

IEUVI Optics Lifetime & Contamination TWG

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ML Coating Lifetime at LLNL: Benchmarking and Development

John S. Taylor, Saša Bajt

Lawrence Livermore National Laboratory

- **Overview**
- **Ru capping layers and benchmark samples**
- **Degradation mechanisms**
- **Thermal stability**
- **Future efforts**



What is known?

- ♦ In an oxidizing atmosphere + EUV → Ru oxidizes
 - For some fluence levels, lifetime \ll 1 year
- ♦ Oxygen and hydrogen will “likely” also diffuse through Ru
- ♦ $C_xH_y-H_2O$ gas blends can mitigate oxidation
- ♦ Degradation mechanisms for classes of capping layers identified

What is unknown?

- ♦ How can properties of nano-layers be tailored to mitigate degradation?

Is Ru acceptable as the baseline approach for a capping layer?

- ♦ Maybe, but with risk → What are fluences and benchmarking results?

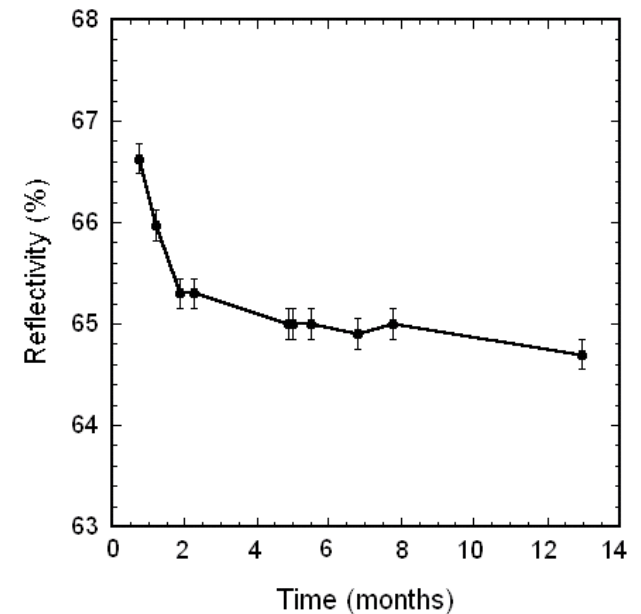
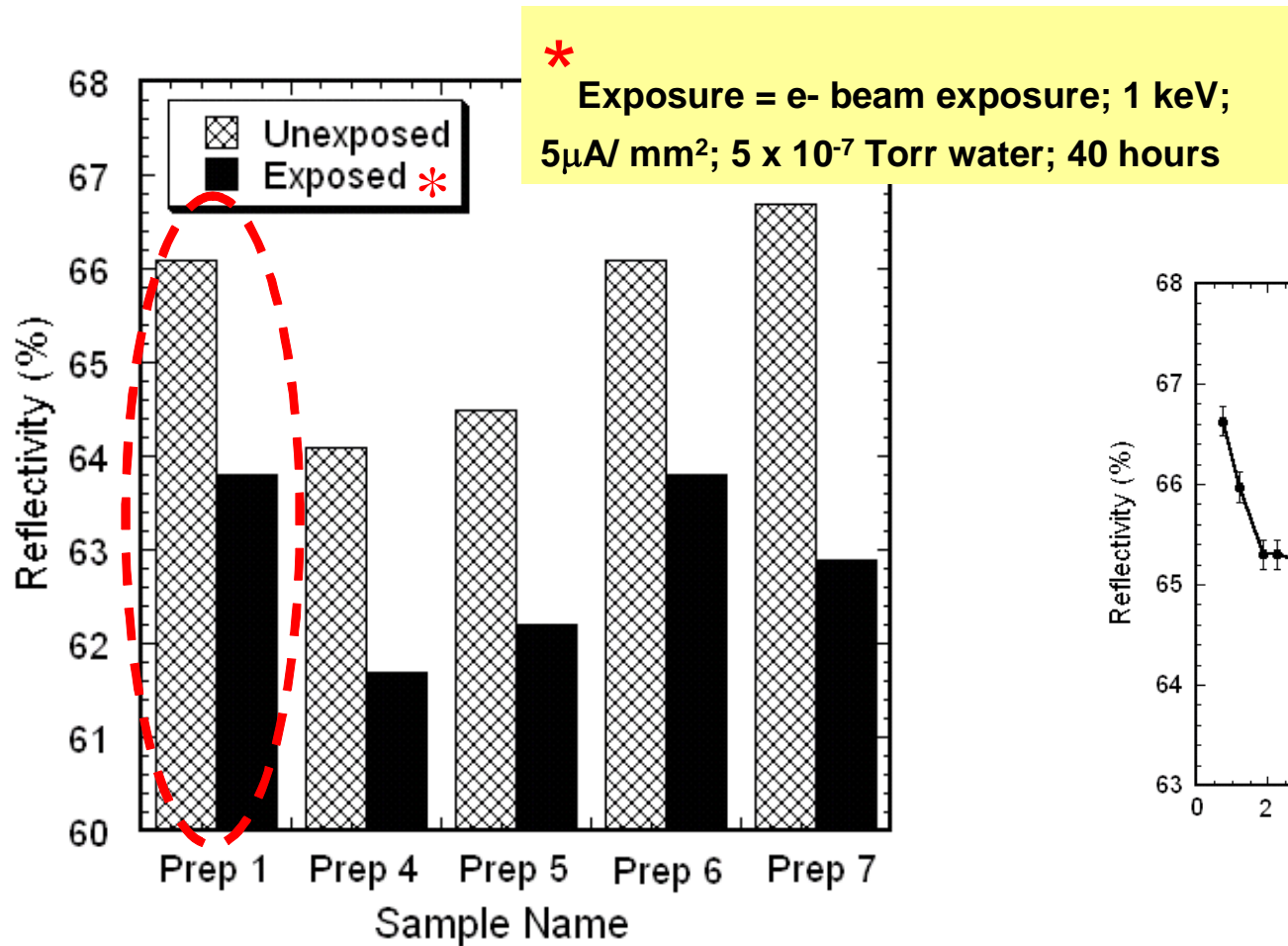
Desired Plan

- ♦ Identify and quantify degradation mechanisms
- ♦ Identify and test solutions to degradation mechanisms

Status of LLNL Program

- ♦ Sematech: Fabricate benchmarking samples
- ♦ Industry: “Try” new capping layers; polymer smoothing; contract coating
- ♦ Leading edge development for non-EUV applications

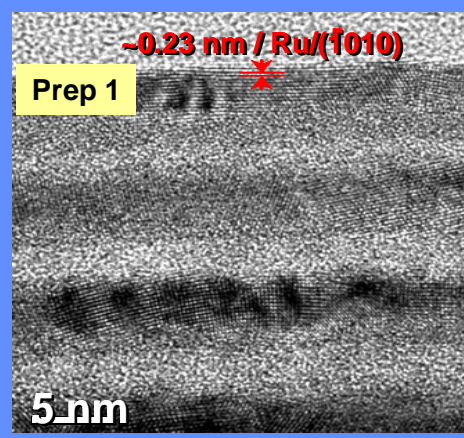
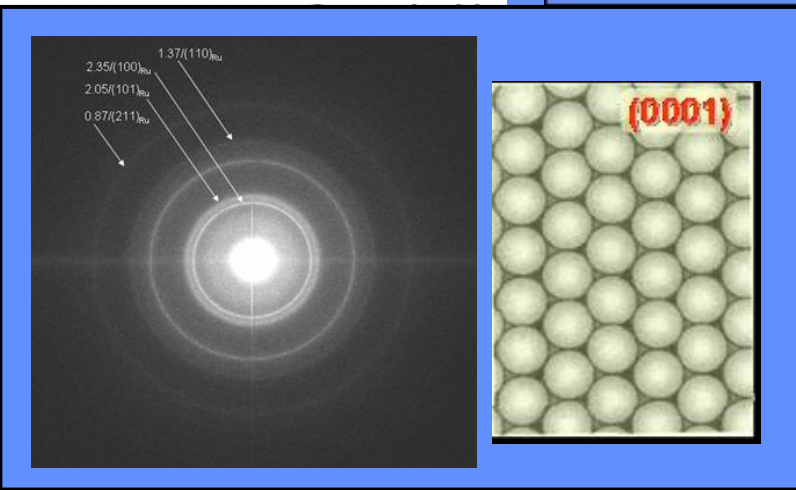
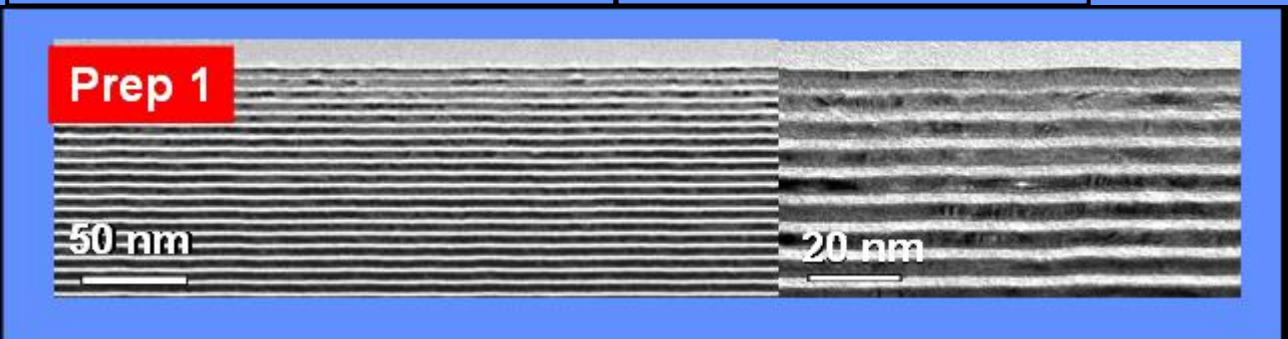
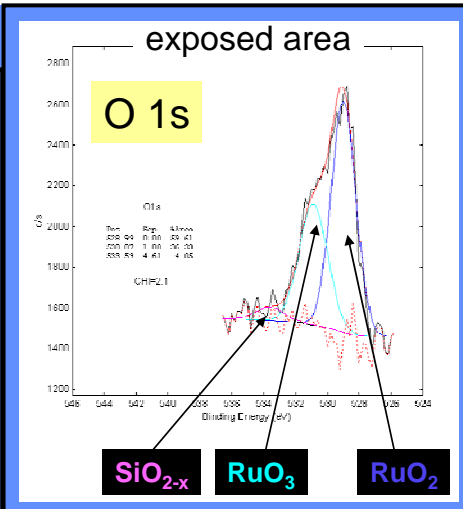
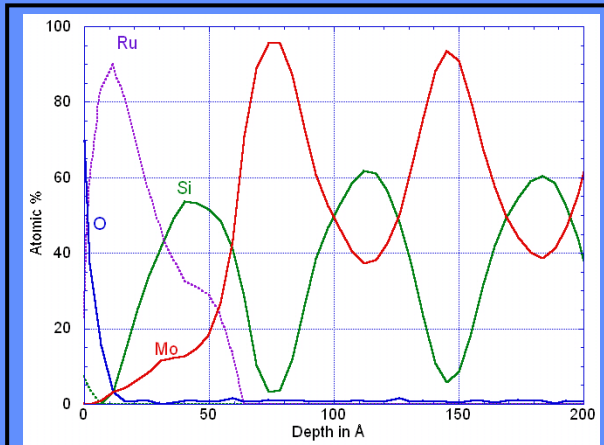
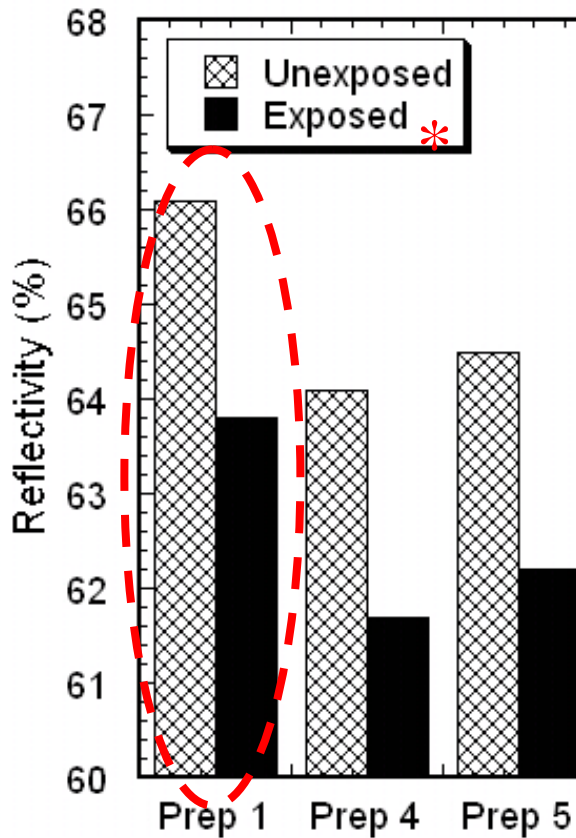
Ru Capping Layers and Benchmarking



*Prep 6 has similar performance to Prep 1

Temporal stability of Prep 1

Ru Capping Layers and Benchmarking



Prep 1 has:
 good crystallinity,
 almost single orientation,
 crystal structure matches
 the metal Ru

However: SAD is needed
 to determine Ru
 orientation

Different classes of capping layer materials suggest different degradation mechanisms

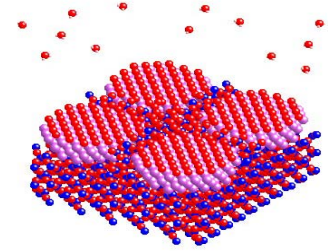


	E-beam exposed samples	
Capping layer	Capping layer XPS results	Underlying multilayer XPS results
Pd	Partial Pd oxidation, Pd diffusion into bulk	Si layer fully oxidized to SiO ₂ , Mo layer partially oxidized
Au _{0.5} Pd _{0.5}	Partial Pd oxidation, Au & Pd diffusion into bulk	Si layer fully oxidized 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

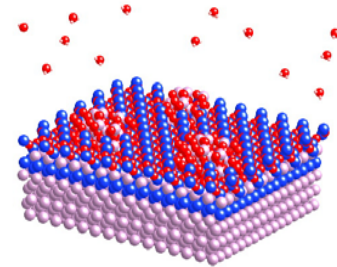
Specific degradation mechanisms have been identified for different classes of capping layers



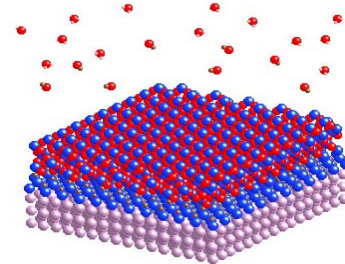
- Oxidation of incompletely covered surfaces



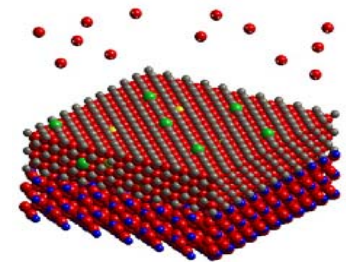
- Oxygen diffusion into the capping layer and subsequent chemical reactions



- Oxidation via defects (pesteing)



- Enhanced oxygen diffusion via mobile vacancies



Specific degradation mechanisms have been identified for different classes of capping layers



Additional key experiments need to be identified to show nano-scale motion of vacancies, diffusion, etc.

Once degradation mechanisms are understood, then materials science can be invoked to mitigate the mechanism(s)

➤ **Close diffusion pathways by**

- Increase stress or density within capping layer
- Introduce a low conc. of interstitial atoms
- ...

➤ **Enhance passivation with oxygen getters**

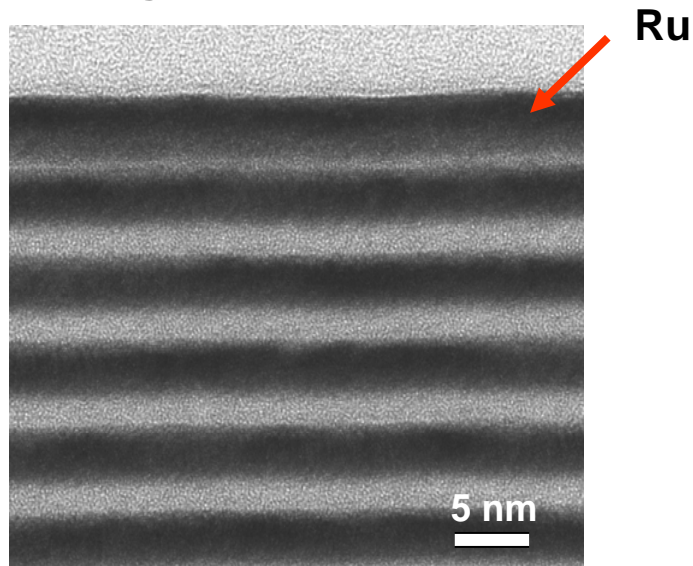
➤ **Catalysis → Volatile products without degradation**

➤ **...**

MLs with good thermal stability have been developed

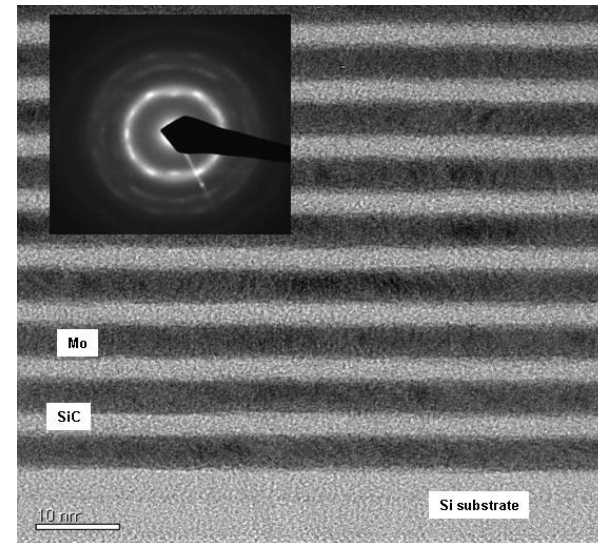


**Interface-engineered MLs
(High R, low Stress)**



**Long term stability at 35°C
(cured at 80°C)**

**New multilayer design
(High R, high thermal stability)**



**Long term stability at 400-500°C
(cured at 400°C)**

Interlayer chemical interactions can be engineered



Fabrication of benchmarking samples

- ◆ Essential to communicate to chip makers:
 - “Is there a problem and how large is it?”
- ◆ Need to continually validate accelerated testing procedures
- ◆ Quantify efficacy of new capping layer approach(es) (Intel contract)

Knowledge of degradation mechanisms essential to development

- ◆ If Ru or trial-and-error testing of key material classes fails
 - Detailed understanding of nano-layer chemistry and transport is essential
 - LLNL would like to participate in the science of understanding degradation mechanisms and developing solutions
 - e.g. White paper and/or experimental development

Longer-term view

- ◆ Supply benchmark samples to Sematech
- ◆ Maintain production quality ML coating equipment (Mag-4, IBD)
- ◆ Polymer smoothing development continues for condenser optics, etc.
- ◆ Focus will shift to leading edge development of novel nano-structures, high-energy x-ray coatings, high-resolution x-ray optics, “cheap” Wolter optics, ultra-light telescope optics, optics for astronomy