Mo/Si multilayers capped by TiO_2

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Contents

- Motivation
- Radiation stability of TiO_2 capped MLs
- Enhancement of Ru capped MLs
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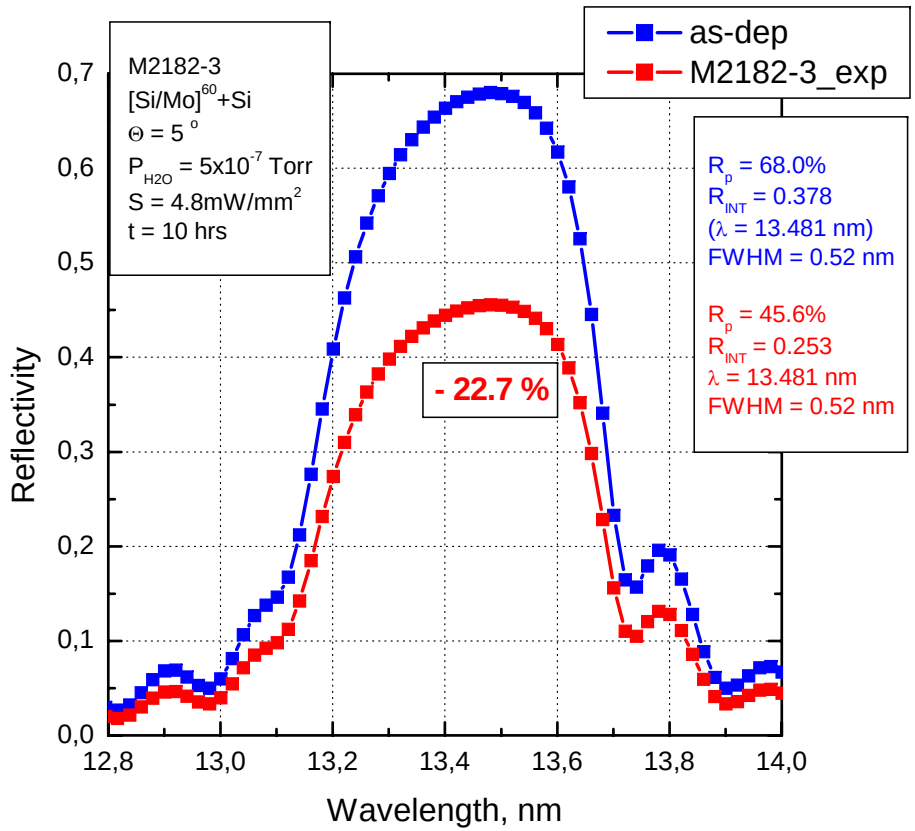
Degradation of EUV optics

Industry goal:

- EUV intensity: $I_{EUV} \sim 10\ mW/mm^2$
- $P_{H2O} < 10^{-7}$ Torr
- $P_{HC} < 10^{-9}$ Torr
- Reflectivity drop: **$\Delta R < 1\%$** over 30000 hours



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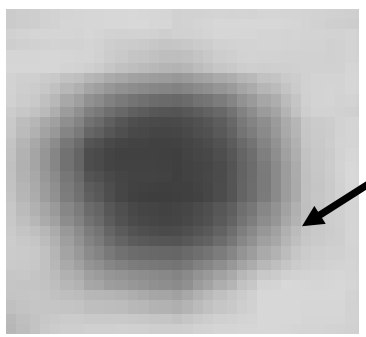
Different capping layers: Previous results

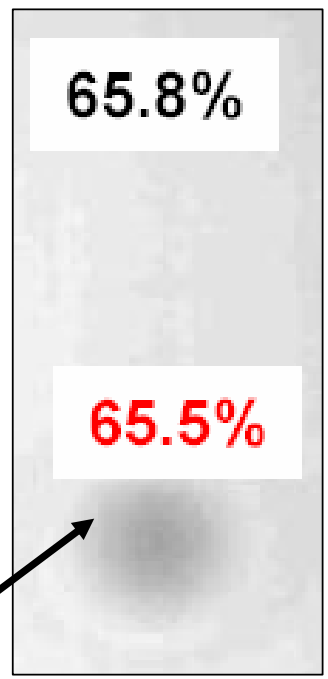
Ru capped MLs: **ΔR = -3.1 %**



38 hours
~5 mW/mm²
7.5 x 10^{-8} Torr H_2O

Pei-Yang Yan et al., BACUS 05, 5992-135

TiO_2 capped MLs: **ΔR = -0.3 %**



40 hours
~5 mW/mm²
2 x10^{-7} Torr H_2O

S. Bajt et al., EUVL Symposium 2005

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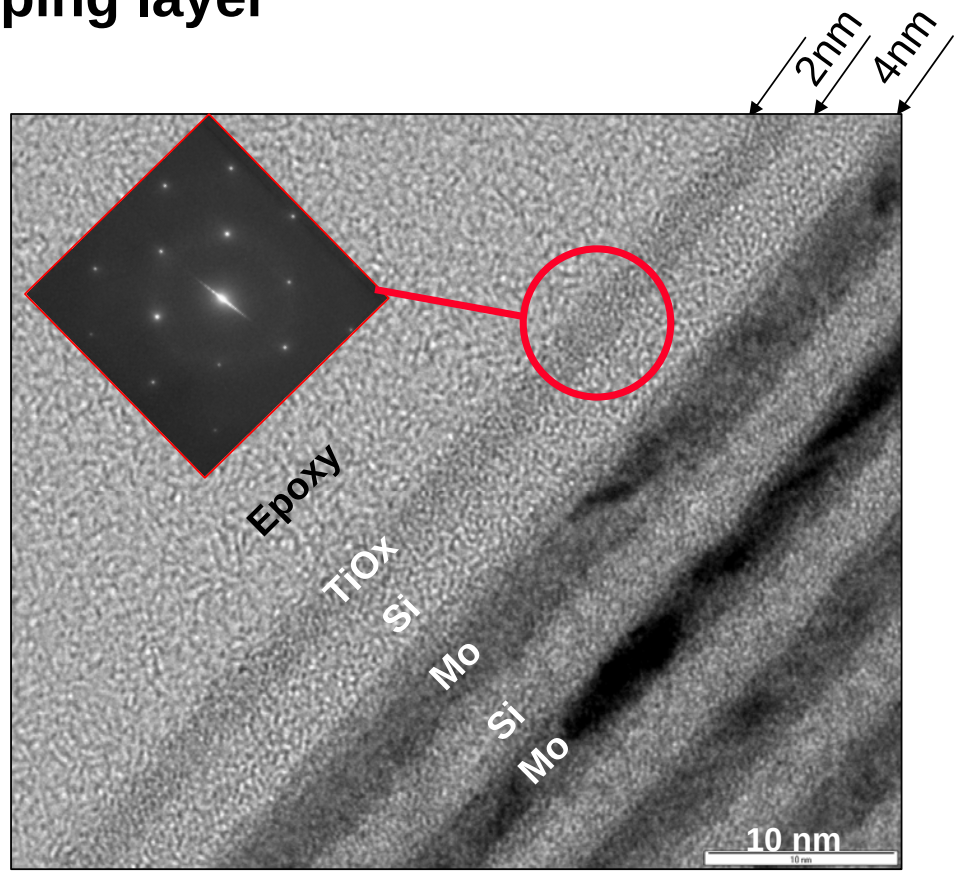
TiO_2 is excellent candidate for capping layer

- Chemically inert to oxygen
- Resistant to diffusion of oxygen and carbon
- Good optical properties
  (R_{th} = 73.6% @13.5 nm with t_{TiO2} = 2.0 nm)
- Amorphous structure
  (t < 2.0 nm is possible)
- Photo - catalytic properties



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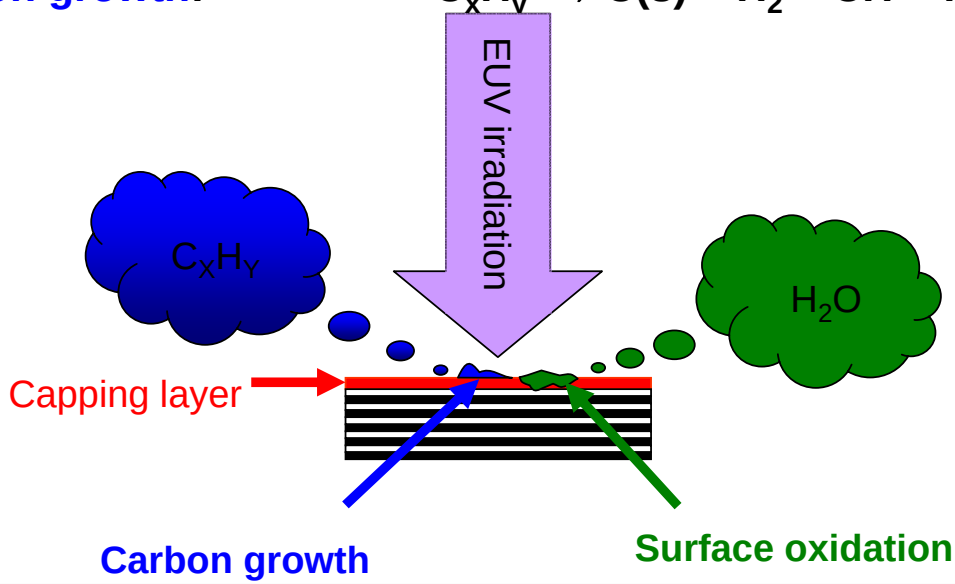
Degradation of EUV multilayers

Damage caused by two mechanisms:

- potentially irreversible **surface oxidation**: $Si + H_2O \rightarrow SiO_2 + H_2$
- demonstrably reversible **surface carbon growth**: $C_xH_y \rightarrow C(s) + H_2 + CH + \ldots$

Main impacts of contamination:

- Drop of peak reflectivity
- Degradation of reflectivity uniformity



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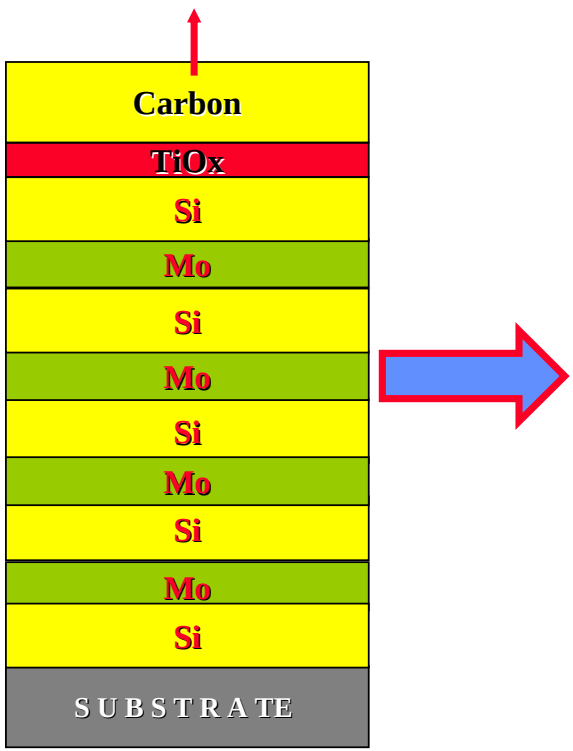
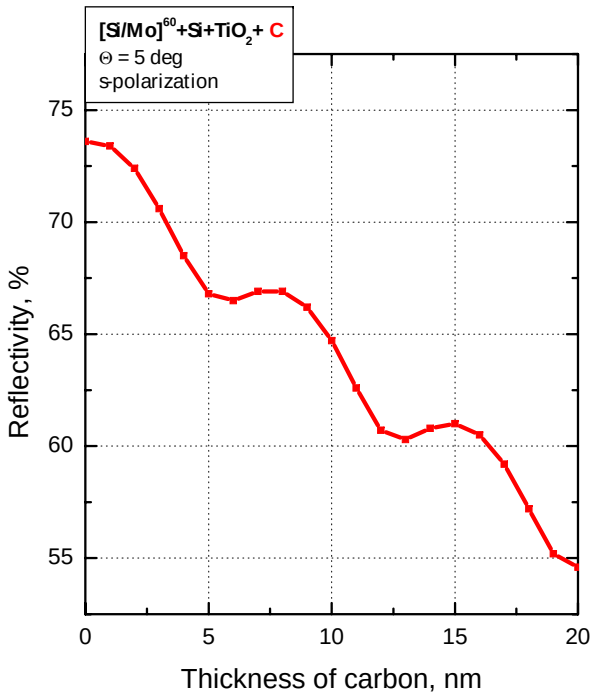
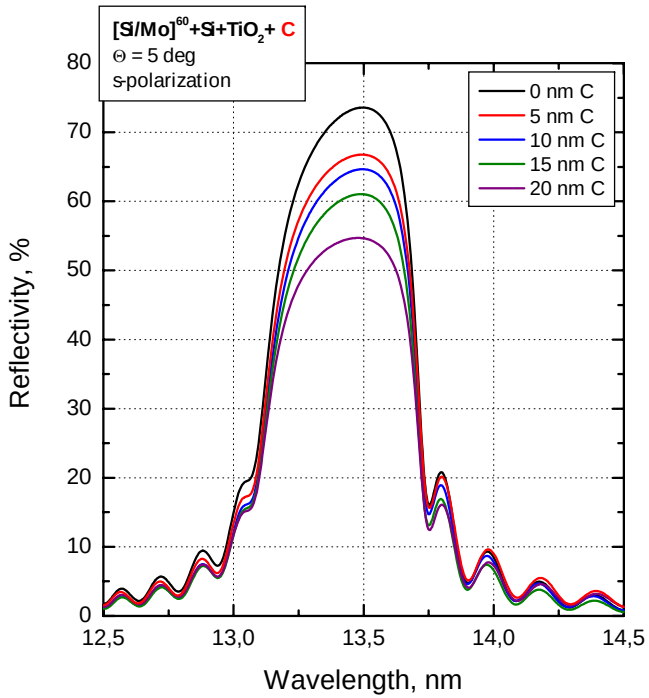
Surface carbonization vs reflectivity of TiO_2 capped Mo/Si MLs

$[Mo/Si]^{60} + TiO_2 +$ C

Theory







20 nm of carbon: ΔR = - 20%

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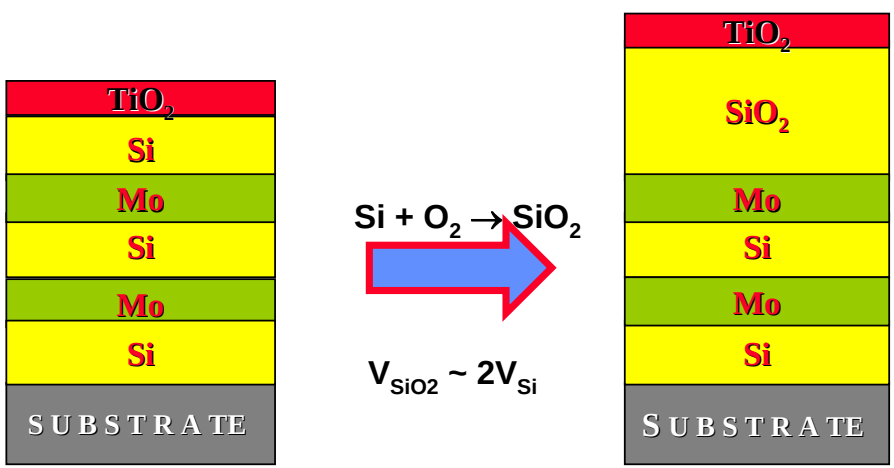
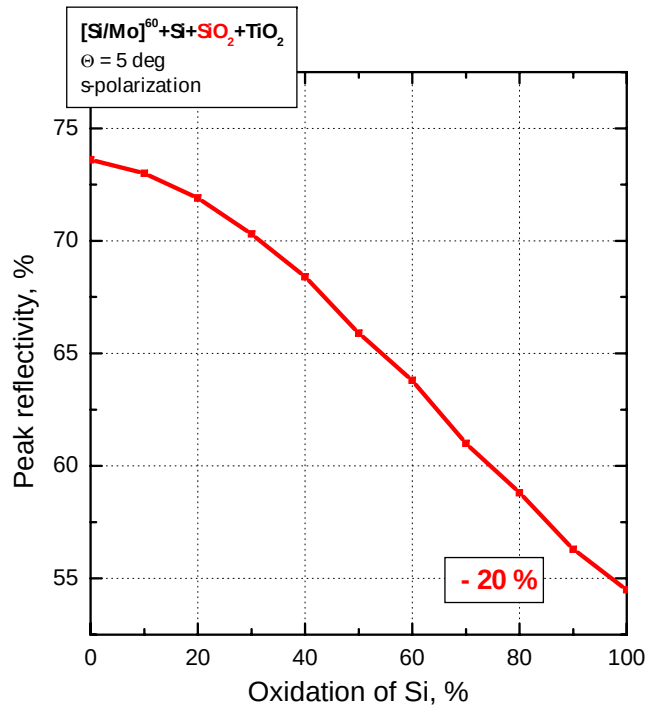
Oxidation vs reflectivity of TiO_2 capped Mo/Si MLs

$[Mo/Si]^{60} + TiO_2$

1. **Increase of absorption** ($Ti \rightarrow TiO_2$, $Si \rightarrow SiO_2$)
2. **Volume changes by oxidation**



Theory



Oxidation of Si sublayer: ΔR = - 20%

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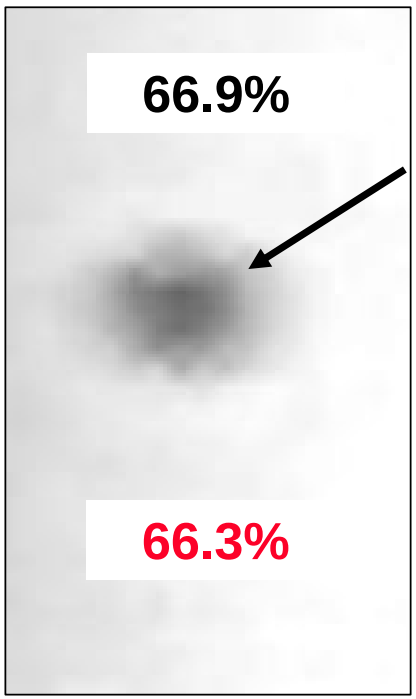
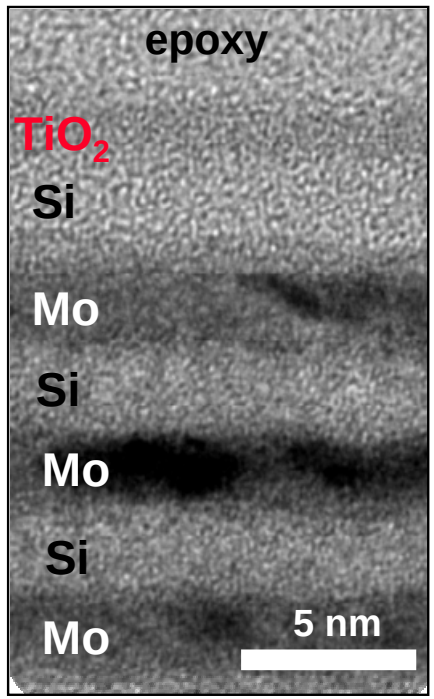
TiO_2 capped Mo/Si multilayers (Experiment)

ΔR = -0.6 %



42 hours
~ 5 mW/mm²
2 x 10^{-7} Torr H_2O
(D = 760J/mm²)



TiO_2 capping layer
~ 1.5 nm thick

R_o = 66.9 % !!!

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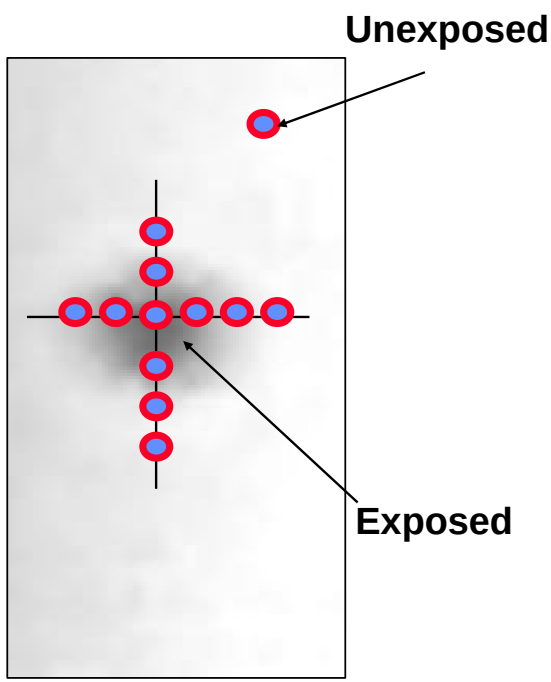
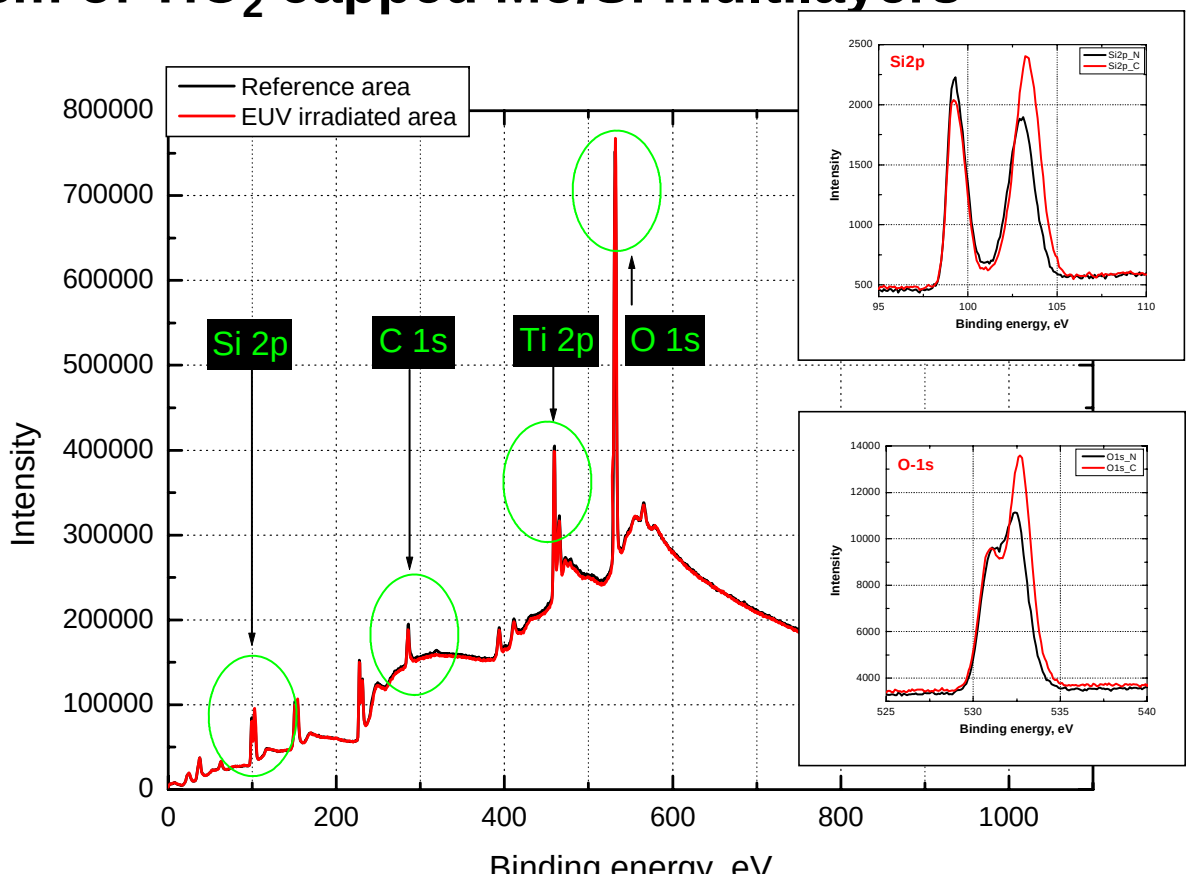
Degradation mechanism of TiO_2 capped Mo/Si multilayers

Micro XPS (spot ~ 100 μm)





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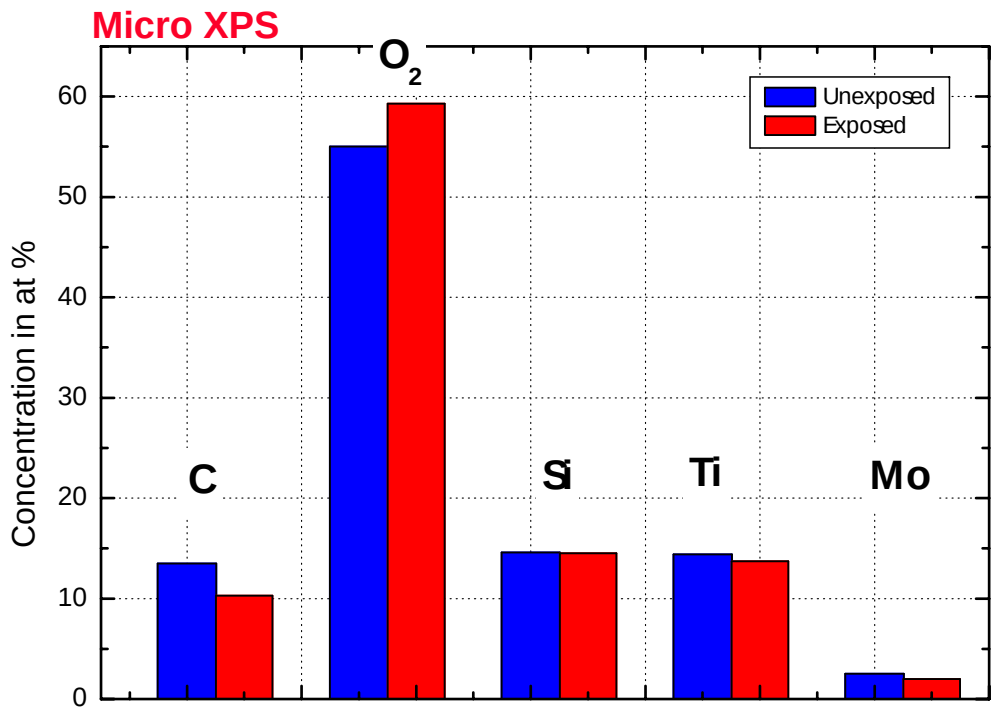
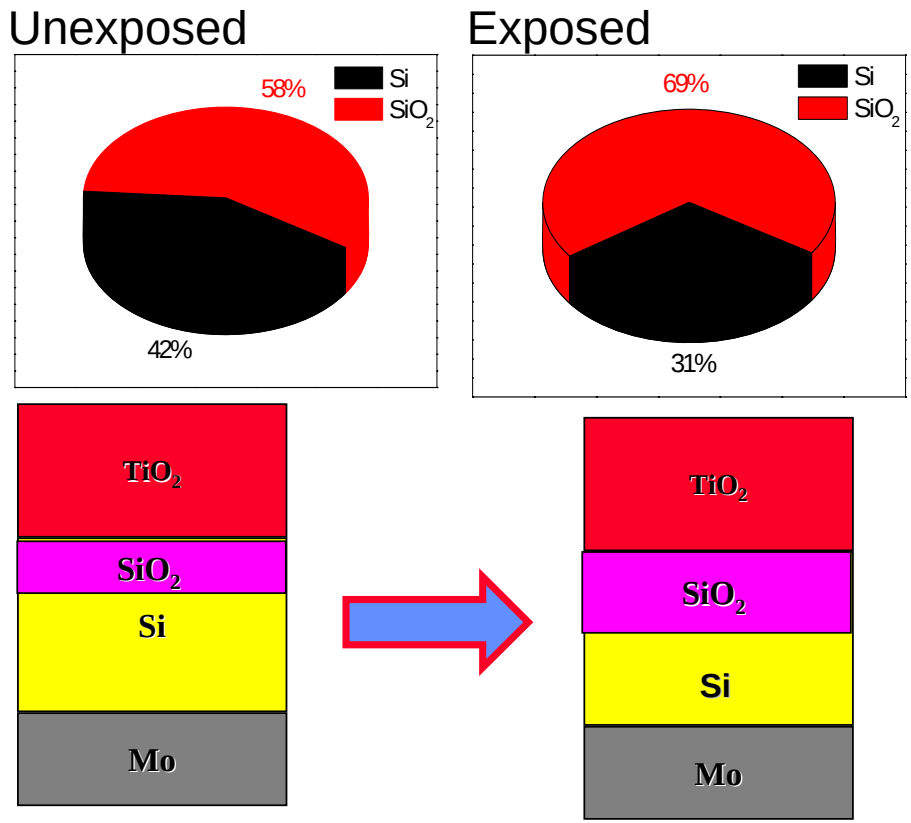
Degradation mechanism of TiO_2 capped Mo/Si multilayers





After exposure: C ↓ and O_2↑

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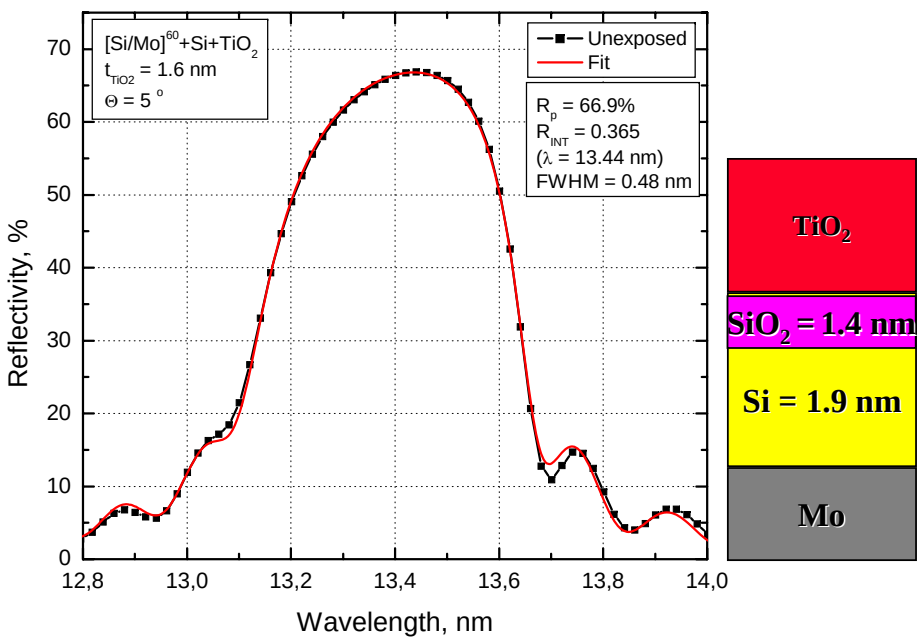
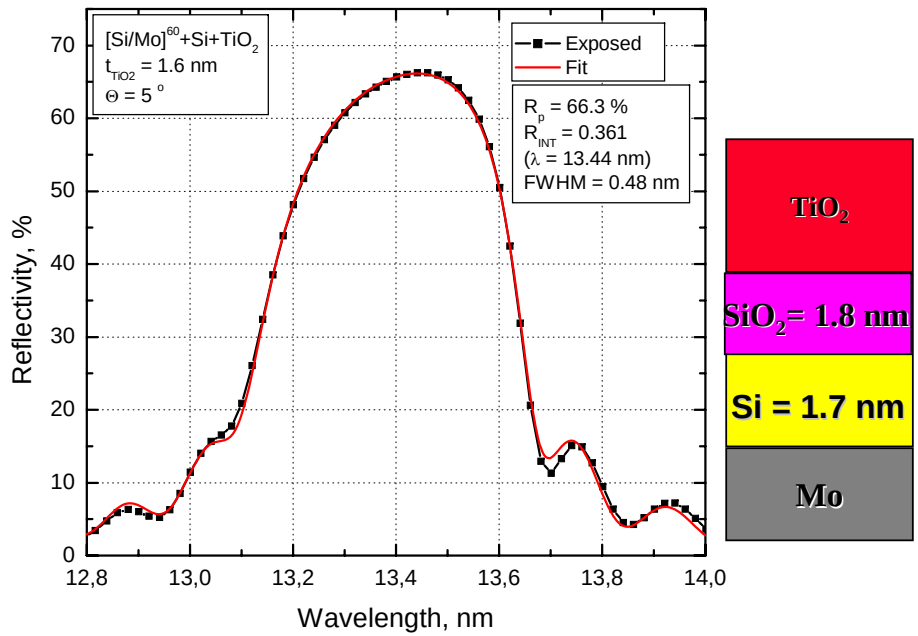
Degradation mechanism of TiO_2 capped Mo/Si multilayers

EUV reflectivity (fit): **unexposed** **exposed**





R_o = 66.9 % → t_{SiO2} = 1.4 nm

R_o = 66.3 % → t_{SiO2} = 1.8 nm

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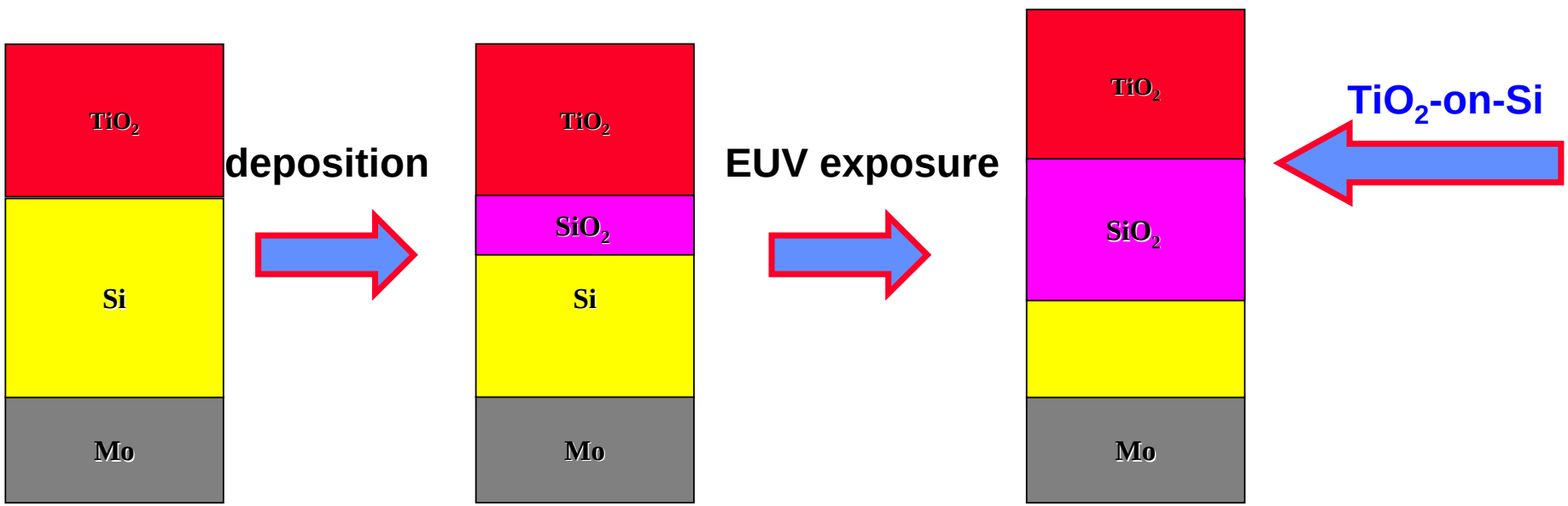
Degradation mechanism of TiO_2 capped Mo/Si multilayers

Ideal structure **Real unexposed structure** **Exposed structure**



Interface TiO_2-on-Si is responsible for degradation and has to be enhanced

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Mo/Si multilayers with Ru-based capping layers

$[Mo/Si]^{60}$ + Ru

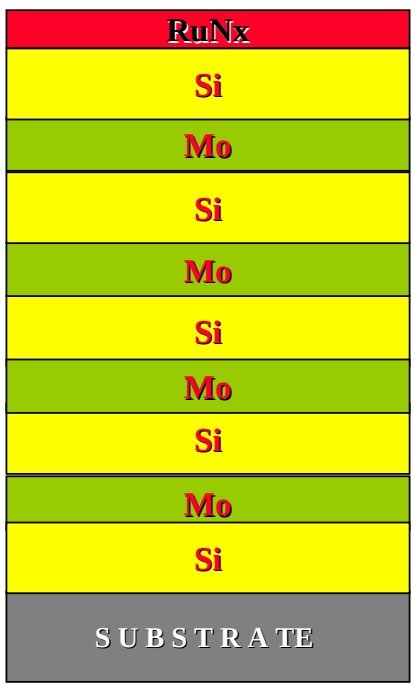
t_{Ru} ~ 1.5 nm

$[Mo/Si]^{60}$ + RuO_2

t_{RuOx} ~ 1.5 nm

$[Mo/Si]^{60}$ + RuN_x

t_{RuNx} ~ 1.5 nm



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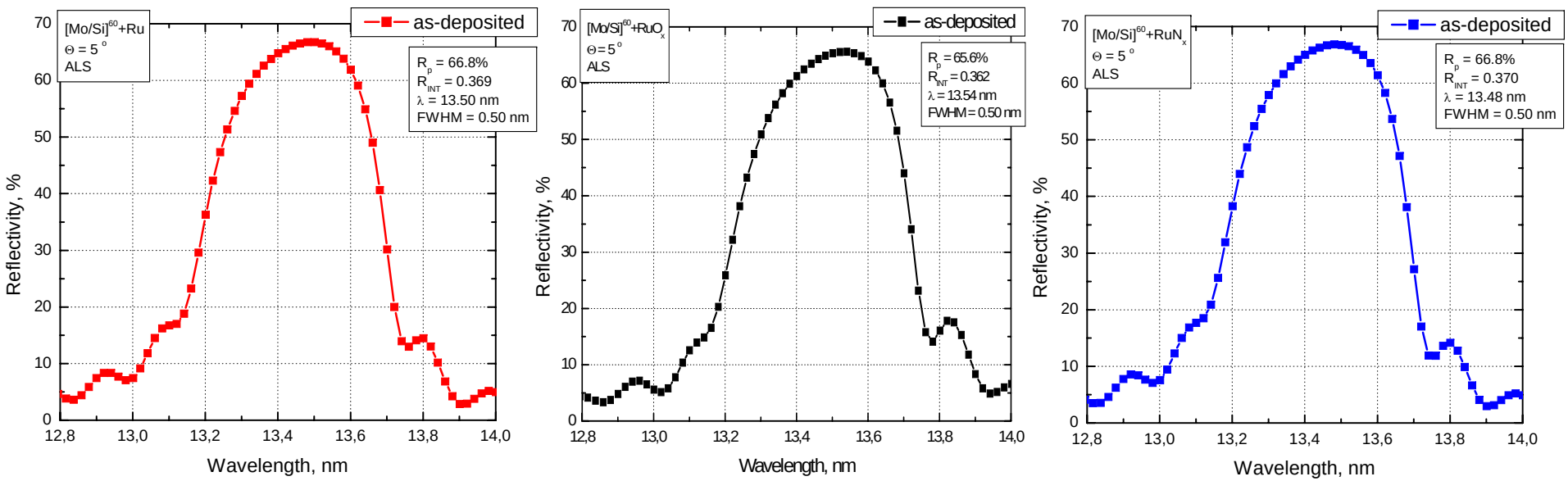
EUV characterization (Experiment)

$[Mo/Si]^{60}$ + Ru **$[Mo/Si]^{60}$ + RuO_2** **$[Mo/Si]^{60}$ + RuN_x**



R = 66.8% @ λ = 13.5 nm **R = 65.6% @ λ = 13.54 nm** **R = 66.8% @ λ = 13.48 nm**

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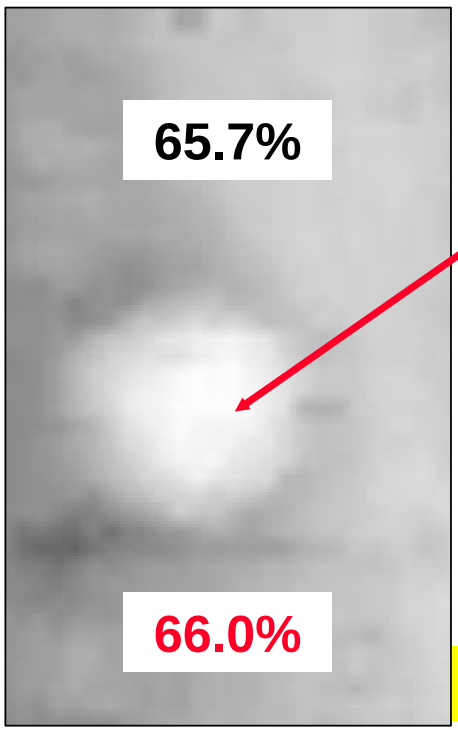
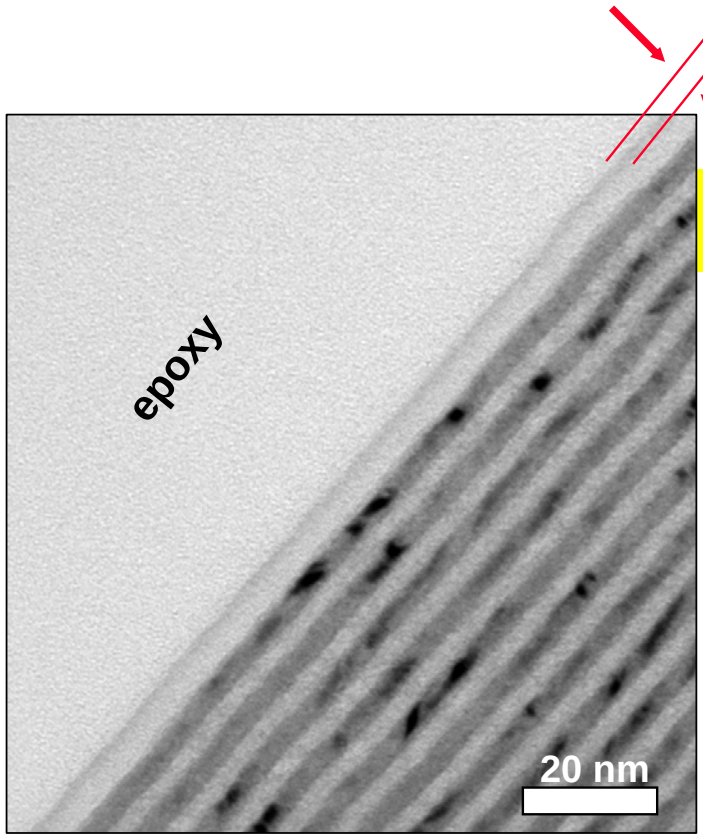
RuO_2 capped Mo/Si multilayers

ΔR = + 0.3 %



41 hours
~5 mW/mm²
2 x 10^{-7} Torr H_2O
(D = 720J/ mm^2)

No degradation !!!



RuO_2 capping layer
~ 1.5 nm thick

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Summary

- Oxides (TiO_2 and RuO_2) are promising materials for capping layers
- **TiO_2**:
  - Maximum reflectivity: R = 66.9 % @ 13.5 nm
  - Reflectivity drop of 0.6 % after EUV exposure with D = 760 J /mm^2
  - Reflectivity degradation was explained by oxidation of Si sublayer
- **RuO_2**:
  - Maximum reflectivity: R = 65.7 % @ 13.5 nm
  - No reflectivity drop after EUV exposure with D = 720 J /mm^2

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Future work

- Interface – engineering for reflectivity and stability improvements (IOF)
- Searching for new promising capping layer systems (IOF)
- Stability tests with other EUV sources (IOF)
- Investigation of photo-catalytic properties:

  - TiO_2 (Ted Madey, State University of New Jersey)
  - RuO_2 (Herbert Over, Justus-Liebig-Universität Gießen)
  - TiO_2 and RuO_2 (Gregory Denbeaux, University at Albany)

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