Multilayer Optics for 1 nm to 13.5 nm: Can we reduce the litho wavelength further?

2018 International Workshop on EUV and soft X-Ray Sources

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optiX fab GmbH, Jena

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Outline

- Introduction
- Multilayers for 1 nm ... 13.5 nm – low reflectance, narrow bandwidth
- Narrow band sources meet narrow band multilayers
- Summary
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optiX fab.

- **History**
  - **1997:** Start of EUV multilayer development @ Fraunhofer IOF
  - **2013:** August 1st: Operations start @ optiX fab.
  - **TODAY:** Delivery of **11,052 EUV and X-ray mirrors** to customers

- **Mission**
  Fabrication of customized EUV optics and optical components for EUV lithography @ 13.5 nm, for EUV, soft and hard X-ray applications, synchrotron and FEL beamlines, metrology, R&D, HHG sources, etc.

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Multilayer mirror – principle of constructive interference

Multilayers for 13.5 nm

- Reflectance $R = 70.12\%$
- Wavelength $\lambda = 13.48\text{ nm}$
- Full Width at Half Maximum (FWHM) $= 0.528\text{ nm}$
- Angle of Incidence (AOI) $= 5\text{ deg.}$

Measured @PTB Berlin
ML coatings for short wavelengths

- main issues for ML coatings at shorter wavelengths ($\lambda < 13.5$ nm):

  1\textsuperscript{st}: lower reflectance
  typical experimental values for near normal incidence:

  13.5 nm: $R \leq 70\%$
  6.7 nm: $R \leq 65\%$
  4.4 nm: $R \leq 15\%$
  2.4 nm: $R \leq 20\%$
1st issue: lower reflectance at lower wavelengths

- real systems: reflection losses due to imperfect interfaces:
  - roughness
  - interdiffusion
  - formation of compounds


![HR-TEM of a La/B-ML for 6.7 nm showing interdiffusion between La and B](image-url)
1st issue: lower reflectance at lower wavelengths

- reflection losses due to imperfect interfaces
- higher losses for shorter wavelengths (stronger influence of interface regions)

![Graph showing normalized reflectivity vs interface width for different wavelengths and thicknesses.]

- high near normal incidence reflectivity ($R > 60\%$) impossible at short wavelengths ($\lambda < 6.6$ nm)

<table>
<thead>
<tr>
<th>Thickness, nm</th>
<th>Wavelength, nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.0</td>
<td>13.5</td>
</tr>
<tr>
<td>3.4</td>
<td>6.7</td>
</tr>
<tr>
<td>2.2</td>
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ML coatings for short wavelengths

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  - **2nd:** lower bandwidth
2nd issue: lower bandwidth at lower wavelengths

- **strongly decreasing bandwidth** (FWHM) of the ML coating for shorter wavelengths
- reason: higher number of required contributing interfaces

![Graph showing bandwidth for different wavelengths and ML coating thicknesses](image)
2nd issue: lower bandwidth at lower wavelengths

- **strongly decreased bandwidth** (FWHM) of the ML coating for shorter wavelengths

- consequences:
  - wavelength matching between mirrors more complicated
  - lower integrated reflection
    - lower photon throughput (assuming broad plasma sources)
## Experimental results

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<tr>
<th>$\lambda$, nm</th>
<th>1.4</th>
<th>2.4</th>
<th>2.7</th>
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<td>26.2</td>
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![Graph](image)
# Experimental results

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![Graph showing reflectance as a function of wavelength](image)
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Multilayer development for water window collector

Reflectivity in water window region (s-pol @ AOI = 1.5deg)

- N4618_0
- N4617_0k
- N4616_0k
- N4616_37k
- N4617_76k
- N4616_76k
- N4616_114k
- N4618_135k

Wavelength, nm

Reflectivity

0.00%  2.00%  4.00%  6.00%  8.00%  10.00%  12.00%  14.00%  16.00%  18.00%  20.00%
Collector mirror – today: Reflectance mapping at $\lambda = 2.478$ nm

$\text{AOI} = 1.500\,\text{deg}$

Color change = 0.08%
Max(color) = 4.81%
Min(color) = 3.38%
Max(data) = 4.81%
Min(data) = 3.38%

$\lambda=2.478\,\text{nm}$

$R = 4.58\%$

$\lambda = 2.478\,\text{nm}$

FWHM = 0.005 nm

AOI = 1.5 deg.

Measured @PTB Berlin
2018 multilayer collector mirror: Wavelength at different positions

Measured @PTB Berlin

center wavelength water window collector N4912 (Sub.ID: 00AA58)
2018 multilayer collector mirror: EUV reflectance at different radii

2015: $R = 2.45\%$
2018: $R = 4.58\%$

$\rightarrow$ 2x more photons!

2015 status:

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Summary

- It’s really hard to make high-reflective multilayers for wavelengths < 13.5 nm
- Challenges: low reflectance, narrow bandwidth
- Please match source emission with multilayer absorption edges...
Still a very long and steep way to go ... but good to start now
Acknowledgements

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