask contamination**

  - **Particle contamination**
  - **Carbon contamination**

  - **EUV light**
  - **Reflectivity loss**

  - TaBO/TaBN A-L (80nm)
  - Ru C-L (2.5nm)
  - Mo-Si M-L (280nm)
  - Substrate (Quartz)
  - Cond. Film (CrN, 70nm)

  - **Particles**: pattern defects on Si wafer
  - **Carbon contaminant**: pattern CD change

  - Pattern defect on wafer by particle on EUV mask

  - Pattern defect on wafer by particle on EUV mask

  - CD change by carbon contamination on EUV mask

  - CD change by carbon contamination on EUV mask


Particle contamination on EUV mask

- Various type of particle can be deposited on the capping or absorber layer
- All types of particles should be removed from EUV mask surface (Capping, Absorber)

**Critical particle size w/ various materials on 16 nm HP node**

Simulation condition
- Fast Litho tool
- Pseudo-Spectral Time Domain (PSTD) method
- Parameters: n, k, thickness

- **Particles: organic, inorganic, metallic**

![Diagram of particle contamination on EUV mask]

![Graph showing critical size (nm) for different materials (Sn, TaN, W, SiO2, C)]
Issue of carbon contaminant removal

Carbon contaminant was removed from ARC surface but not from Ru surface

Why carbon contaminant not removed from Ru surface ?
- Carbon contaminants on Ru surface have higher density and thickness than on ARC surface ?
- Carbon contaminants have higher adhesion with Ru than ARC surface ?

H. Lee et al., ECS Transactions, 58 (6), 93 (2013)
Research objective

Surface interactions between contaminants and EUV mask surfaces

- **Contaminants**
- **Particles** (inorganic, organic)
- **Carbon contaminant**
- **EUV mask surface**
- **Ruthenium** (Capping layer)
- **Tantalum nitride** (Absorber layer)
Experiments

- **Particle removal test**
  - 2 kinds of particles
    - Silica, PSL standard particles (100 nm, Corpuscular, USA)
  - 3 kinds of surfaces
    - Si wafer, TaN and Ru coated wafer (2 cm x 2 cm)
  - Particle deposition (spin method, particles in DIW)
  - Akrion 0.84 MHz megasonic cleaning with DIW, dNH₄OH and dTMAH

- **Carbon contaminant removal test**
  - Hydrocarbon film deposition on TaN and Ru surface
    - Using PECVD, 40 nm thickness
  - Hydrocarbon removal using solvent based cleaning solution
    - Dimethyl sulfoxide (DMSO) 80% with NH₄OH or TMAH (0.1M), 65 ℃, 20min (dipping)

- **Analysis**
  - Particle removal efficiency measurement
    - Optical microscope (dark field mode, LV-100D, Nikon, Japan)
  - Chemical bonding analysis using FTIR (Nicolet iS50, Thermo Scientific, USA)
    - Multiple internal reflection (MIR) and attenuated total reflection (ATR) method
  - Contact angle analyzer (Phoenix, SEO, KOREA)
Silica particle removal with various surfaces

- PRE of silica particles @ various surfaces

\[ \text{Si} \quad \leftarrow \quad \text{TaN} \quad \leftrightarrow \quad \text{Ru} \]

- Silica particle removal efficiency was very lower @ Si surface even 6hr aging time
- Silica particle was easily removed from Ru surface

\[ \rightarrow \text{ Why PRE is different with surface materials?} \]
Surface interaction (hydrogen bonding)

- Hydrogen bonding between Si surface and oxide particle

- **Si surface and inorganic oxide particles can interact to form hydrogen bonds**
- **Adhesion force of hydrogen bonding is much larger than van der Waals force**

<table>
<thead>
<tr>
<th>Hydrogen bonding with silica ($F_{H-bond}$)</th>
<th>600 nN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Van der Waals force with silica ($F_{vdW}$)</td>
<td>30 nN</td>
</tr>
</tbody>
</table>

Hydrogen bonding analysis (MIR-FTIR)

- Hydrogen bond peak (3300 cm\(^{-1}\)) was measured using MIR-FTIR method
- OH peak is much higher @ Si than TaN surface
  \(\rightarrow\) PRE was much lower @ Si surface

<table>
<thead>
<tr>
<th>Surface</th>
<th>Hydrogen bonding with silica</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>Strong</td>
</tr>
<tr>
<td>TaN</td>
<td>Weak</td>
</tr>
<tr>
<td>Ru</td>
<td>None (only F(_{vdW}))</td>
</tr>
</tbody>
</table>
In case of PSL particle, PRE was lower @ Ru surface than Si and TaN surface

Ru (transition metal) can form chemical bonding with aromatic ring of PSL particle → Increase adhesion force
Effect of TMAH on PSL particle removal

- No effect of cleaning solution on silica particle removal @ Ru surface
- TMAH cleaning with megasonic showed higher PRE on PSL particle from Ru surface
  → TMAH can break the metal-carbon bonding as solvent

TMAH is very effective to remove organic particle from Ru surface
Hydrocarbon film deposition

- RF-PECVD (SRN-501, Sorona, Korea)

<table>
<thead>
<tr>
<th>Process condition</th>
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</thead>
<tbody>
<tr>
<td>Gas ratio (CH₄ : Ar)</td>
</tr>
<tr>
<td>Plasma power</td>
</tr>
<tr>
<td>Temperature</td>
</tr>
<tr>
<td>Chamber pressure</td>
</tr>
</tbody>
</table>

- Density of hydrocarbon film (1.3 g/cm³)

![Graph showing absorbance and wavenumbers](image-url)

- 2870 cm⁻¹: CH₃
- 2924 cm⁻¹: CH₂ and CH
- 2964 cm⁻¹: CH₃
Hydrocarbon removal from TaN and Ru surface

- TMAH can help remove hydrocarbon with DMSO
- Carbon peaks of hydrocarbon film was removed at TMAH added DMSO cleaning solution from TaN surface
- Hydrocarbon film was not removed from Ru surface @ TMAH with DMSO cleaning solution
Hydrocarbon removal from TaN and Ru surface

- Surface images after cleaning process (OM)

<table>
<thead>
<tr>
<th></th>
<th>#1 (DMSO + NH₄OH)</th>
<th>#2 (DMSO + TMAH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TaN surface</td>
<td><img src="image1.png" alt="Image" /> CA: 76°</td>
<td><img src="image2.png" alt="Image" /> CA: 40°</td>
</tr>
<tr>
<td></td>
<td>Not removed Hydrocarbon film</td>
<td>Removed Carbon residue</td>
</tr>
<tr>
<td></td>
<td>200X 100μm</td>
<td>200X 100μm</td>
</tr>
<tr>
<td>Ru surface</td>
<td><img src="image3.png" alt="Image" /> CA: 71°</td>
<td><img src="image4.png" alt="Image" /> CA: 77°</td>
</tr>
<tr>
<td></td>
<td>Not removed Hydrocarbon film</td>
<td>Partially removed Hydrocarbon film</td>
</tr>
<tr>
<td></td>
<td>200X 100μm</td>
<td>200X 100μm</td>
</tr>
</tbody>
</table>

Hydrocarbon film is still remained on Ru surface (partially removed)
Mechanism of hydrocarbon removal

- Hydrocarbon removal in DMSO with TMAH cleaning solution

More difficult to remove hydrocarbon film from Ru surface by transition metal – carbon interaction than those from TaN surface

Summary

● Need to understand the surface interaction between contaminants and substrates in EUV masks

● Silica & PSL particle removal
  - Hydrogen bonding is dominant on oxide particle removal from surface
    → PRE of silica: Si << TaN < Ru
  - PRE of PSL is lower @ Ru surface due to metal – carbon interaction
    → TMAH is effective to enhance organic particle removal from Ru surface

● Hydrocarbon film removal
  - DMSO with TMAH cleaning solution can remove hydrocarbon film from TaN surface
  - More difficult to remove carbon contaminant from Ru surface
    → Transition metal – hydrocarbon interaction between Ru and hydrocarbon film
THANK YOU FOR YOUR ATTENTION!!