New developments in cleaning of EUVL mirrors and reticles

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Outline

• TNO cleaning research and facilities
• SMIRP process
• SMIRP cleaning results
• SMIRP source development
• Conclusions
• Encore
TNO cleaning research and facilities

- Wet cleaning of Ultra Clean Vacuum (UCV) components
- Wet cleaning with Süß cleaner
- Particle removal with \( \text{CO}_2 \) and nano bubbles
- Ultra- and Megasonics for particle removal
- Plasma cleaning

Analytical facilities
- SEM with EDX/WDX
- Particle scanner
- Scanning He Ion Microscope
- XPS
- Ellipsometry
- Mass spectrometry
SMIRP Cleaning Module Concept

- SMIRP (Shielded Microwave Induced Remote Plasma)
  - Large to very small sources possible
  - Line of sight cleaning
  - Tunable Cleaning Rate (CR)
  - Tunable Heat Load (HL)
  - Electromagnetically shielded
  - High efficiency
  - Resonant cavity source
Shielded Microwave Induced Plasma (SMIRP)

At TNO
Science & Industry:
- Semicon
- Medical
- Surface treatment
- Layer deposition
- Research

PATS
CD400
RF source
MW source
Plasma in a bag

Prague, October 18 - 21, 2009
New developments in cleaning of EUVL mirrors and reticles
Cleaning rate Hydrogen

Data shown at EUVL 2008, Lake Tahoe

Carbon removal rate versus Average Power

- 100% duty cycle @ $P_{\text{peak}} = 370 \text{W}$
- 50% duty cycle @ $P_{\text{peak}} = 740 \text{W}$

$P_{\text{avg}} = P_{\text{peak}} \times \text{Duty Cycle}$

Pulse: CW, 500, 250, 130 µs
Pressure: 100 Pa
Flow: 100 sccm
Distance: 1 mm

Temperature versus Duty Cycle

- Carbon on Quartz E
- Metal on Quartz E
- Carbon on Quartz 3x E
SMIRP Cleaning Results

Cleaning Rate vs Heatload

Distance: 6 – 60 mm  CR ↓ HL ↓
Pulse length: 60 – 1000 µs  CR ↑ HL ↑
Pulse power: 110 – 1000 W  CR ↑ HL ↑
Duty cycle: 05 – 16.7 %  CR ↑ HL ↑
Pressure: 50 – 120 Pa  CR ↓ HL ↑
SMIRP Cleaning Results

- Added turbo pump
- Increased flow due to higher pump speed

- Maximum Cleaning Rate: 11.6 nm/hr with ~44 mW/cm² HL
  (10% DC, 100 µs, 1000 W, 35 Pa, 60 mm, 60 min)
- CR and HL depends on Mean Free Path:
  - At lower pressure: increase in efficiency: MFP~CR~HL⁻¹
  - At constant pressure proportionality: CR~HL

<table>
<thead>
<tr>
<th>Pressure [mbar]</th>
<th>Cleaning Rate (nm/hr)</th>
<th>Heat Load (mW/cm²)</th>
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<tr>
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</table>

Cleaning rate & Heat load vs. pressure

- High pump speed
- Low pump speed
SMIRP Cleaning Results

Cleaning Rate vs Heatload

- distance
- pulselength
- pulse power
- dutycycle
- working pressure
- working pressure 2

Cleaning Rate (nm/hr) vs Heatload (mW/cm^2)
SMIRP Cleaning Results

Over-exposure of sample EUV multilayer mirror, equivalent to 11.6 nm C-removal:
- No reflectivity loss
- No degradation of capping layer
- No cross contamination found with XPS analysis

<table>
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<th>Date</th>
<th>Pre</th>
<th>Post</th>
<th>Difference</th>
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<tr>
<td>Date</td>
<td>17-10-08</td>
<td>23-09-2009</td>
<td>48,7 weeks</td>
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<td>$R$ (%)</td>
<td>100,00</td>
<td>99,997</td>
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<td>$CTW96$ (nm)</td>
<td>13,612</td>
<td>13,607</td>
<td>-0,005 nm</td>
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<td>$CTW50$ (nm)</td>
<td>13,555</td>
<td>13,542</td>
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<td>$FWHM$ (nm)</td>
<td>0,581</td>
<td>0,584</td>
<td>0,002 nm</td>
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<tr>
<td>$SE$ peak (nm)</td>
<td>13,36</td>
<td>13,34</td>
<td>-0,027 nm</td>
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</table>

Reflectivity is normalised!
SMIRP advantages

- Large to very small sources possible
- Line of sight cleaning
- Tunable Cleaning Rate (CR)
- Tunable Heat Load (HL)
- Electromagnetically shielded
- High efficiency
- Reliable
- Active species H*, H+
- Other gasses possible
SMIRP Miniaturization

- First working model: 70 x 100 mm cavity size
SMIRP Miniaturization

- Dimensions as small as 30 mm possible for 2.45 GHz MW sources
- Retrofitting possible using standard flanges and feedthroughs
- Smaller sizes possible when using higher MW frequencies
- Solid state power supplies for low power applications
Conclusions

SMIRP cleaning showed:

- No damage to mirrors
- High cleaning rate
- Low heat load
- Good tunability
- Small SMIRP modules are possible
- Lowering pressure increases efficiency

SMIRP plasma cleaning shows good results and can be applicable for EUV mirror cleaning and EUV reticle cleaning
And now………..

For something completely different!
EDICT, a new way for inspection of Mask Blanks

• Finds EUV printable defects in mask blanks or EUV mirrors
• Holographic exposure of resist on blanks and inspection of developed resist
• can be available for pilot lines: inspection by existing metrology tools

Expose, Develop, Inspect, Clean and Test

• Expose resist coated blank to coherent actinic light
• Develop resist
• Inspect with existing tools
• Clean of resist
• Test cleanliness of blank

Patent Pending
EDICT, a new way for inspection of Mask Blanks

Dose variation due to phase shift errors range from a minimum of 100-70% = 30% to a maximum of 100+70% = 170% of the EUV-in dose.

Ergo, the local dose can vary over factor 1-6.

Local dose variations at faults => resist modification.
Thank you for your attention!

We wish to thank:

PTB
ALS
FOM
Carl Zeiss SMT AG