PELLICLE AND THIN FILM SHORT-WAVELENGTH METROLOGY

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## Pellicle requirements

<table>
<thead>
<tr>
<th>Pellicle requirement</th>
<th>HVM Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUV transmission</td>
<td>90% single pass</td>
</tr>
<tr>
<td>Spatial non-uniformity of the transmission</td>
<td>&lt;0.2%</td>
</tr>
<tr>
<td>Angular non-uniformity of the transmission</td>
<td>&lt;300 mrad</td>
</tr>
<tr>
<td>Dynamic heat load</td>
<td>5.6 W/cm² (250 W IF)</td>
</tr>
</tbody>
</table>

Pellicle illumination conditions NXE:3300

@ reticle

NA @ reticle = \frac{\text{NA}}{\text{MAG}}

Projection with MAG 4x

CRAO 6°
NA 0.33

@ wafer

Example
NXE:3300

26 mm
33 mm

\begin{align*}
\text{NA}_{\text{mask}} &= 0.0825 \\
\text{illumination angles (Y-axis) are between } &1.27° \text{ and } 10.73°
\end{align*}
Pellicle illumination conditions NXE: High NA

@ reticle

104 mm

132 mm

@ wafer

Anamorphic Projection, e.g. with
MAG 4x in x
MAG 8x in y
CRAO 6°
NA > 0.5

MAGx = 4(4.8)
MAGy = 8(7.5)

NA_{wafer} = 0.55 \rightarrow NA_{mask_x} \sim 0.1375 (0.115), NA_{mask_y} \sim 0.068(0.073)

illumination angles in X direction are between -7.9(-6.6°) and 7.9°(6.6°)
illumination angles in Y direction are between 2.1°(1.8°) and 9.9°(10.2°)
Ray Tracing Analysis

- Defects on the pellicle can lead to a non-uniform transmission through the pellicle at different reticle coordinates.
- The target specification states a transmission of 90% with <0.2% uniformity.
- Via ray tracing, the influence on the illumination profile of differently sized defects is investigated.

![Diagram of ray tracing analysis](image)

- Defect
- Pellicle
- Projection optics
- Reticle

- NA = 0.33/4

Page 5
Influence of defect size

- Different types of defects are investigated
  - Circular absorber defects
    - 100% absorption
    - 50% absorption
  - Circular hole defects (100% transmission instead of 90% pellicle transmission)
- The defect size (diameter of circular defect) is varied

![Graph showing transmitted intensity vs defect size and reticle coordinate]
Effective pellicle pixel model

\[ T = T_{\text{pellicle}} - T_{\text{defect}} \times \frac{\text{Area}_{\text{defect}}}{\text{Area}_{\text{pellicle\_pixel}}} \]

\[ \text{Area}_{\text{pellicle\_pixel}} \approx d \times (\tan \theta_{\text{max}} - \theta_{\text{min}}) \]

NXE 3300: 420-450µm (2.5 mm stand-off)

NXE High NA: X-direction (~700(600)µm)
Y-direction (~350 (375)µm)

In the worst case (100% absorbing) defects with <20µm diameter size is allowed per effective pellicle pixel (350-700µm)

For off-axis illumination pellicle pixel has to be multiplied with pupil fill factor (PFR), this can reduce the allowed defect size to sub-10µm

For pellicle transmission uniformity metrology even for aggressive dipoles there is no need to resolve pellicle uniformity better than 50µm
Membrane is fixed at **6 mm** distance to the EUV-sensitive CCD with **13µm** pixels

Transmission uniformity measurements

Intensity after pellicle

Uniformity noise floor $\sigma=0.13\%$ for the chosen data stack (10 pictures)

Knife-edge resolution 48µm
Pellicle OoB reflectivity

Pellicle OoB reflectivity

**n,k data:**
- p-Si (CXRO+Palik (1985))
Pellicle OoB reflectivity

- OoB reflectivity of a pellicle can exceed 50%
- This may have influence on the performance of the scanner
- Capping layers can influence the effect strongly
- OoB reflectivity characterization is necessary

Currently there are no tools for the region between 20 nm and 200 nm

no “fresh” n,k data for modelling either

OoB specification?
EUV Reflectometer @ Aachen

Angular dependencies allow to extract refractive index data at each wavelength.

multi angle system (1°-15°)
wavelength range 9-17 nm
Multi-angle measurement results
Layered systems investigation

Excellent sensitivity to thickness and composition

For complex stacks independent thickness measurement (XRR, ellipsometry, TEM) may be required to decrease ambiguity of the model
Near-edge EUV Reflectometry

Absorption edges of elements in working wavelength range

- Direct elemental sensitivity
- Less ambiguous modelling
- Near-edge fine structure

<table>
<thead>
<tr>
<th>Element</th>
<th>Binding Energy (eV)</th>
<th>Corresponding Wavelength (nm)</th>
<th>Electron state</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Be</td>
<td>111,5</td>
<td>11,12</td>
<td>K 1s</td>
</tr>
<tr>
<td>12 Mg</td>
<td>88,7</td>
<td>13,98</td>
<td>L1 2s</td>
</tr>
<tr>
<td>14 Si</td>
<td>99,82</td>
<td>12,42</td>
<td>L2 2p1/2</td>
</tr>
<tr>
<td>15 P</td>
<td>136</td>
<td>9,12</td>
<td>L2 2p1/2</td>
</tr>
<tr>
<td>37 Rb</td>
<td>113</td>
<td>10,97</td>
<td>M4 3d3/2</td>
</tr>
<tr>
<td>38 Sr</td>
<td>136</td>
<td>9,12</td>
<td>M4 3d3/2</td>
</tr>
<tr>
<td>57 La</td>
<td>105,3</td>
<td>11,77</td>
<td>N4 4d3/2</td>
</tr>
<tr>
<td>59 Pr</td>
<td>115,1</td>
<td>10,77</td>
<td>N4 4d3/2</td>
</tr>
<tr>
<td>60 Nd</td>
<td>120,5</td>
<td>10,29</td>
<td>N4 4d3/2</td>
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<tr>
<td>61 Pm</td>
<td>120</td>
<td>10,33</td>
<td>N4 4d3/2</td>
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<tr>
<td>62 Sm</td>
<td>129</td>
<td>9,61</td>
<td>N4 4d3/2</td>
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<tr>
<td>63 Eu</td>
<td>133</td>
<td>9,32</td>
<td>N4 4d3/2</td>
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<tr>
<td>89 Ac</td>
<td>80</td>
<td>15,50</td>
<td>O4 5d3/2</td>
</tr>
<tr>
<td>90 Th</td>
<td>92,5</td>
<td>13,40</td>
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<tr>
<td>91 Pa</td>
<td>94</td>
<td>13,19</td>
<td>O4 5d3/2</td>
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<tr>
<td>92 U</td>
<td>102,8</td>
<td>12,06</td>
<td>O4 5d3/2</td>
</tr>
</tbody>
</table>
Near-edge EUV Reflectometry

Near-Edge X-Ray Absorption Fine Structure (NEXAFS)

- Determination of chemical bonds and local symmetry
- Quick qualitative interpretation (fingerprinting)

[*] M. Banyay, Surface and Thin Film Analysis by Spectroscopic Reflectometry with EUV Emitting Laboratory Sources, PhD (RWTH Aachen, 2011).
SUMMARY

- Pellicle transmission spec resolution should not be below 50µm
- Metrology with this resolution is not a challenge
- OoB pellicle reflectivity may become a problem and should be controlled
- New reliable n,k data are necessary to model the performance, preferable measured directly on a pellicle
- Hard to measure in VUV wavelength region, no reflectometers or ellipsometers in the range between 20 and 200 nm
- Reflectometry (and n,k) measurements near the absorption edges (e.g. near Si L-edge @12.4nm) are often NEXAFS-modified and difficult to model precisely