Screening of oxidation resistant capping layers for EUV multilayers

Saša Bajt

Erik J. Nelson, Zurong Dai, Giles A. Graham, Jennifer Alameda, Sherry Baker, Nhan Nguyen, Cheryl Evans, Art J. Nelson, John S. Taylor,

Lawrence Livermore National Laboratory

Miles Clift, Dean Buchenauer

Sandia National Laboratories

Andy Aquila, Eric M. Gullikson

Lawrence Berkeley National Laboratory

and

N. V. Ginger Edwards, Stefan Wurm and Obert Wood

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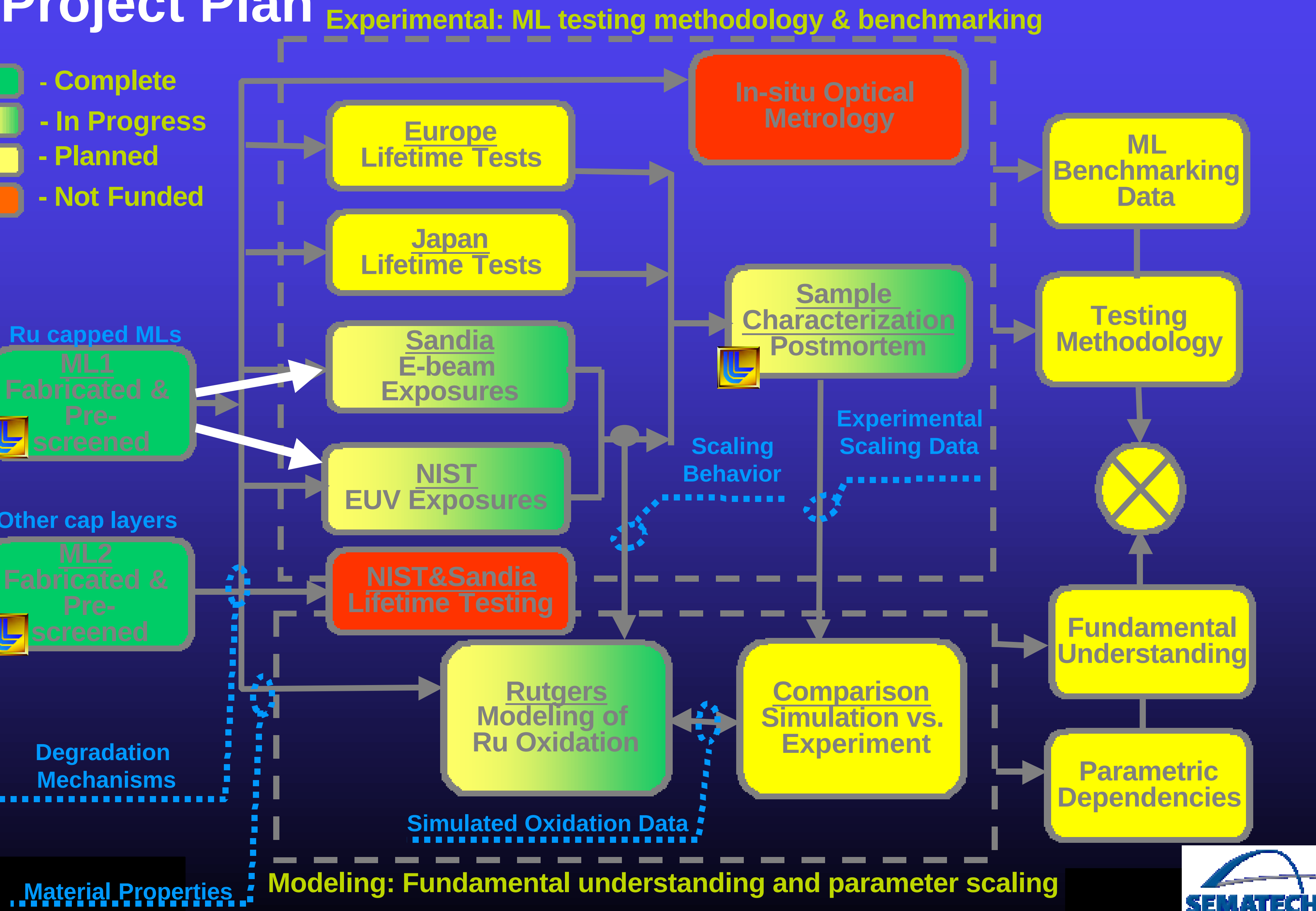
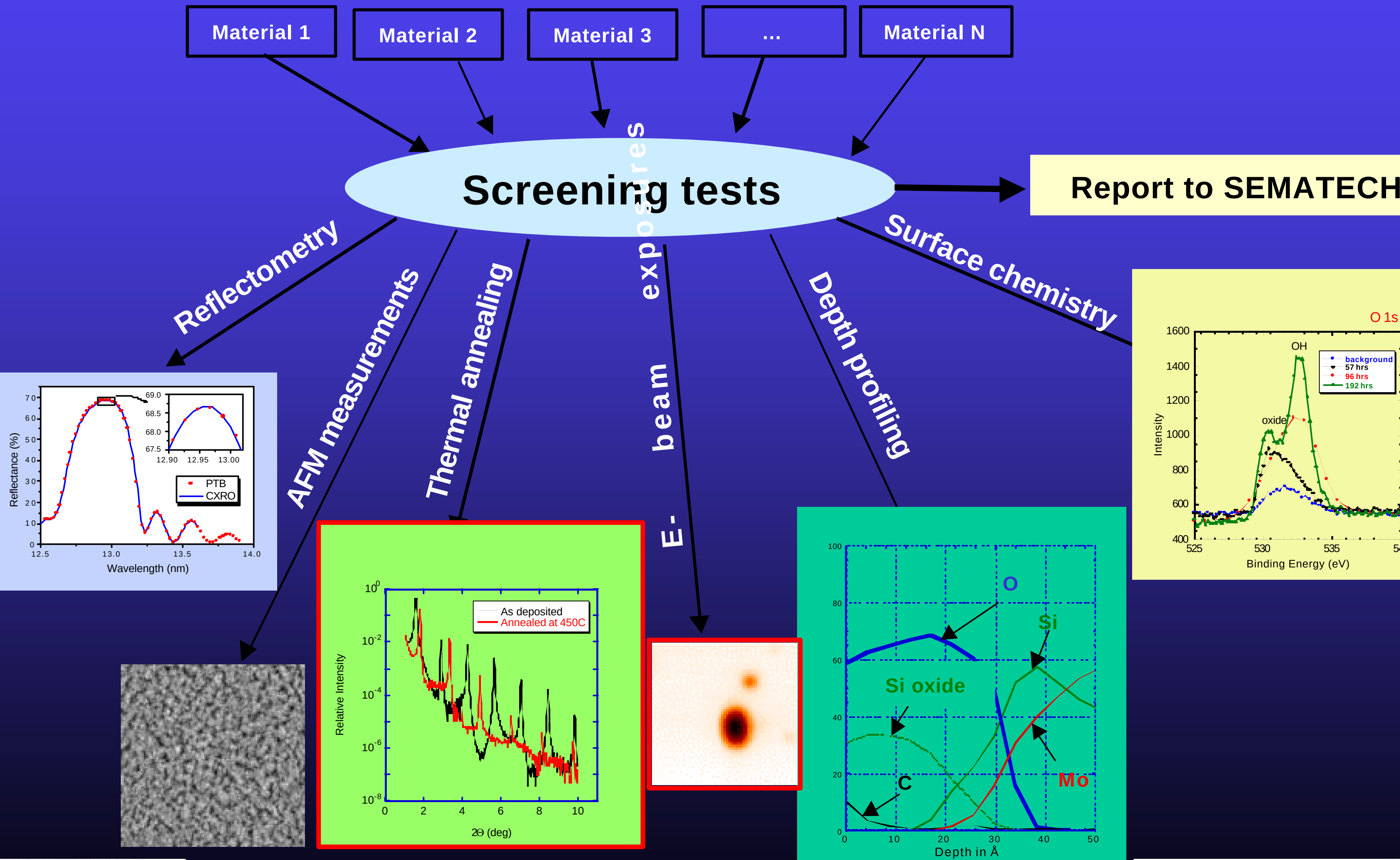
SEMATECH LITH160 – Projection Optics Lifetime Project Plan



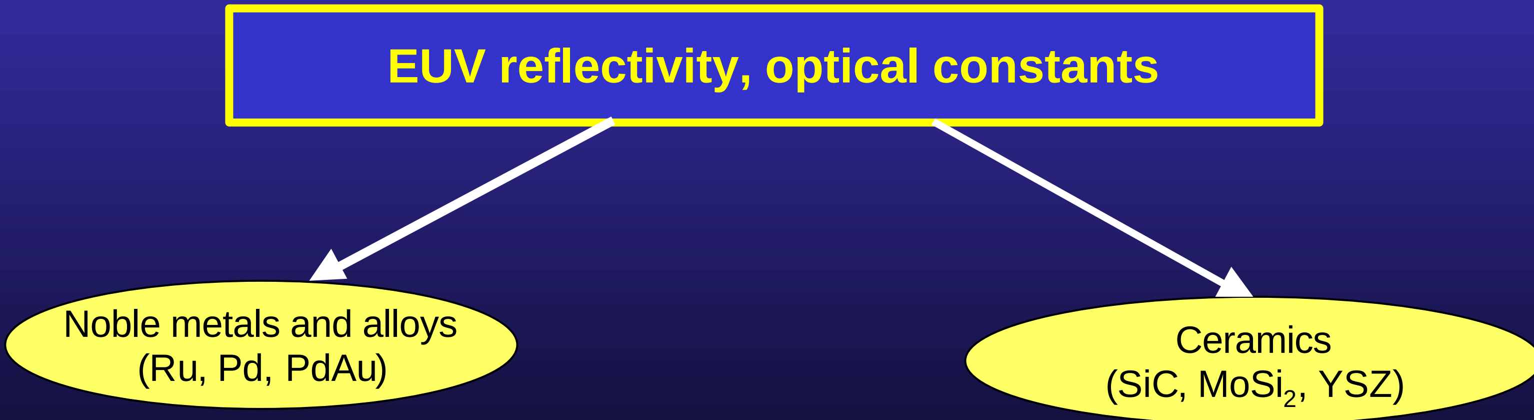
Screening tests overview



Multilayer Selection Criteria

Functional requirement:
- Long term stability EUV multilayers

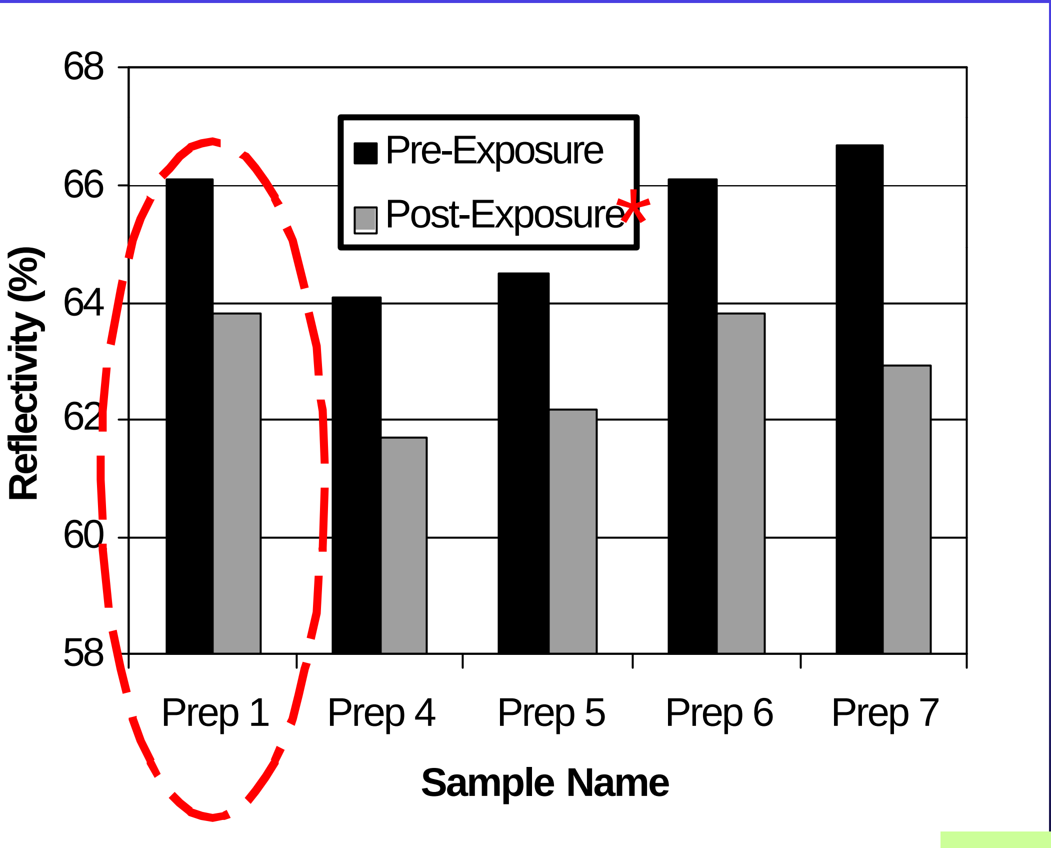
Capping layer requirements:
- Impervious to diffusion of oxygen
- Limited thickness
- Complete coverage
- Chemically inert to the material underneath
- Thermally stable



ith the exception of Ru all these materials were only screened, not optimized for EUVL applicatio

Multilayer 1 Sample Set Details

ML1 EUV Reflectivity

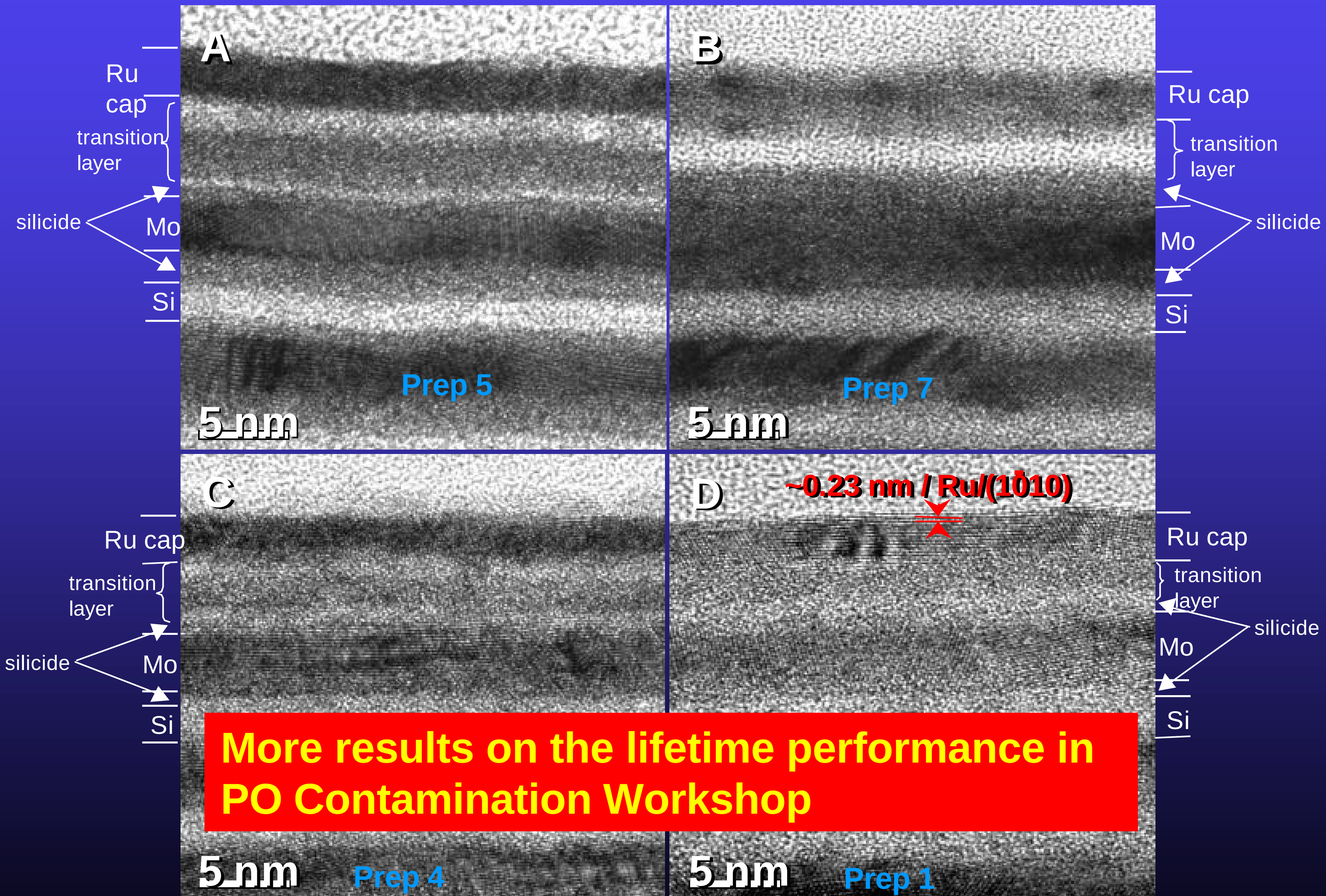


- Candidate for accelerated life-testing protocol development needed
- ML1 was a large set of candidate samples
- Deposition parameters strongly influenced EUV reflectivity & lifetime response
- Sample with best combination of reflectivity, thermal stability, and e-beam lifetime chosen

Preparation 1 (power change)
Preparation 4, 5 and 6 (gas mixture variation)
Preparation 7 (material variation)

***Exposure = electron beam exposure; 1 KeV; 5mA/ mm^2; 5 x 10^{-7} Torr water; Time = 40 hours**

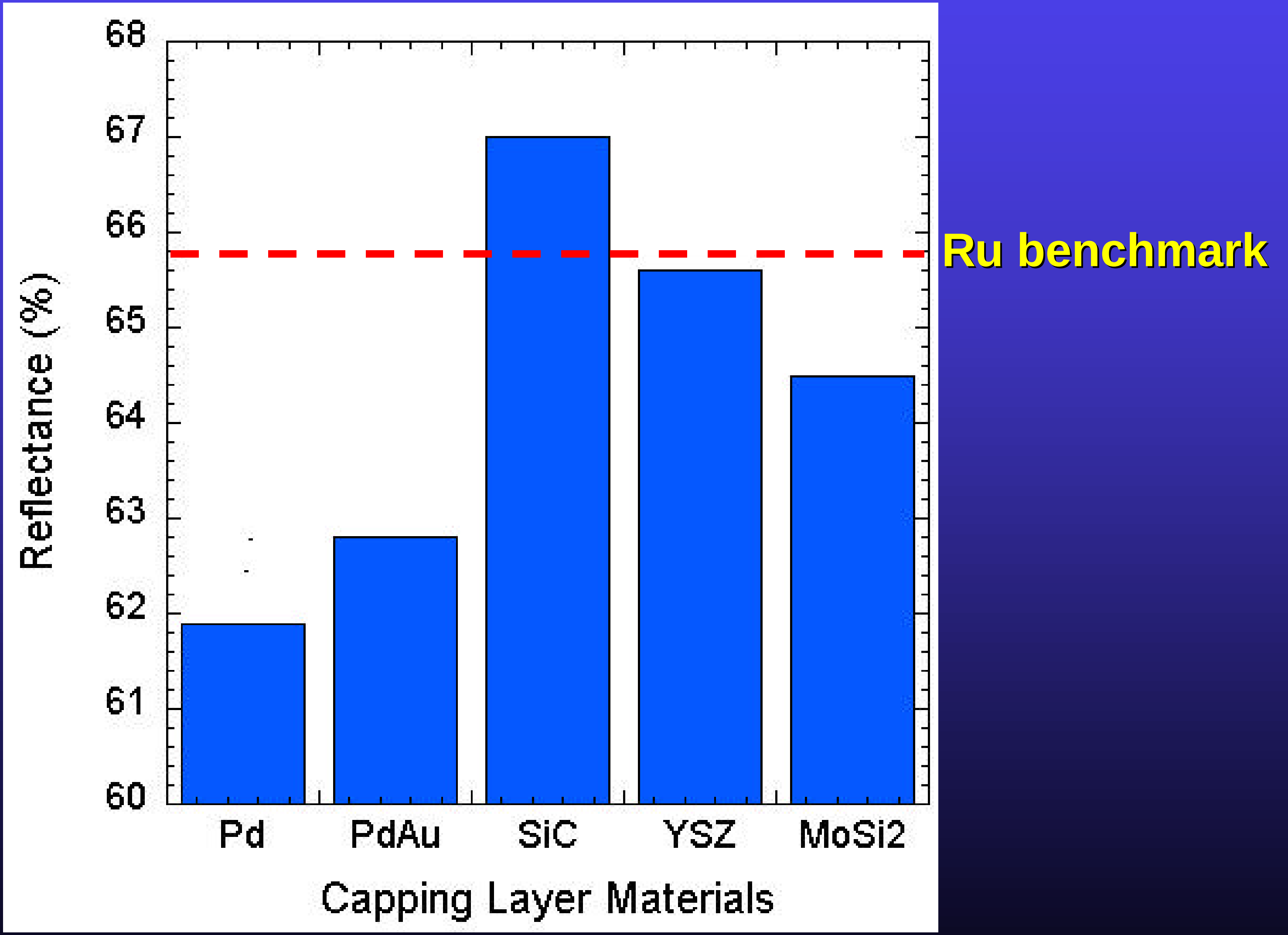
High lifetime of ML1 (Prep 1) is associated with a dense, crystalline capping layer



More results on the lifetime performance in PO Contamination Workshop

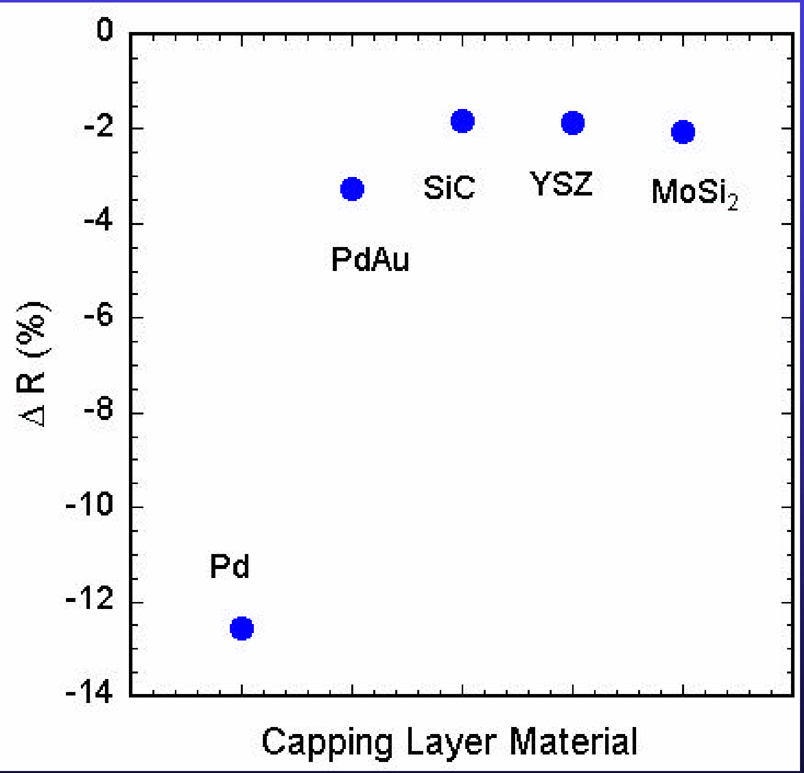
Virtual National Laboratory

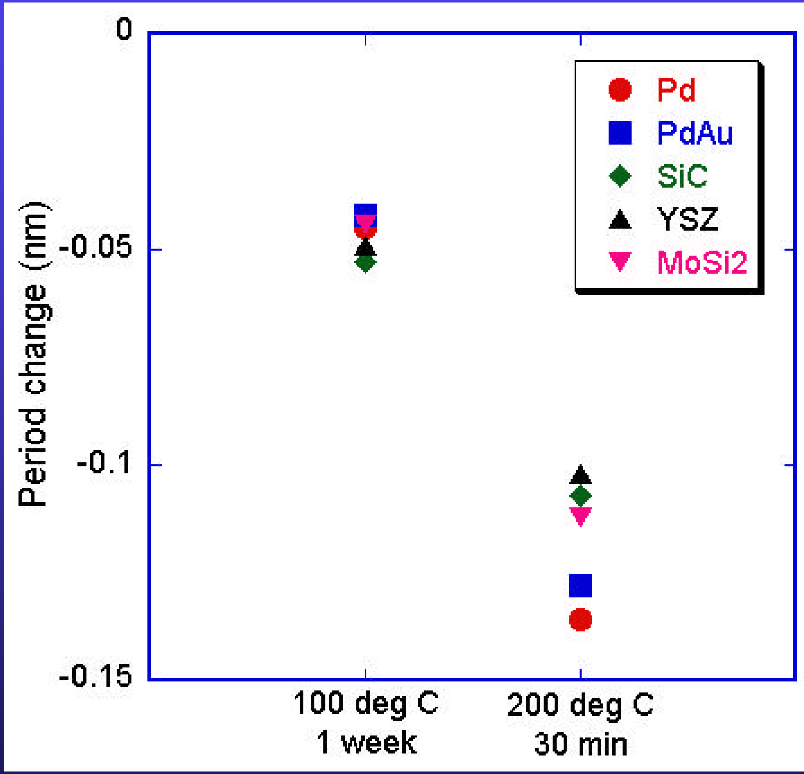
EUV reflectivity is one of the selection criteria for capping layer candidates



Annealed Pd-capped MLs show high reflectivity loss with notable period change

Multilayers exposed to 200ºC for 30 minutes





Pd- and PdAu-capped MLs show significantly larger period change than other multilayers although all of them consists of the same Mo/Si stack with 50 bilayers.

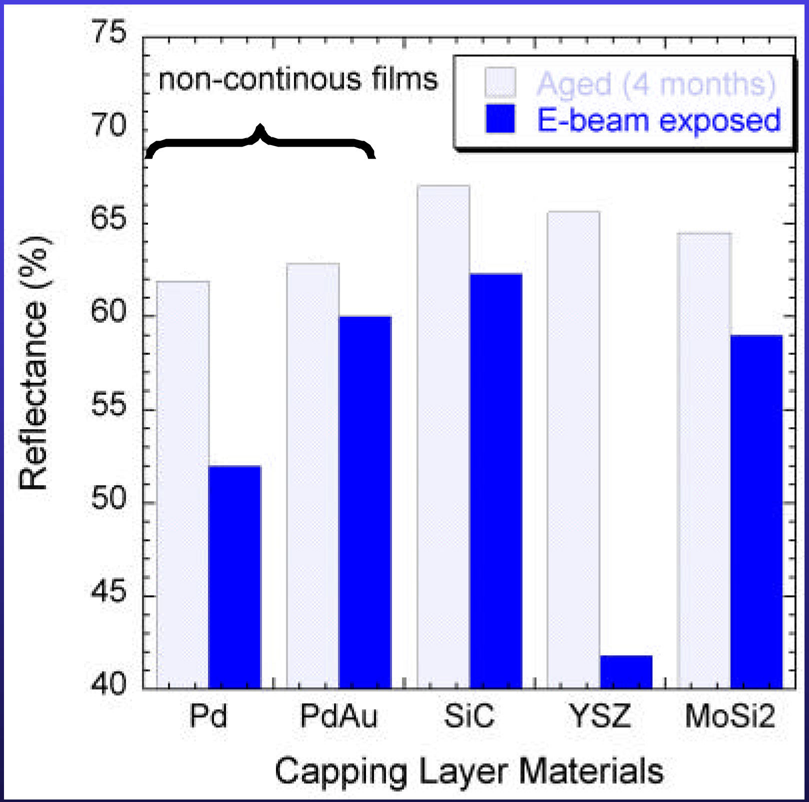
Thermal annealing considerably increased surface roughness of Pd- and PdAu-capped MLs

Material	As-deposited HSFR (nm)	After 200ºC for 30 min HSFR (nm)
Pd	0.22	0.70
PdAu	0.39	0.57
SiC	0.17	0.17
YSZ	0.22	0.20
$MoSi_2$	0.21	0.26

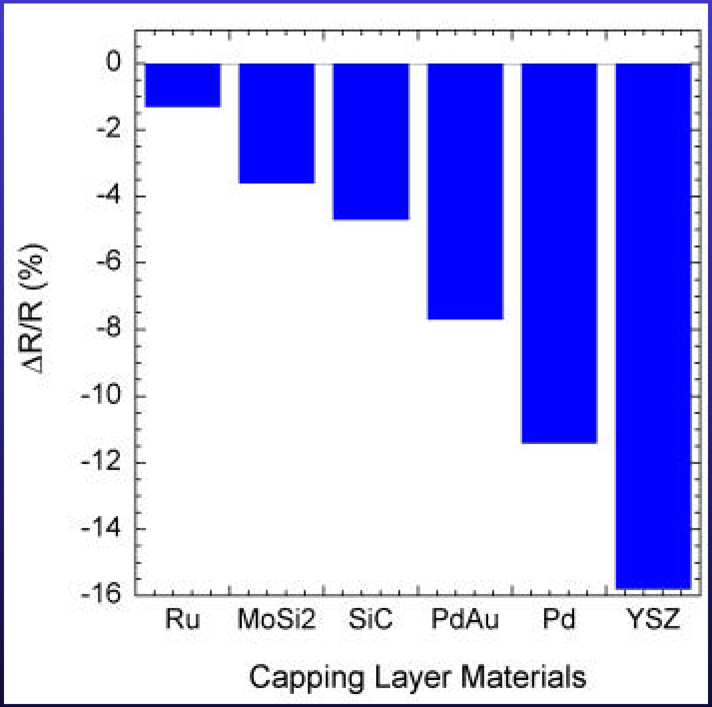
Large change (Pd, PdAu)

No change (SiC, YSZ)

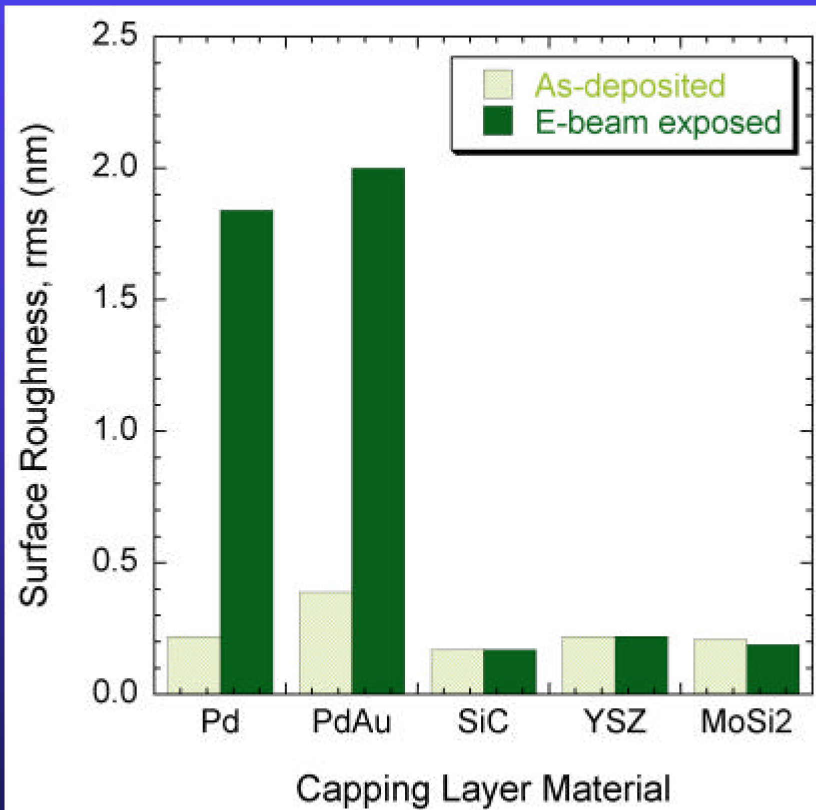
What is the cause of the reflectance drop in these materials?

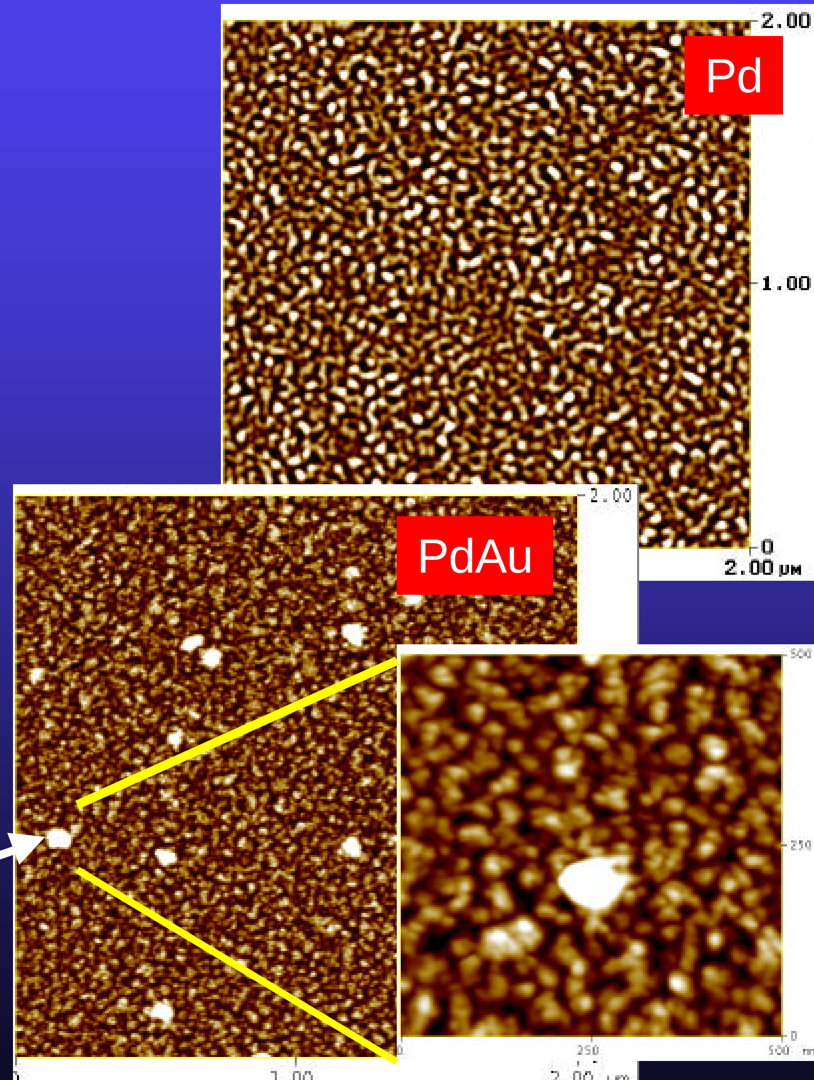


Large variation in reflectance drop for different capping layer materials suggests different degradation mechanisms



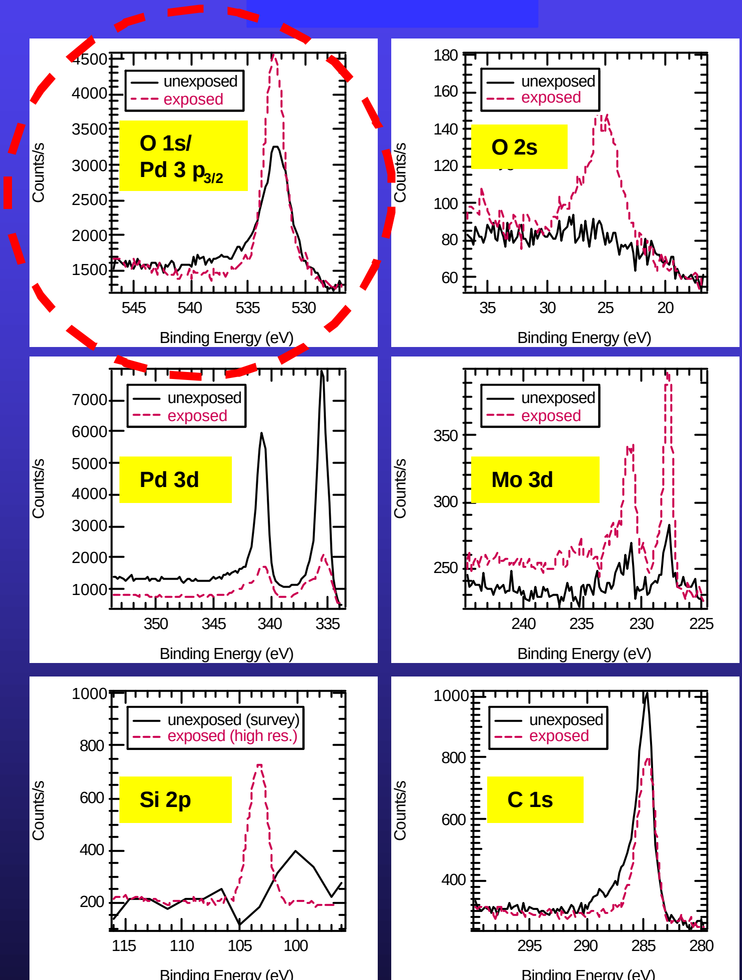
Surface roughness in e-beam exposed areas of Pd- and PdAu-capped MLs increased dramatically



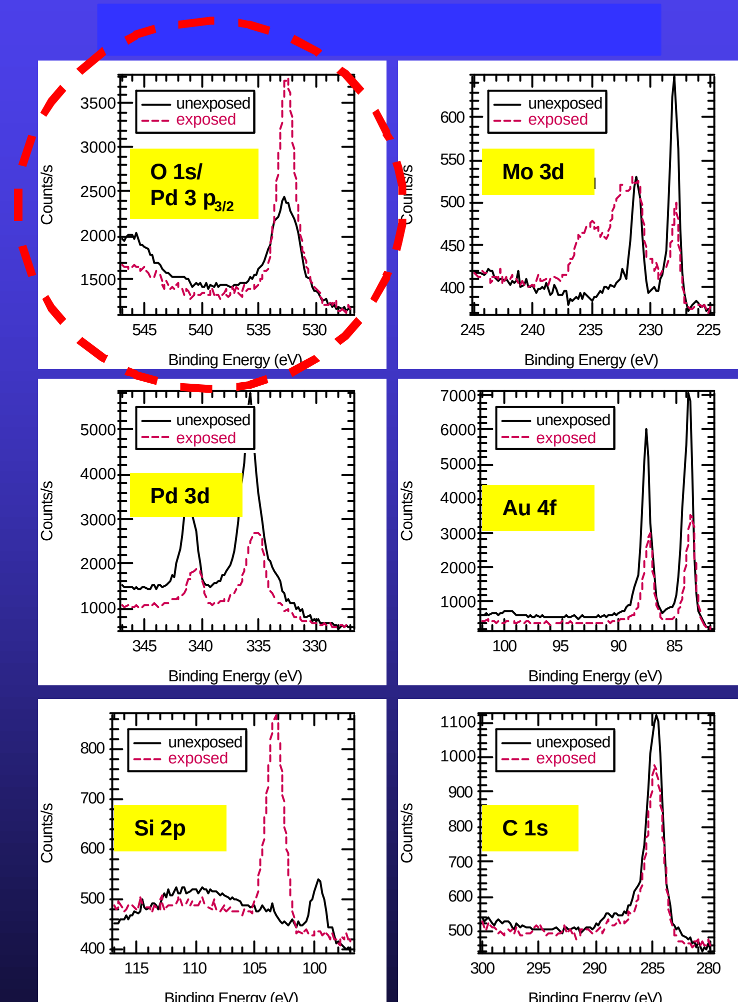


These bright spots are ~14 nm tall and their chemical composition could not be determined

Exposed areas in Pd and PdAu-capped MLs show increase in oxygen peak



Pd-capped multilayer



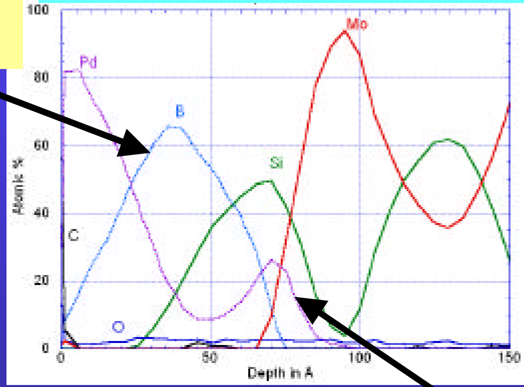
PdAu-capped multilayer

Depth Auger profiles reveal diffusion barrier breakdown in the e-beam exposed areas

Boron carbide diffusion barrier

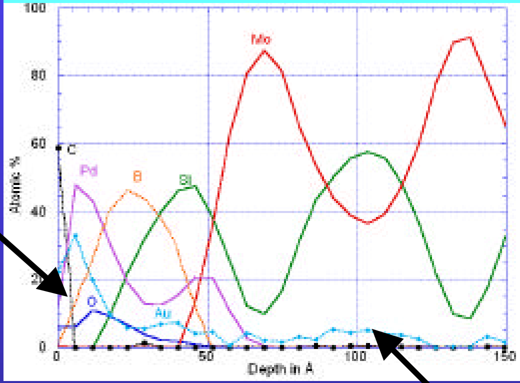
Where is carbon?

Pd capping layer - as-deposited



Partly oxidized Pd even in as-deposited state

PdAu capping layer – as-deposited

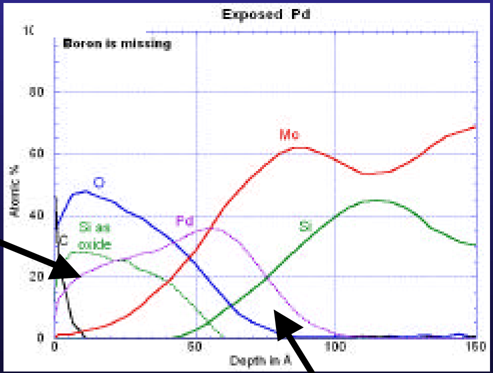


Pd peak increase below diffusion barrier

Presence of Au deeper in the ML

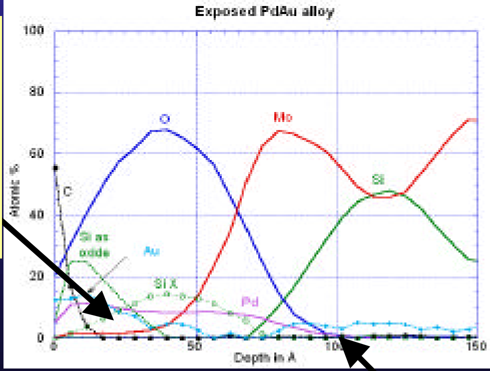
No boron - Boron possibly reacted with hydrogen to form gaseous species

Pd capping layer - exposed



Highly oxidized surface – Some silicon formed an unidentified alloy

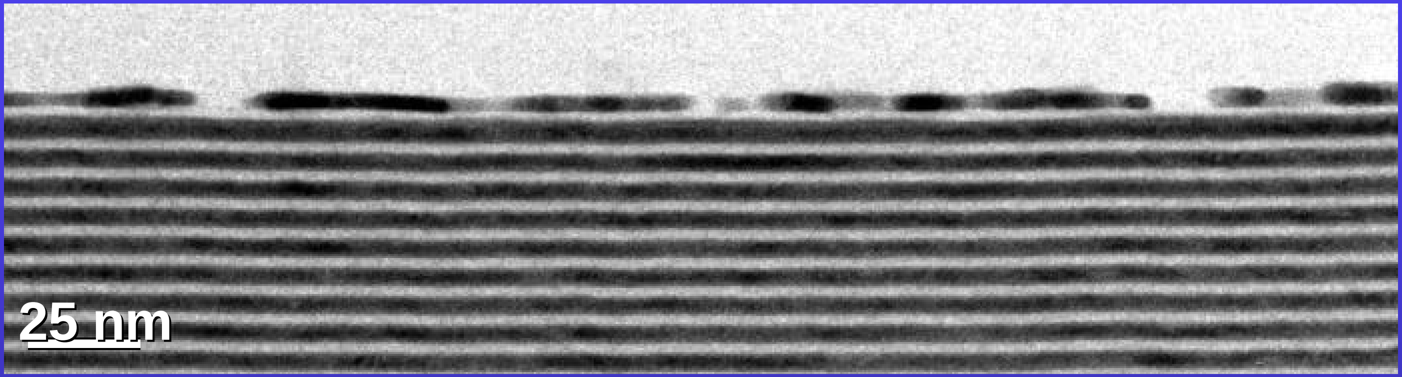
PdAu capping layer – exposed

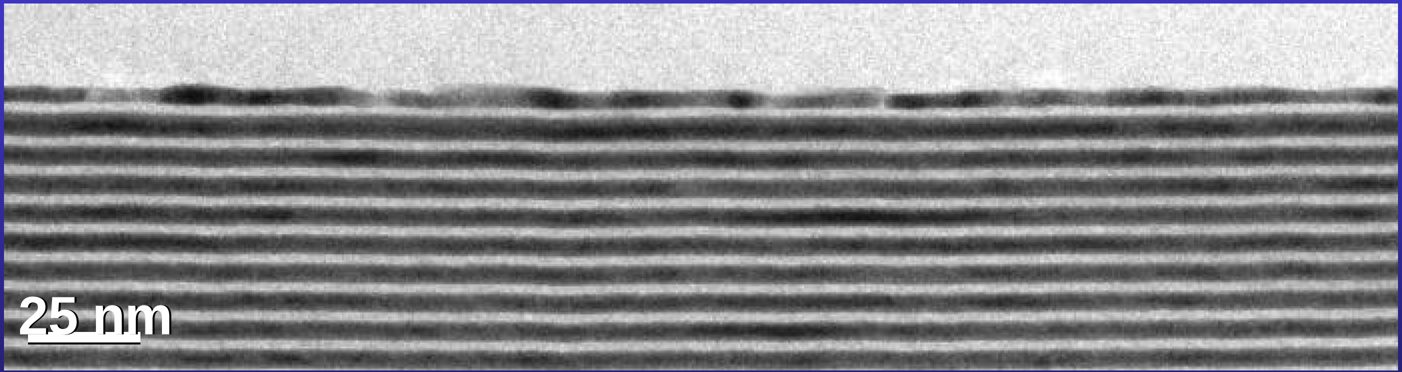


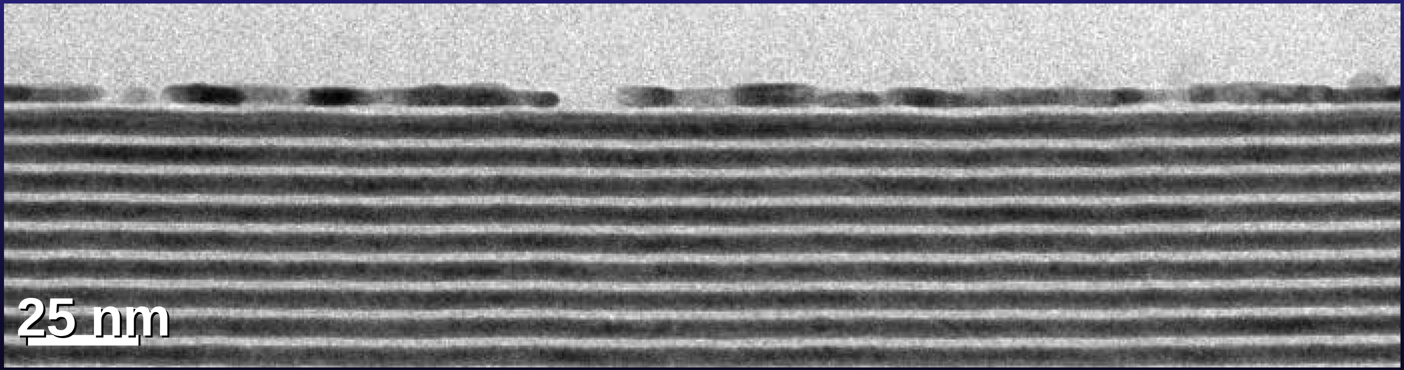
Pd oxidized and diffused further into the ML

Both Pd and Au diffused into the ML

Cross section TEM image clearly shows coverage problems on PdAu-capped multilayer

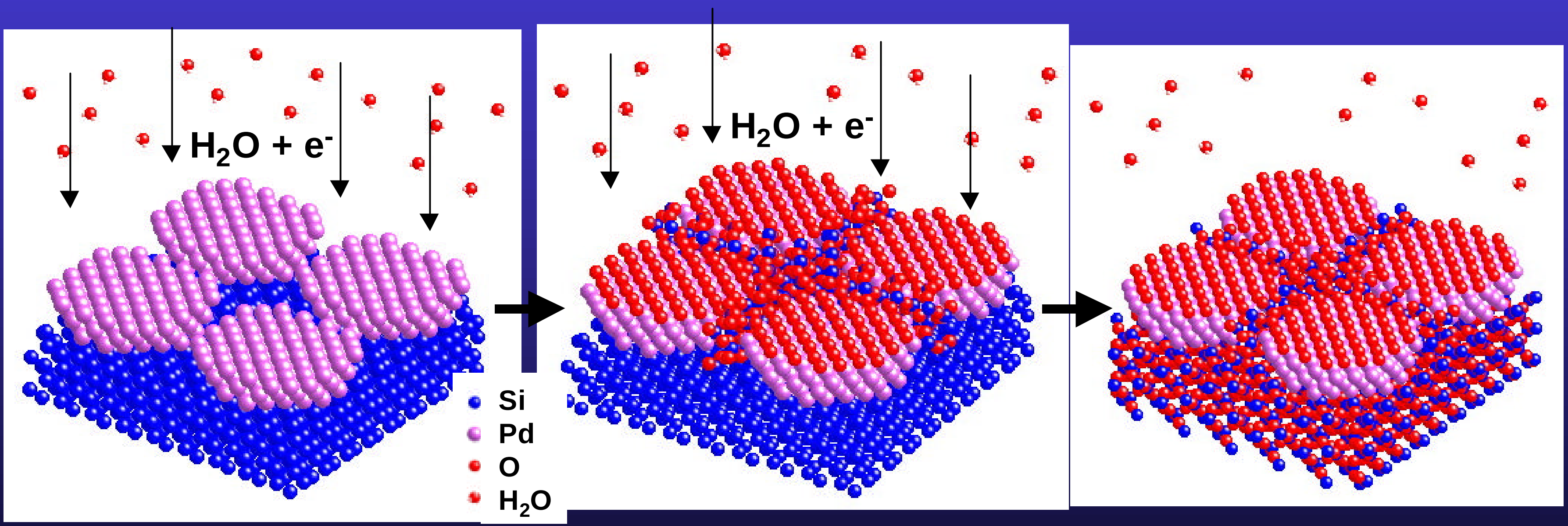






Oxidation mechanism in Pd-capped multilayers

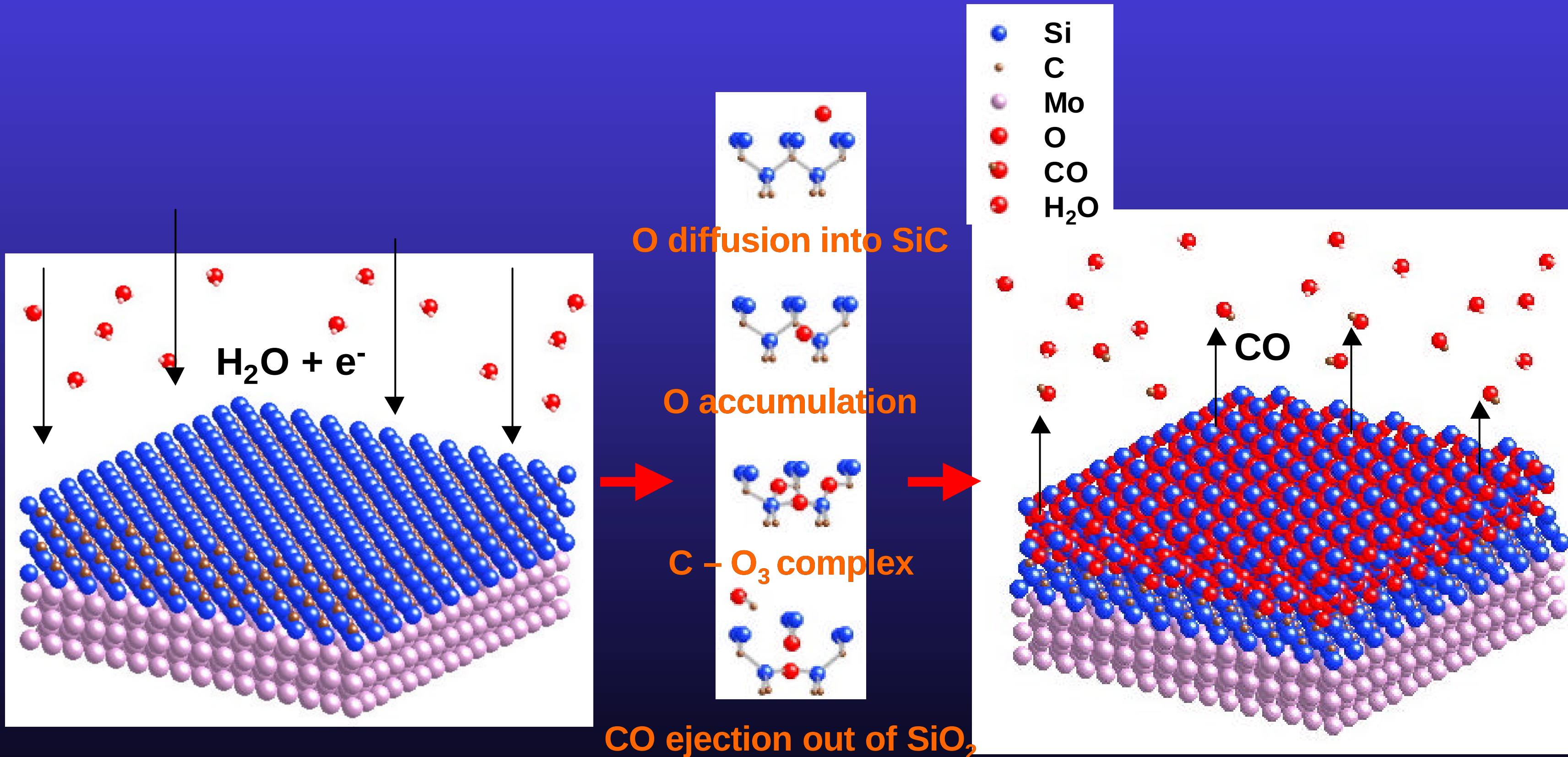
- Pd island growth
- Pd oxidation
- Expansion of SiO_2 into spaces between islands
- Oxidation of Si and Mo layers underneath



Similar mechanism expected in PdAu-capped multilayers

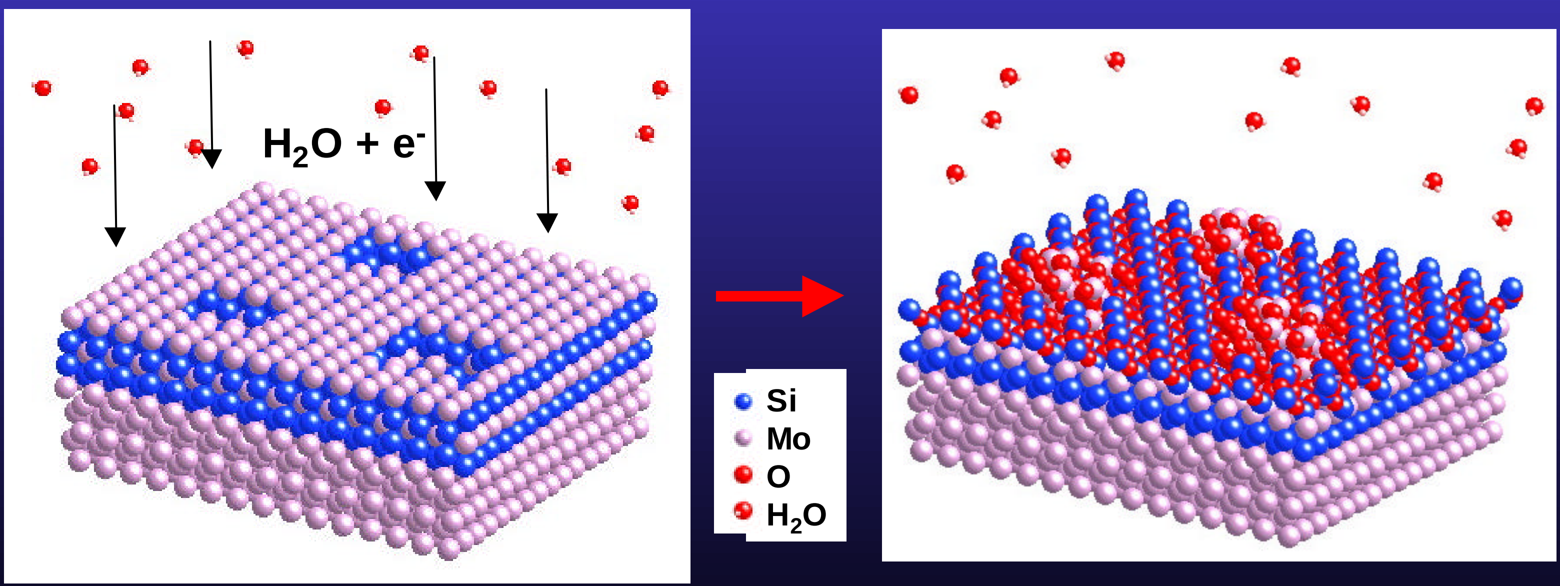
Oxidation mechanism in SiC-capped multilayers

- SiC converts to SiO_2 + C + CO(g)
- O diffuses into SiC, CO gas escapes through SiO_2, C left at interface
- M. Di Ventra and S. T. Pantelides, Phys. Rev. Lett. **83**, 1624 (1999).



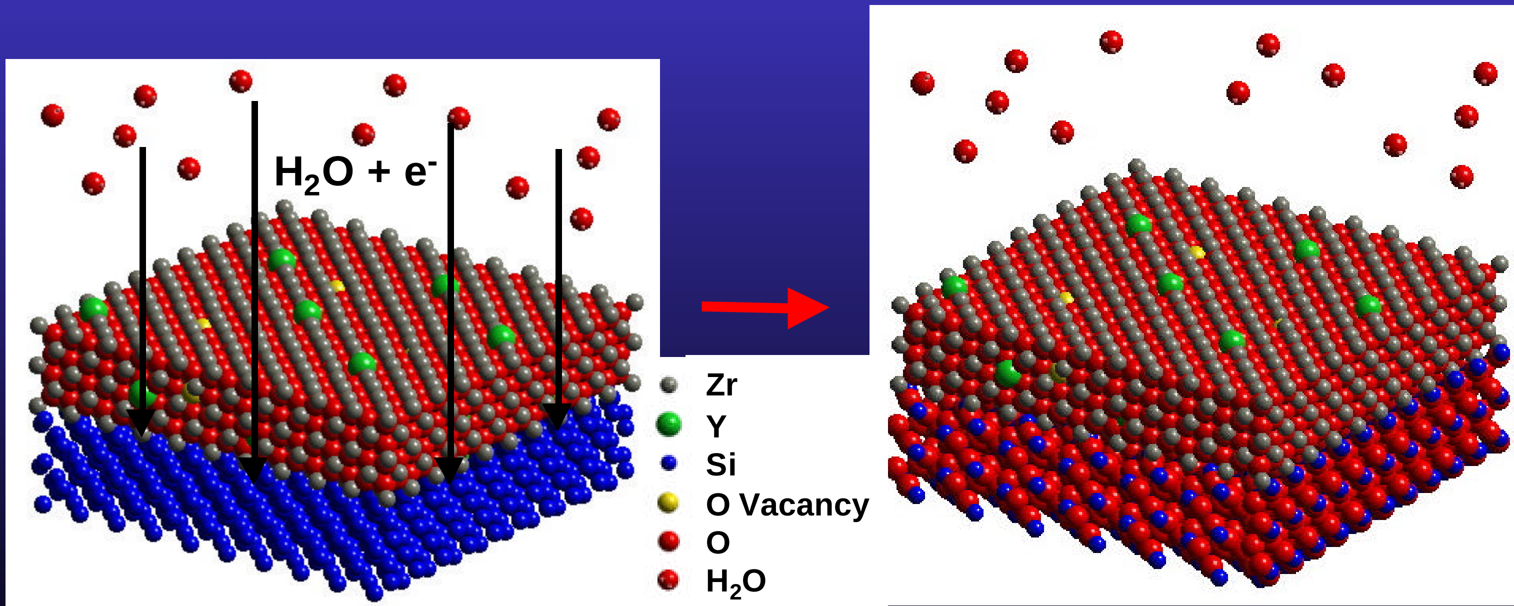
Oxidation mechanism in $MoSi_2$-capped multilayers

- Oxidation accelerated by non-stoichiometry, defects
- Protective SiO_2 formation on smooth stoichiometric surface, no MoO_3
- MoO_3 and SiO_2 formation starts at defects (pores, cracks)
- Volume increase at defects -> pesting



Oxidation mechanism in YSZ-capped multilayers

- Yttria-stabilized Zirconia (YSZ) unchanged
- Y stabilizes fluorite structure and introduces vacancies
  - 3% Y doping makes 0.75% of O sites vacant
- Mobile vacancies -> Enhanced oxygen diffusion in YSZ
- Oxidation of Si and Mo layers underneath



XPS and depth Auger results summary

Non-destructive XPS technique was used to obtain local chemical environment analyzing up to 5 nm into the multilayer

	E-beam exposed samples	
Capping layer	Capping layer XPS results	Underlying multilayer XPS results
Pd	Partial Pd oxidation, Pd diffusion into bulk	Si layer fully oxidized to SiO_2, Mo layer partially oxidized
$Au_{0.5}Pd_{0.5}$	Partial Pd oxidation, Au & Pd diffusion into bulk	Si layer fully oxidized to SiO_2, Mo layer partially oxidized to MoO_3
SiC	SiC converts to SiO_2 + C + CO	Si layer fully oxidized to SiO_2, Mo layer unchanged
YSZ	YSZ unchanged	Si layer partially oxidized to SiO_2, Mo layer partially oxidized to MoO_3
$MoSi_2$	Si oxidized to SiO_2, Mo removal or diffusion into bulk	Si layer fully oxidized to SiO_2, Mo layer partially oxidized

Summary

- Fabricated and pre-screened ML1 and ML2 samples. No capping layer development efforts were funded.

- Oxidation/EUV reflectivity degradation mechanisms determined for selection of novel capping layer materials for EUV multilayer mirrors.

- Ruthenium capping layer still a leading candidate for oxidation protection. Further improvements are required, however, need fundamental understanding of Ru surface science.

- The differences in the mechanisms demonstrate that test protocols will have materials dependence that cannot be ignored.