IEUVI Optics Lifetime & Contamination TWG

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ML Coating Lifetime at LLNL: Benchmarking and Development

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

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Overview - LLNL

What is known?

- In an oxidizing atmosphere + EUV → Ru oxidizes
  - For some fluence levels, lifetime << 1 year
- Oxygen and hydrogen will "likely" *also* diffuse through Ru
- C_xH_y-H_20 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

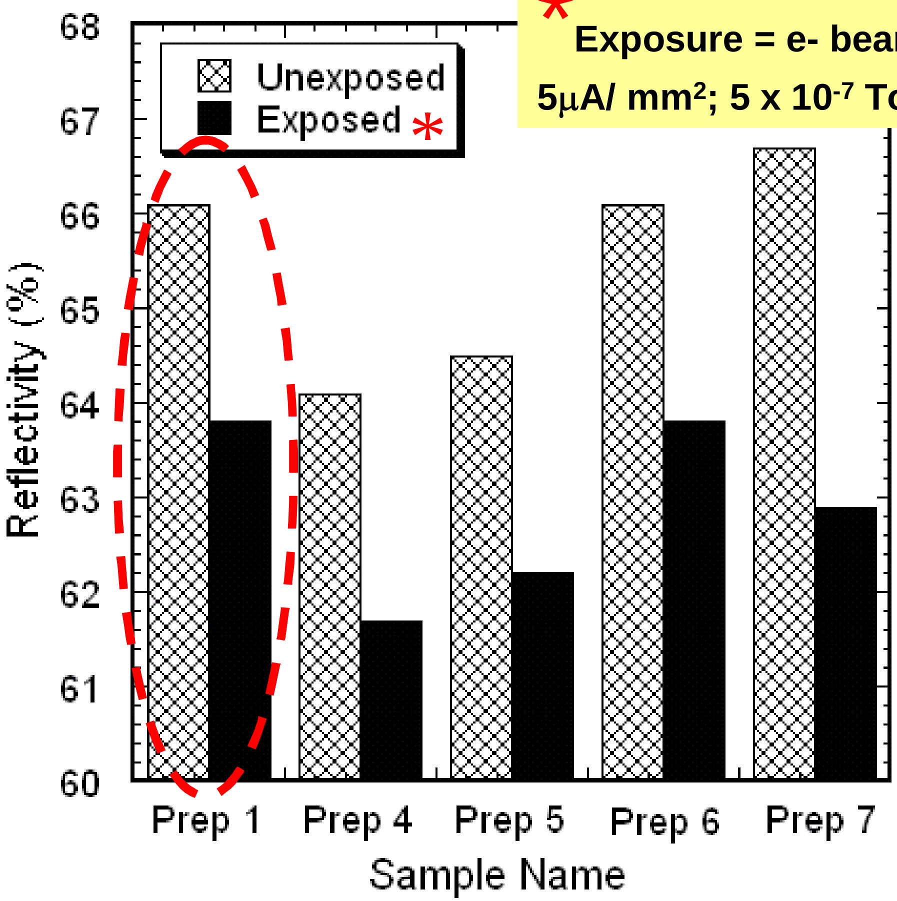
- Identify and quantify degradation mechanisms
- Identify and test solutions to degradation mechanisms

Status of LLNL Program

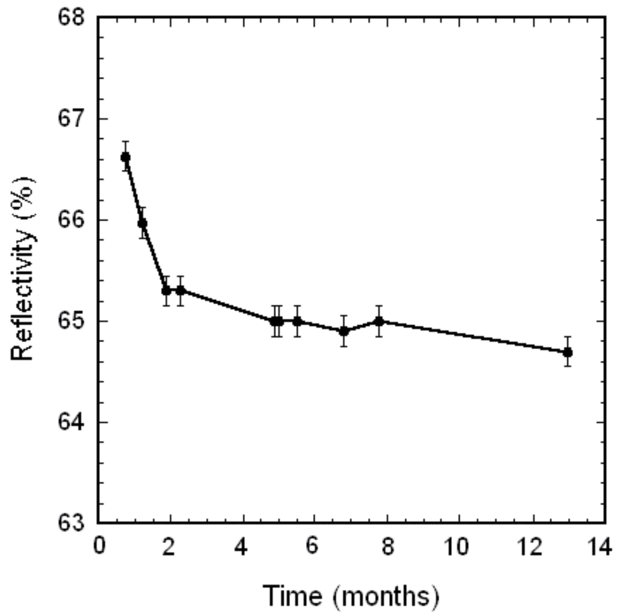
- Sematech: Fabricate benchmarking samples
- Industry: "Try" new capping layers; polymer smoothing; contract coating
- Leading edge development for non-EUV applications

Ru Capping Layers and Benchmarking

*** Exposure = e- beam exposure; 1 keV; 5μA/ mm²; 5 x 10^{-7} Torr water; 40 hours**

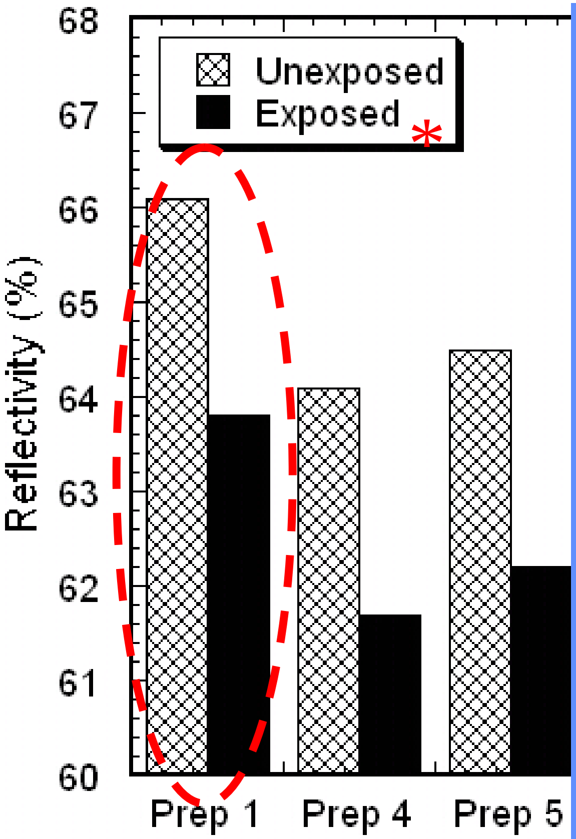


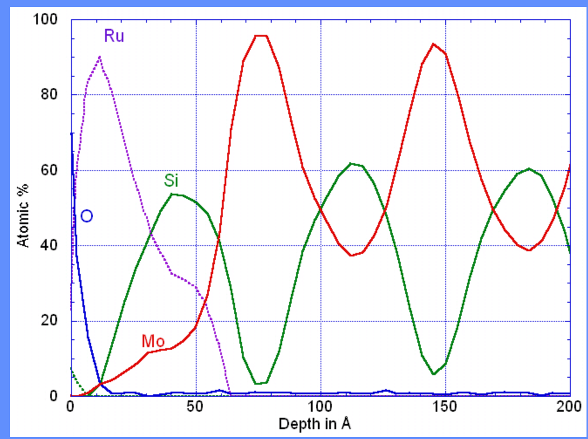
*Prep 6 has similar performance to Prep 1

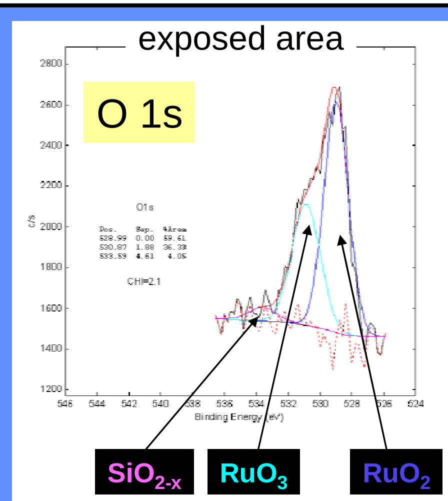


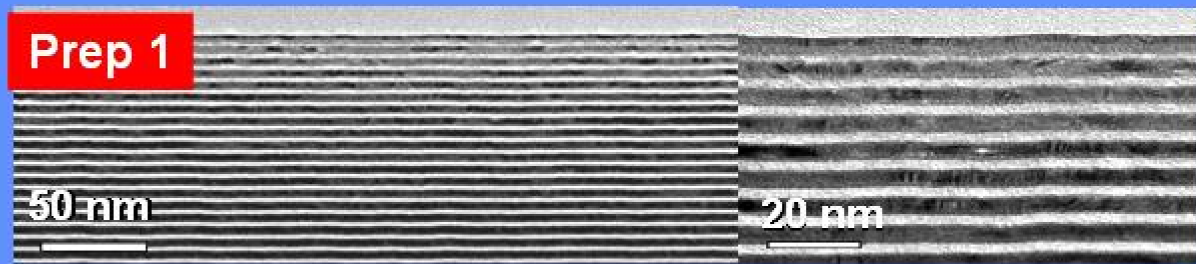
Temporal stability of Prep 1

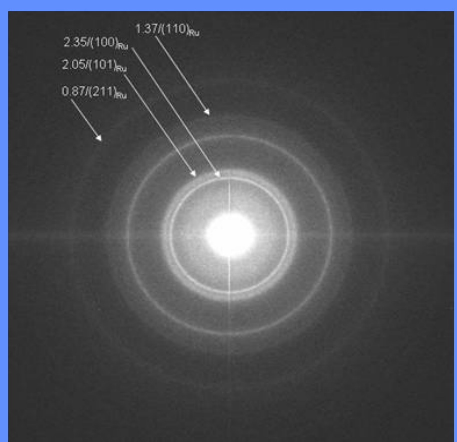
Ru Capping Layers and Benchmarking

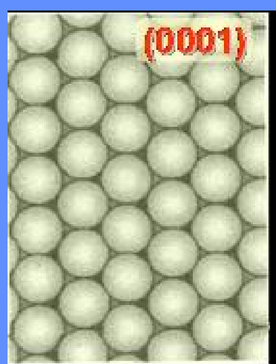


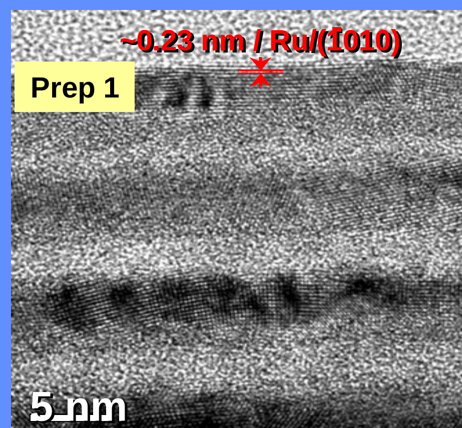












Prep 1 has:
good crystallinity,
almost single orientation,
crystal structure matches the metal Ru

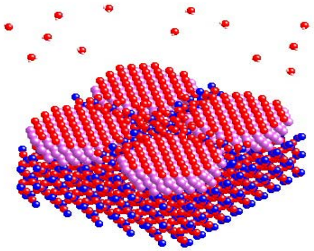
However: SAD is needed to determine Ru orientation

Different classes of capping layer materials suggest different degradation mechanisms

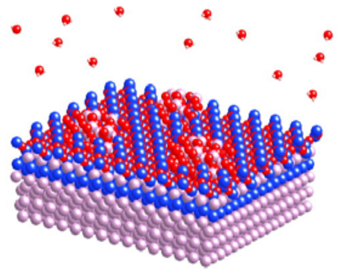
	E-beam exposed samples	
Capping layer	Capping layer XPS results	Underlying multilayer XPS results
Pd	Partial Pd oxidation, Pd diffusion into bulk	Si layer fully oxidized to SiO_2, Mo layer partially oxidized
$Au_{0.5}Pd_{0.5}$	Partial Pd oxidation, Au & Pd diffusion into bulk	Si layer fully oxidized 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

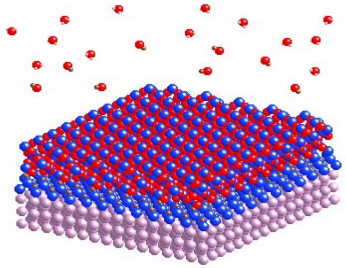
- Oxidation of incompletely covered surfaces



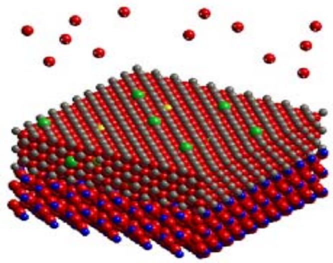
- Oxygen diffusion into the capping layer and subsequent chemical reactions



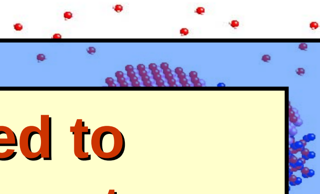
- Oxidation via defects (pesting)



- Enhanced oxygen diffusion via mobile vacancies



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



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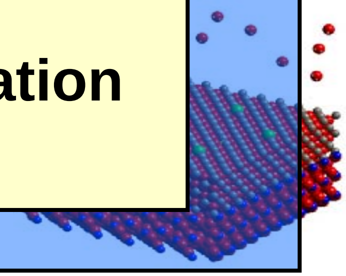
Additional key experiments need to be identified to show nano-scale motion of vacancies, diffusion, etc.

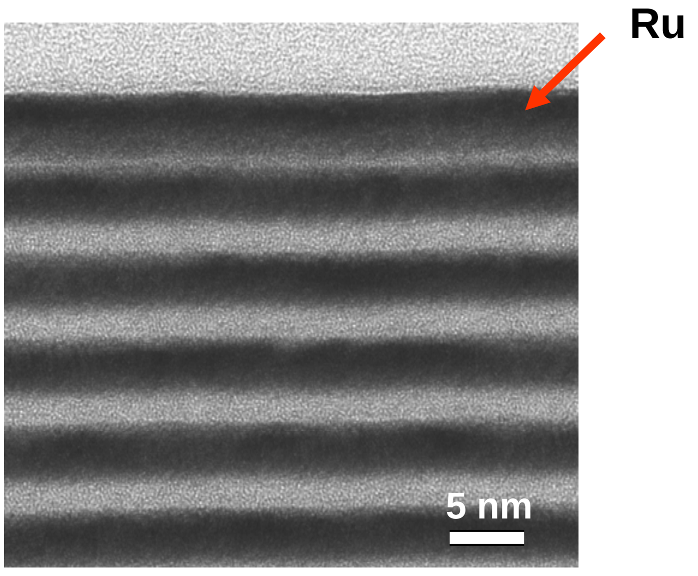
Once degradation mechanisms are understood, then materials science can be invoked to mitigate the mechanism(s)

- **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**
- **…**



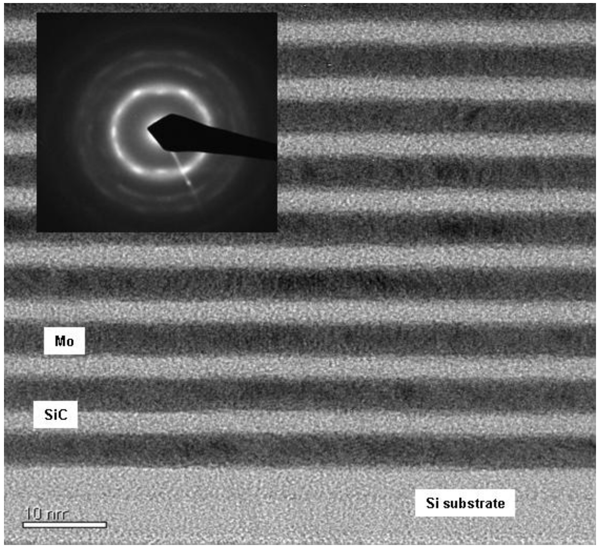
MLs with good thermal stability have been developed

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

Future Work – ML Coating at LLNL

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