Investigation of Oxidation Resistance of EUV Multilayers

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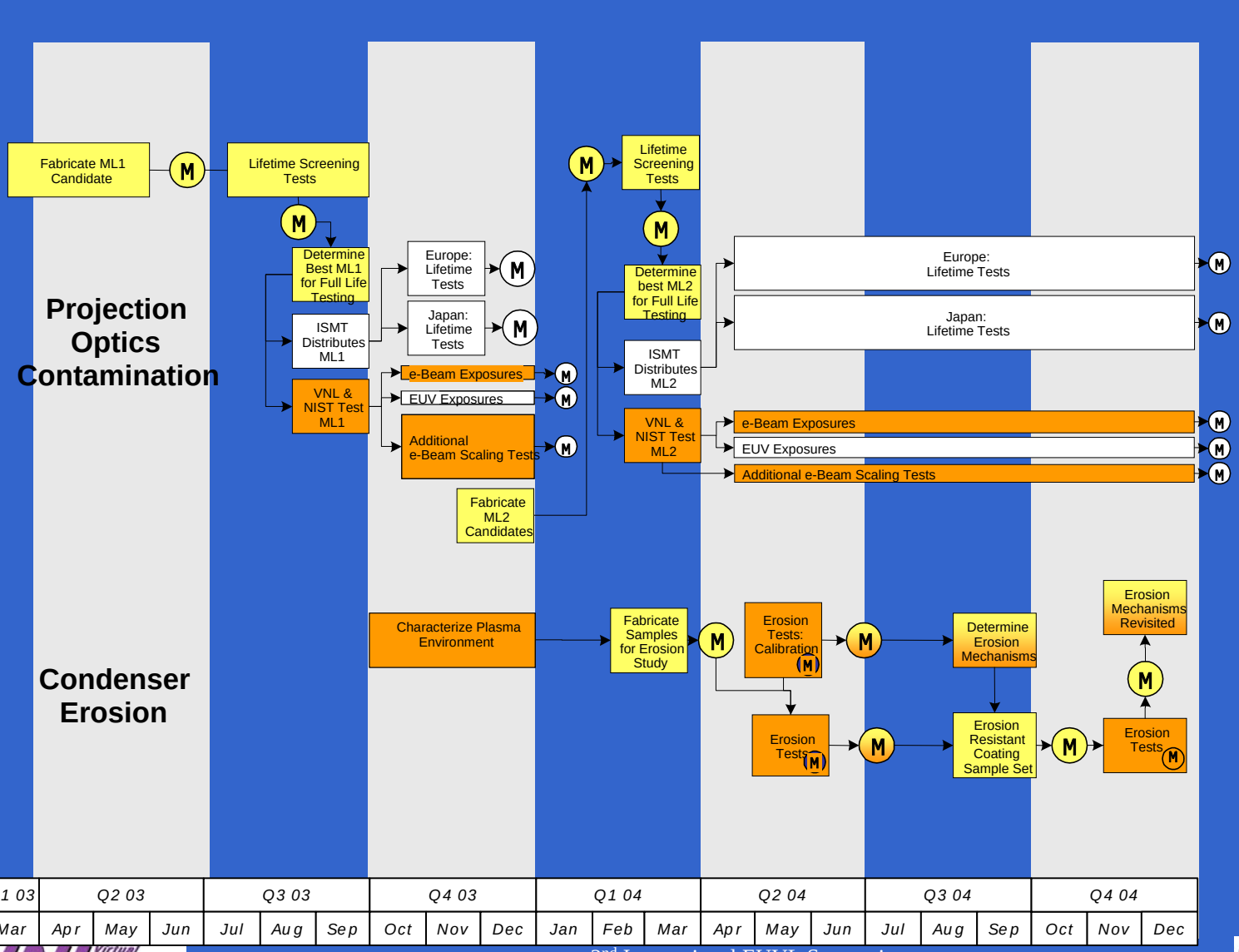
Parametric and Scaling Studies are essential to estimate Multilayer Lifetimes

Issue	Current status 2003	β-tool 2004	Commercial tool 2007
Peak Reflectance – optics	65%	68%	70%
Lifetime (Imaging Optics)	1.6%/week - Si 1.6%/4 months - Ru	1.6%/3years	1.6%/5years
Lifetime (First Condenser Optic)	Unknown	10%*/year	10%*/year
Lifetime (Other Condenser Optics)	Unknown	2.5%*/year	2.5%*/year
Max Operation Temp (Imaging Optics)	25°C	25°C	25°C
Mask Rapid Thermal Cycle	150°C, <2min	200°C, <2min	200°C, <2min
Max Operation Temp (Mask Plane)	25°C	30°C	35°C
ML Added Figure Error	0.1 nm rms	0.05 nm rms	0.05 nm rms
Relative Optical Throughput**	1.0	1.5	2.0

*Relative percent **Assuming a system with 10 multilayer-coated surfaces

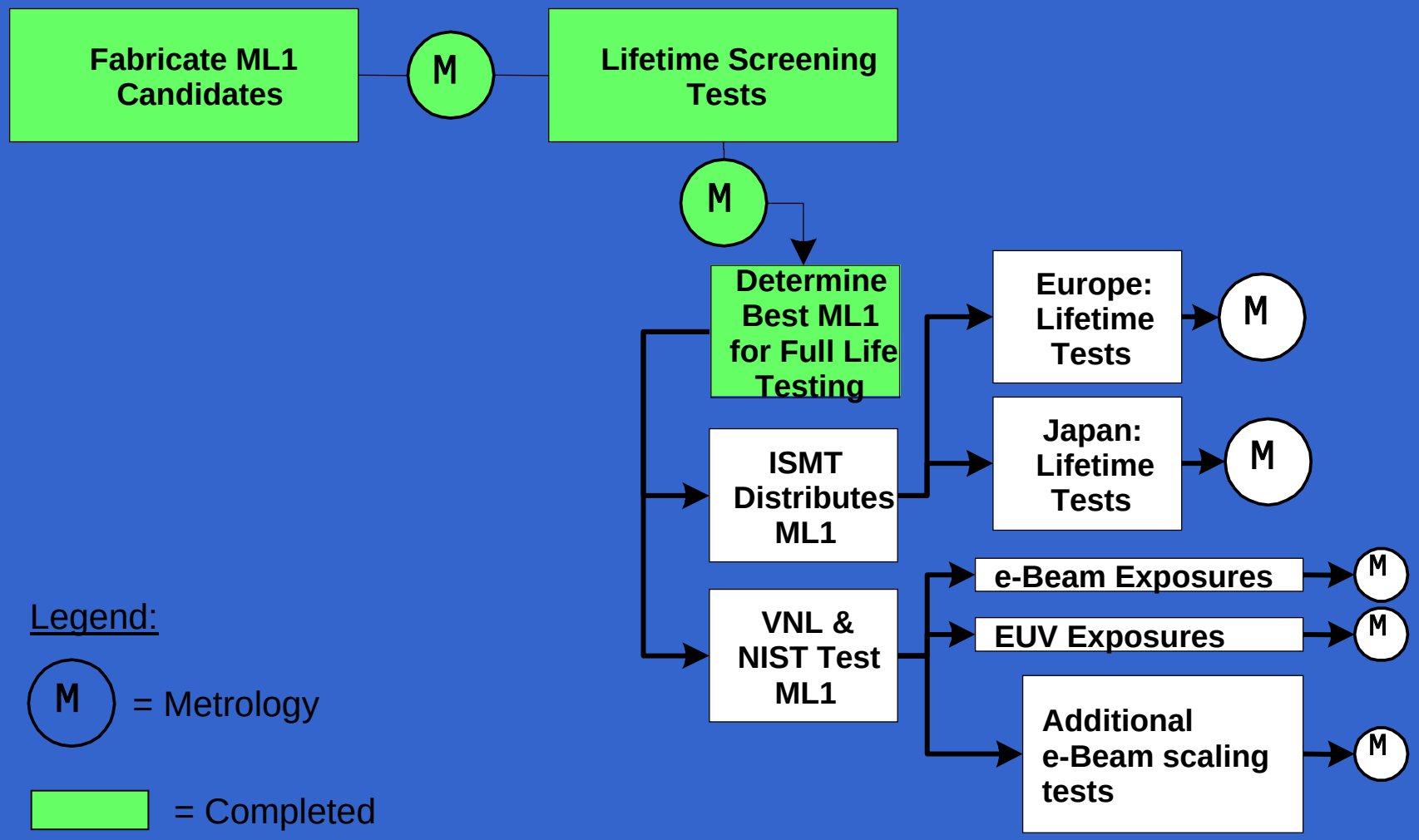
LITH160 – 2004 Project Outline



Output:
- Accelerated life testing protocol
- Parametric dependences
- Scaling laws
- Improved ML technology

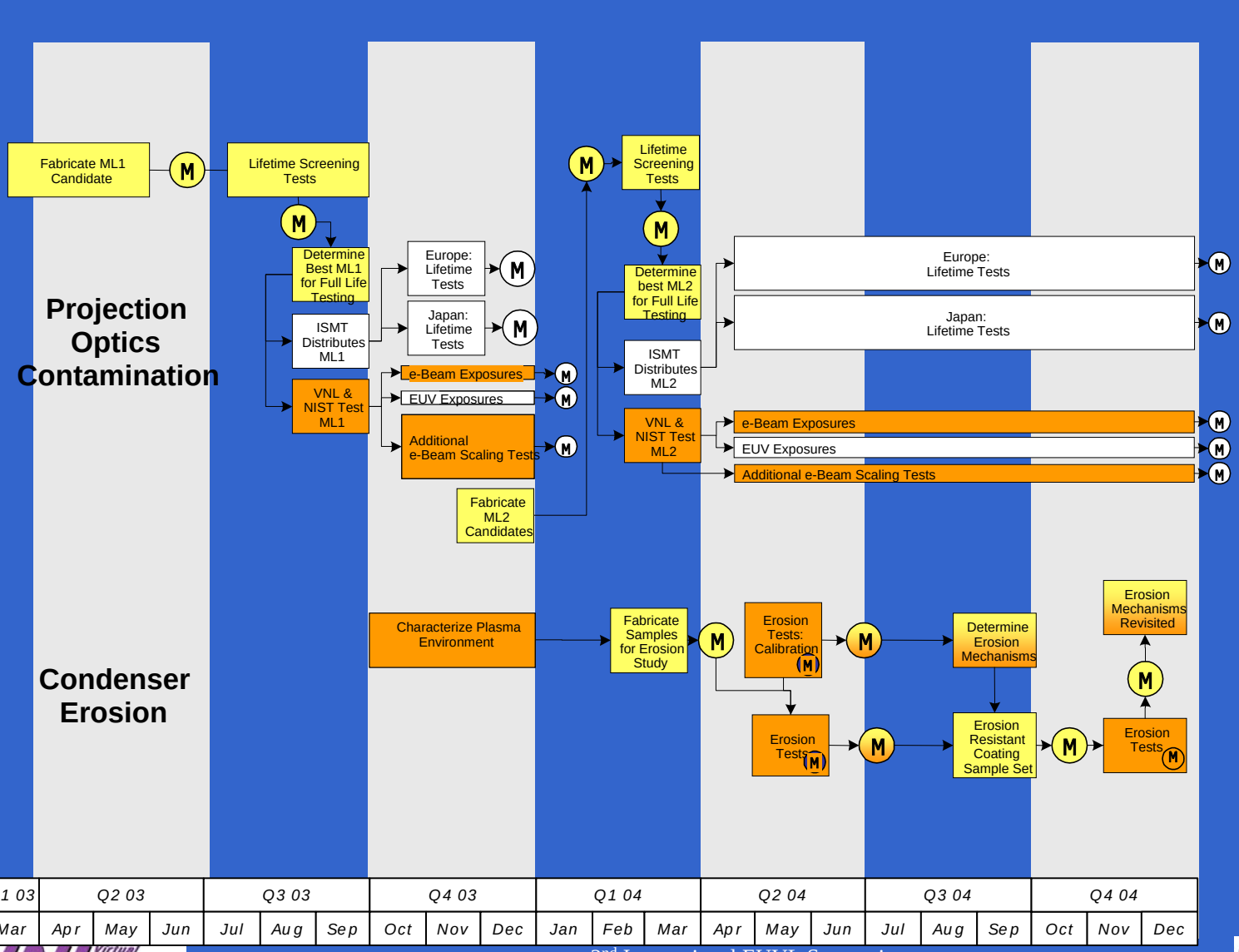
Output:
- Methodology for testing
- Erosion mechanisms
- Erosion resistant coating

LITH 160 – 2003 Project Outline



Q 1 0 3	Q 2 0 3	Q 3 0 3	Q 4 0 3	Q 1 0 4

LITH160 – 2004 Project Outline



Output:
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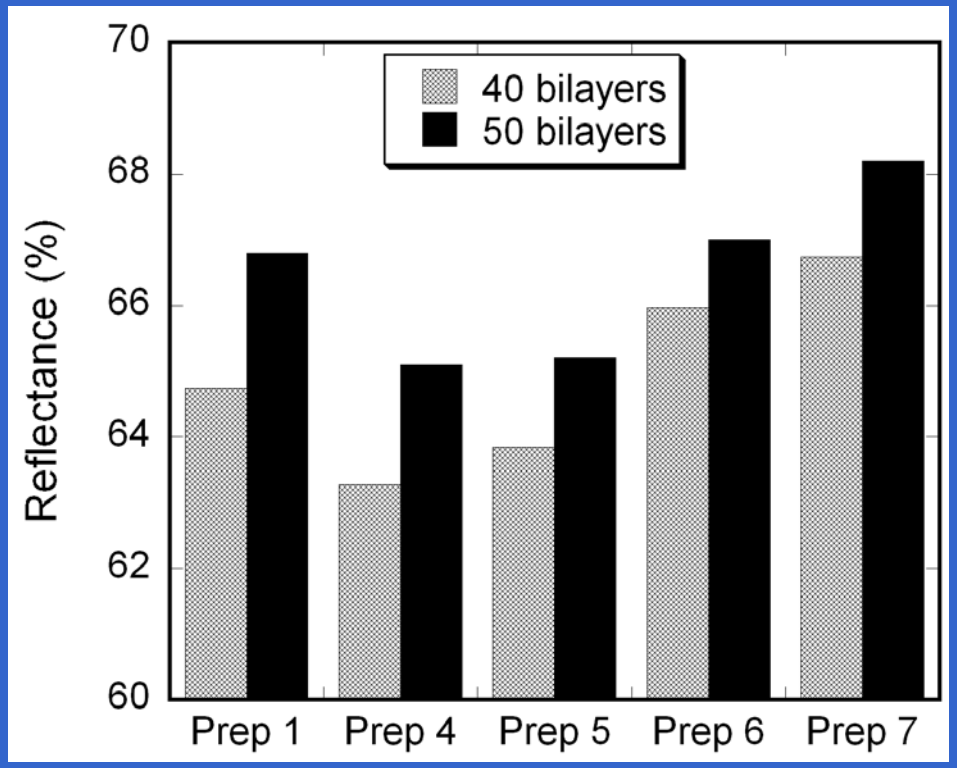
Ru-Capped Multilayers Prepared with Various Deposition Parameters Show Different EUV Reflectivities



- **Good candidate for accelerated life-testing needed**
- **ML1 is a large set of candidate samples**
- **Deposition parameters strongly influenced EUV reflectivity**
- **Understanding physical origin of these differences is underway**

Preparation 1 (power change)

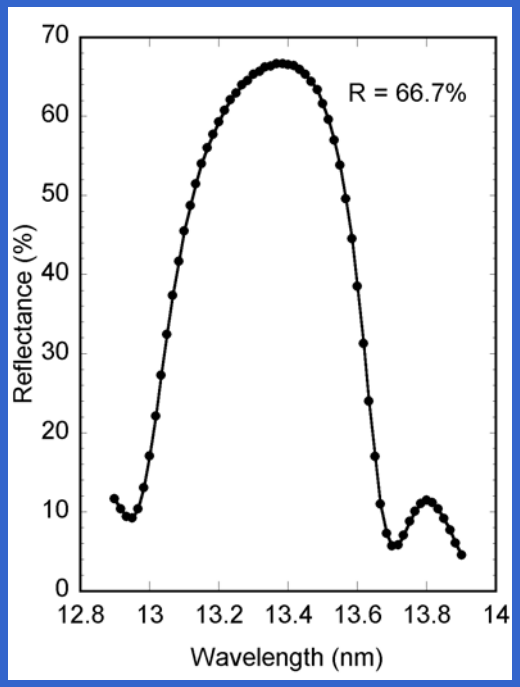
Preparation 2 and 3 (gas pressure variation)

Preparation 4, 5 and 6 (gas mixture variation)

Preparation 7 (material variation)

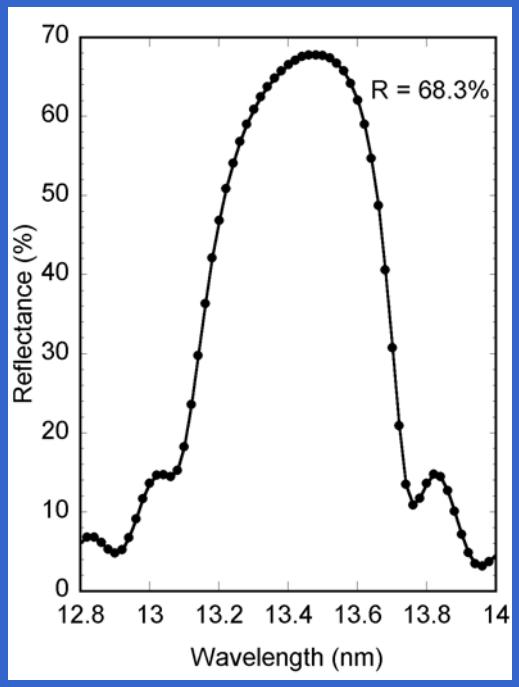
World-class Reflectivities for Ru Capped Layers Achieved

R= 66.7%



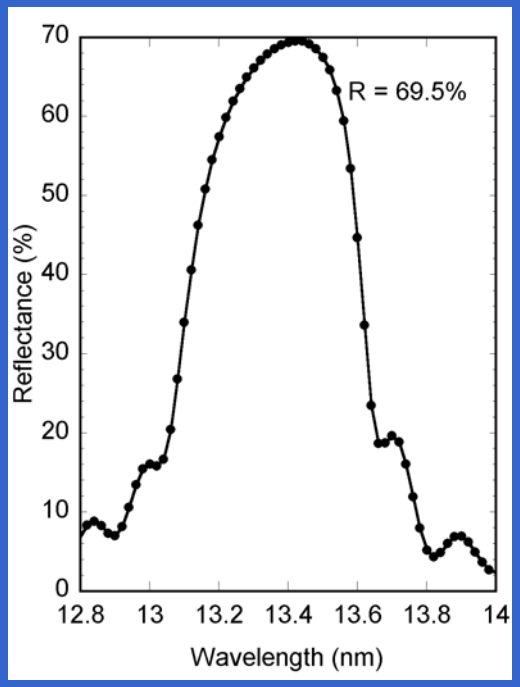
Past work (EUV LLC)
with diffusion barrier

R= 68.3%



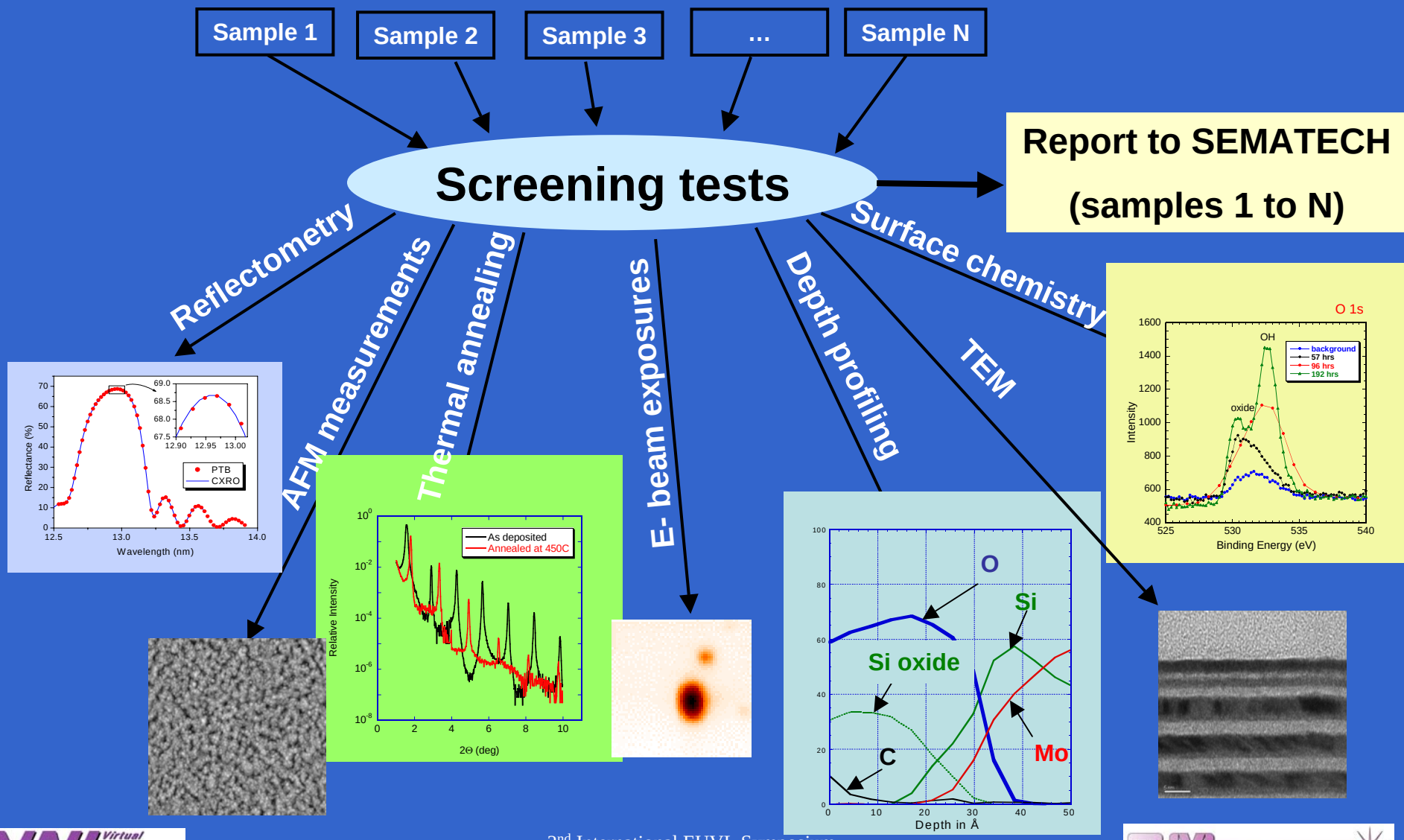
Multilayer 1
no diffusion barrier

R= 69.5%

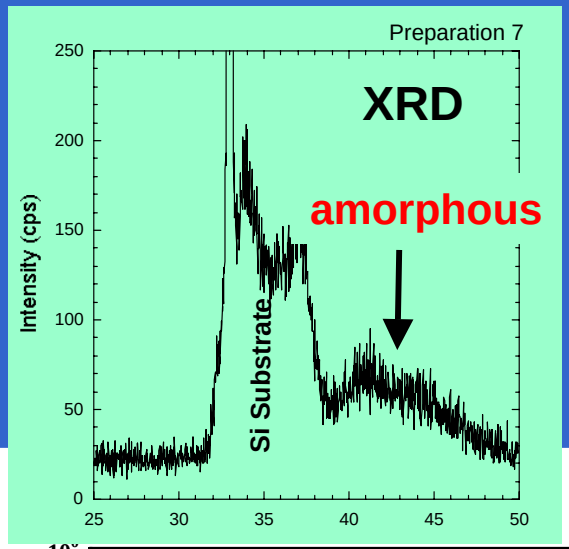


Multilayer 1
with diffusion barriers

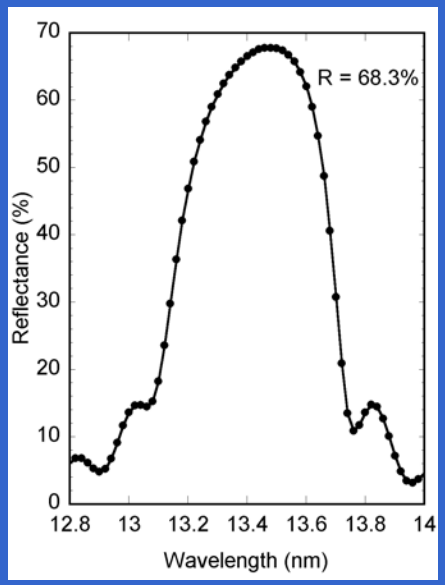
Screening Tests for Determining Optimal Deposition Conditions

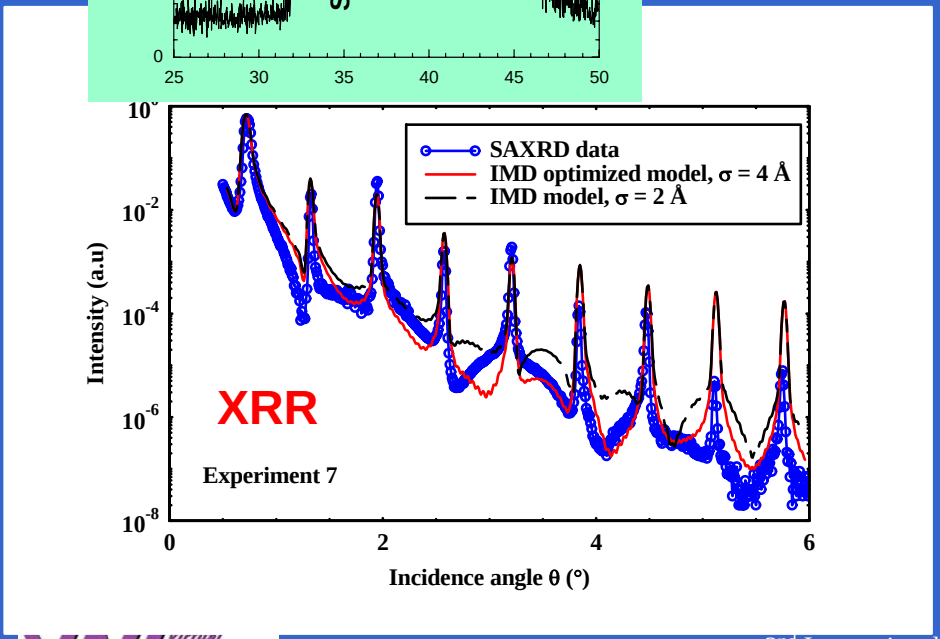


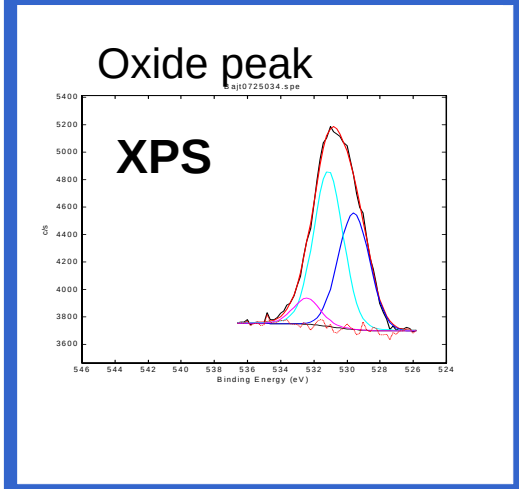
Analytical Characterization of ML1 Samples

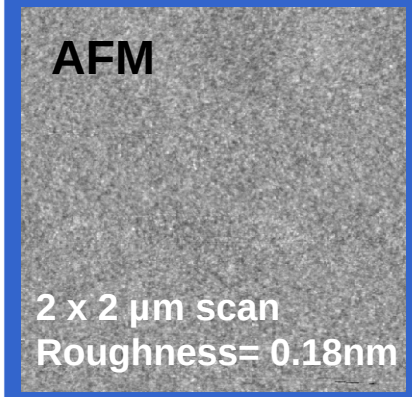


To understand physical origins of reflectivity differences and to create pre-lifetime testing baseline

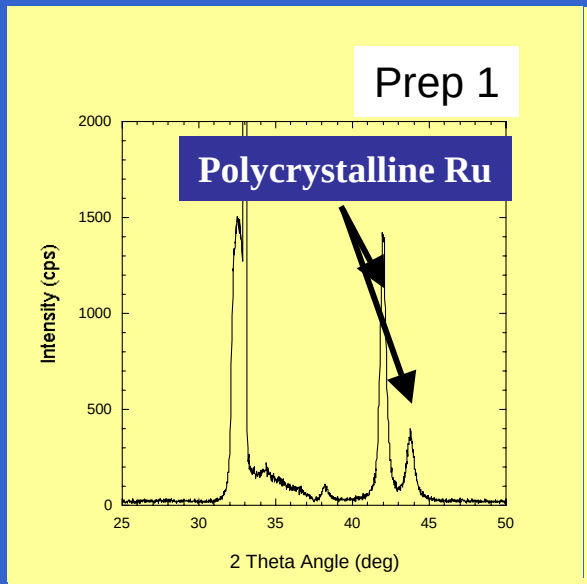


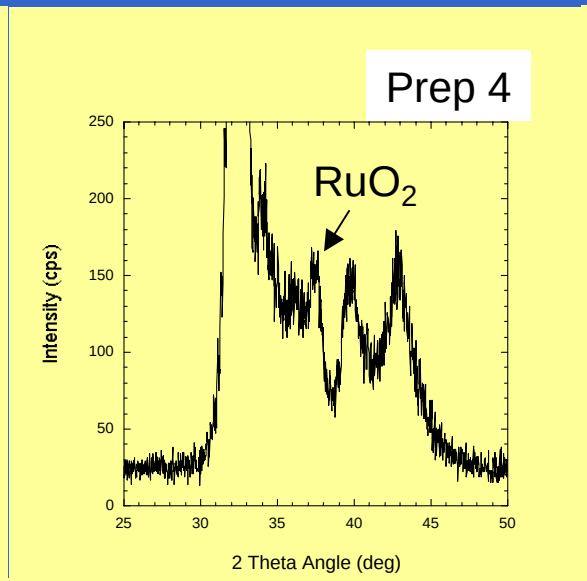


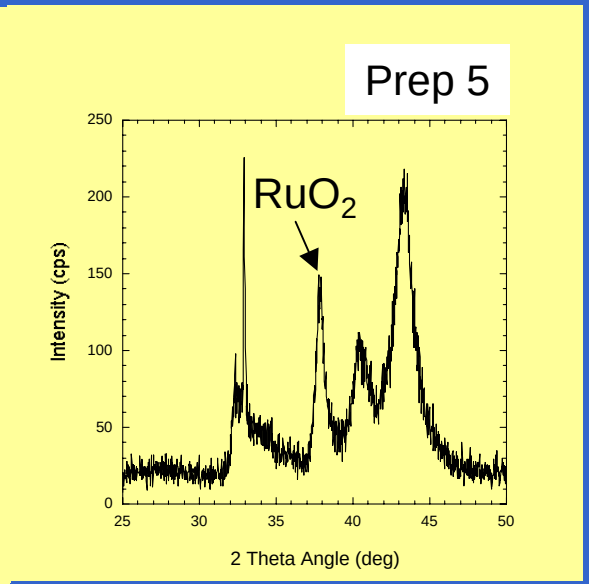


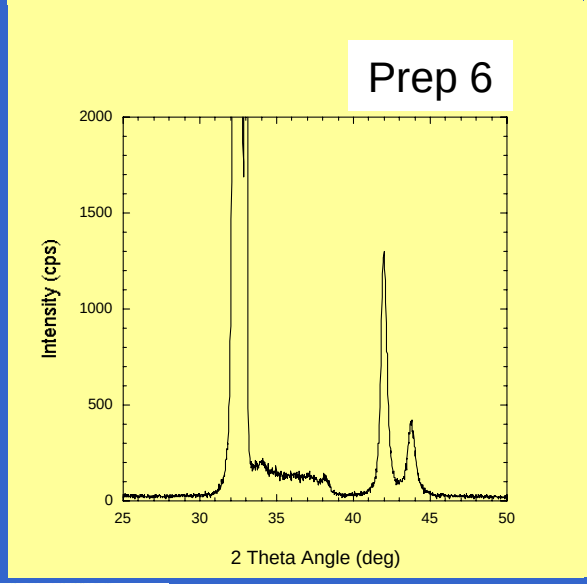


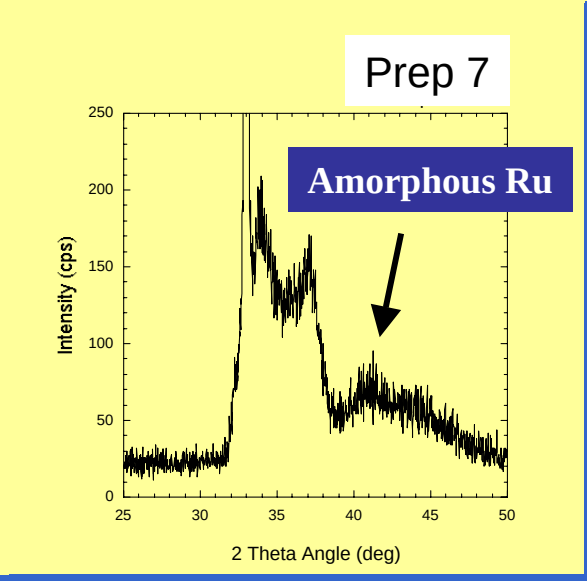
Deposition Parameters Strongly Influence the Crystallinity of Thick Ru Films







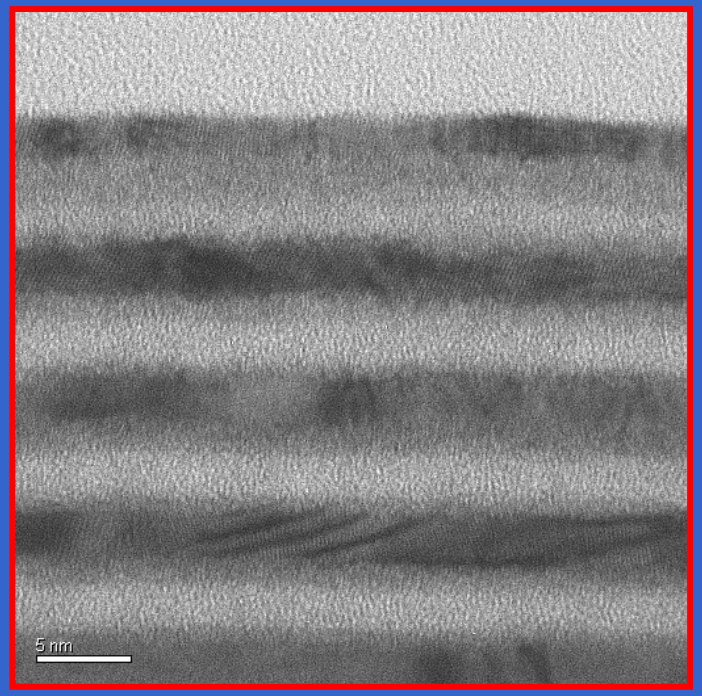




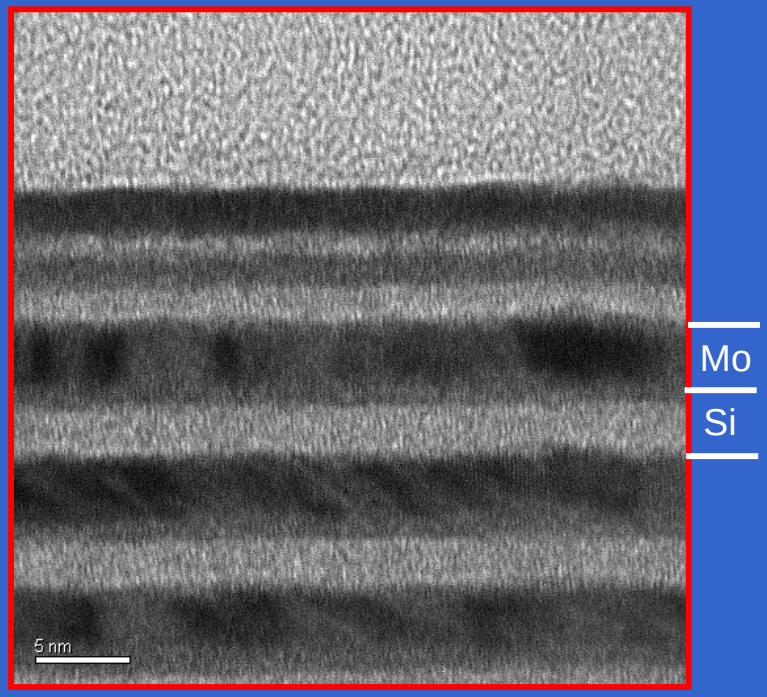
How does the microstructure of the capping layers affect initial reflectivity, thermal stability and oxidation resistance?

Cross Section TEM Images show Differences in Capping Layer Microstructure

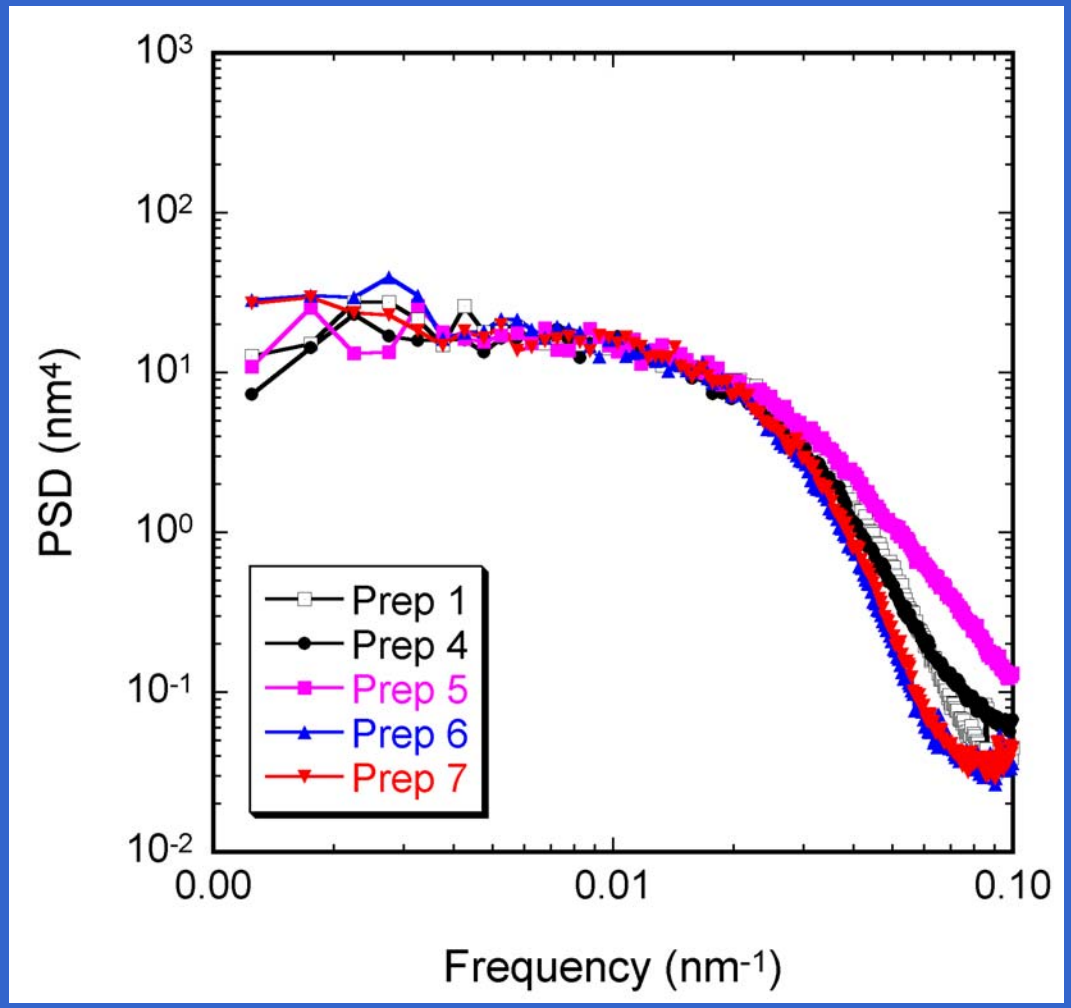
Preparation 1



Preparation 4



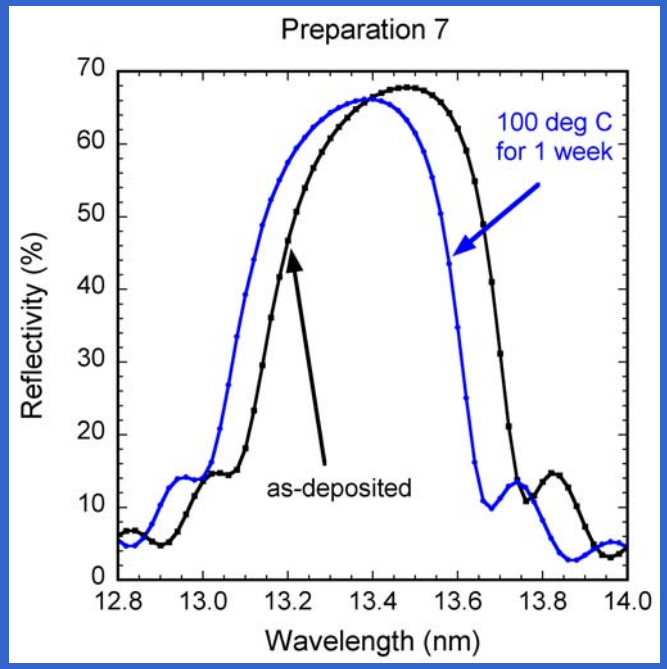
However, the surface roughness on Ru-capped multilayers is very similar

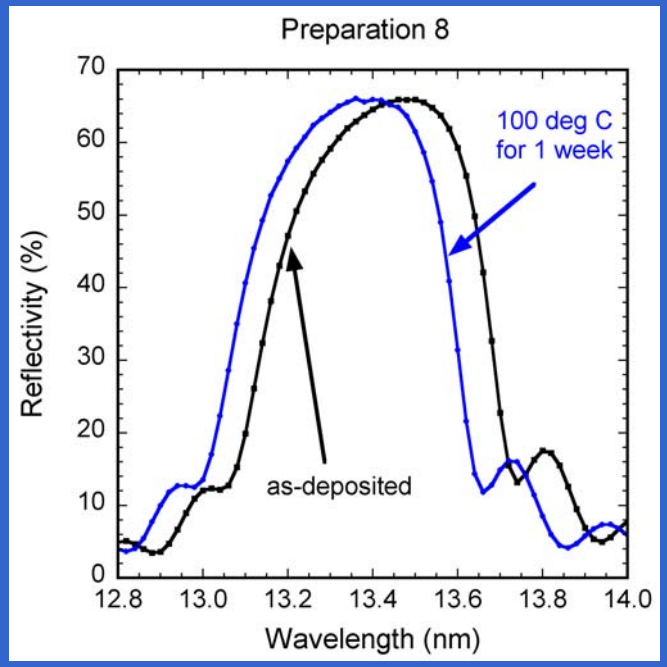


Preparation	Rms (nm)
1	0.18
4	0.18
5	0.21
6	0.17
7	0.17

Mostly oxidized

High initial reflectivity is not necessarily an indicator of good performance during thermal stability testing

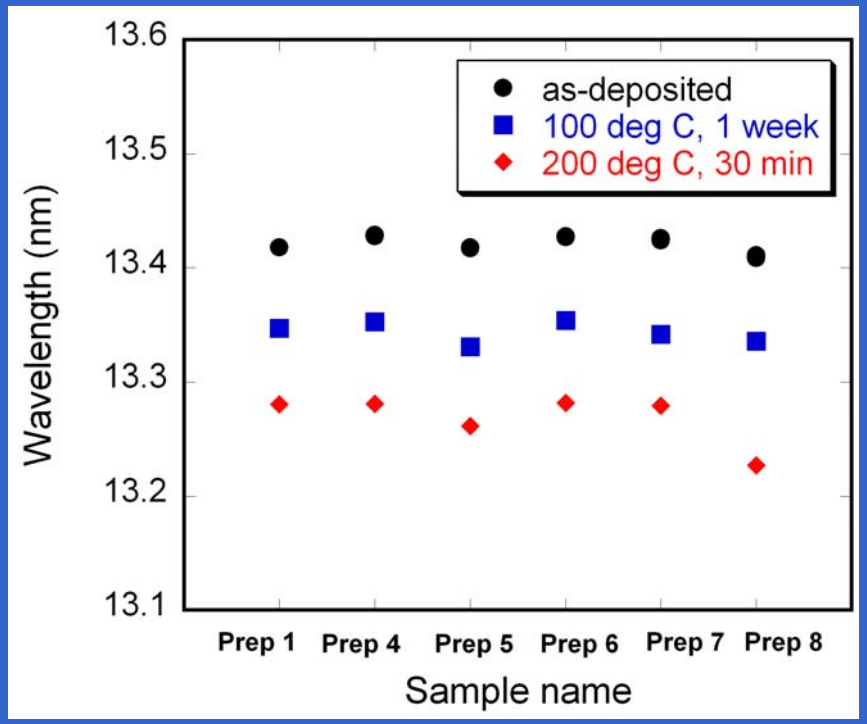




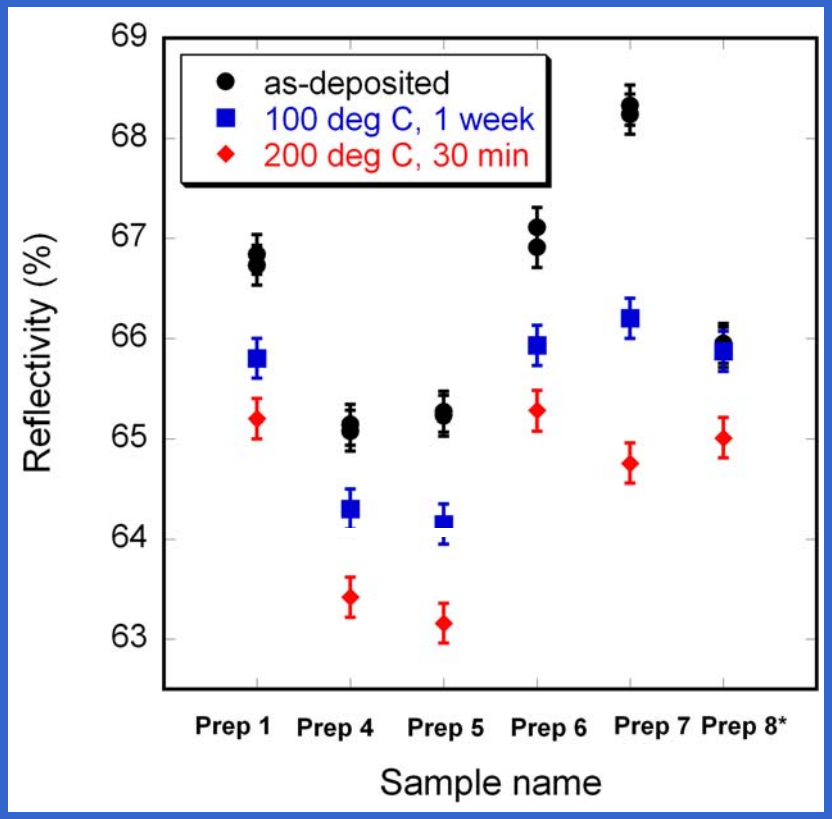
Sample name	Initial reflectivity (%)	ΔR (%) (100ºC, 1 week)	Δλ (nm)
Preparation 7	68.3	- 2.1	0.07
Preparation 8	65.9	- 0.1	0.08

Thermal Annealing Causes Identical Wavelength Change (Bulk) but Different Reflectance Change (Surface)

Wavelength change

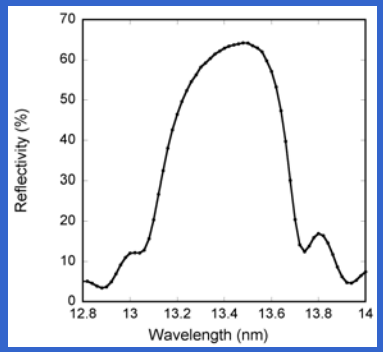


Reflectivity change



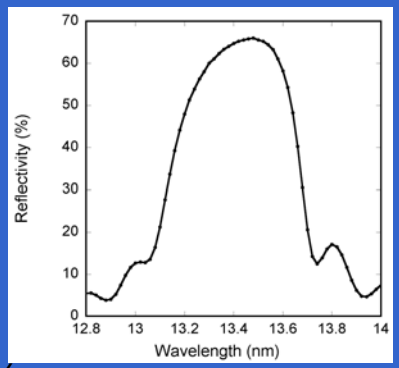
With tight temperature controls Preparation 7 shows the highest reflectivity.

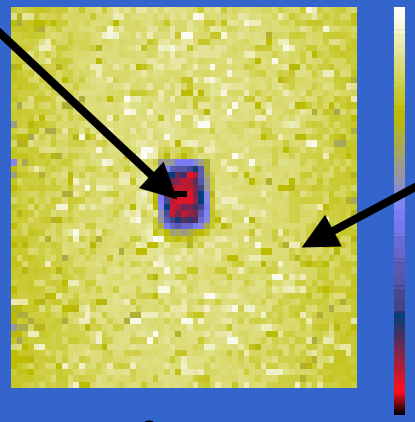
Electron Beam Exposure Testing is Our Final Step in Selecting Optimal Capping Layer for Further Testing

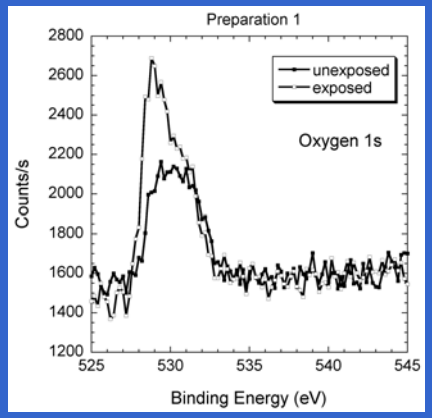


How to chose a candidate for accelerated lifetime testing:

•High reflectivity is not the only consideration

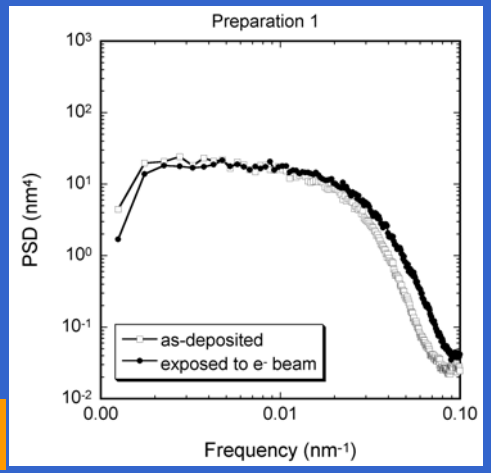






XPS data clearly show changes in the surface oxide due to exposure

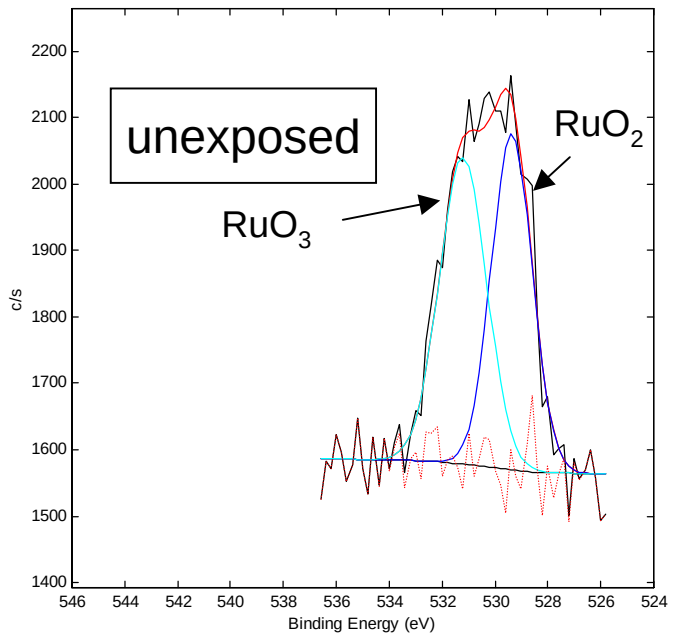
40 hr electron beam exposure in H_2O

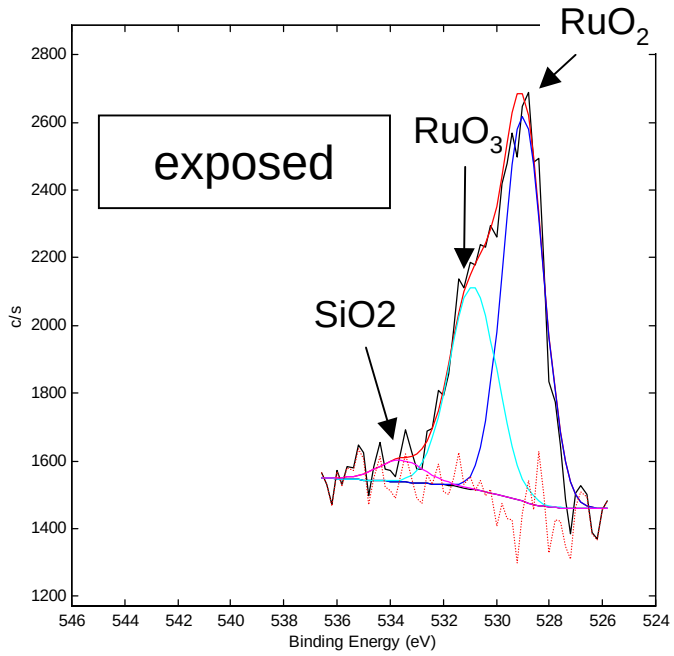


PSD data calculated from AFM show increase in surface roughness

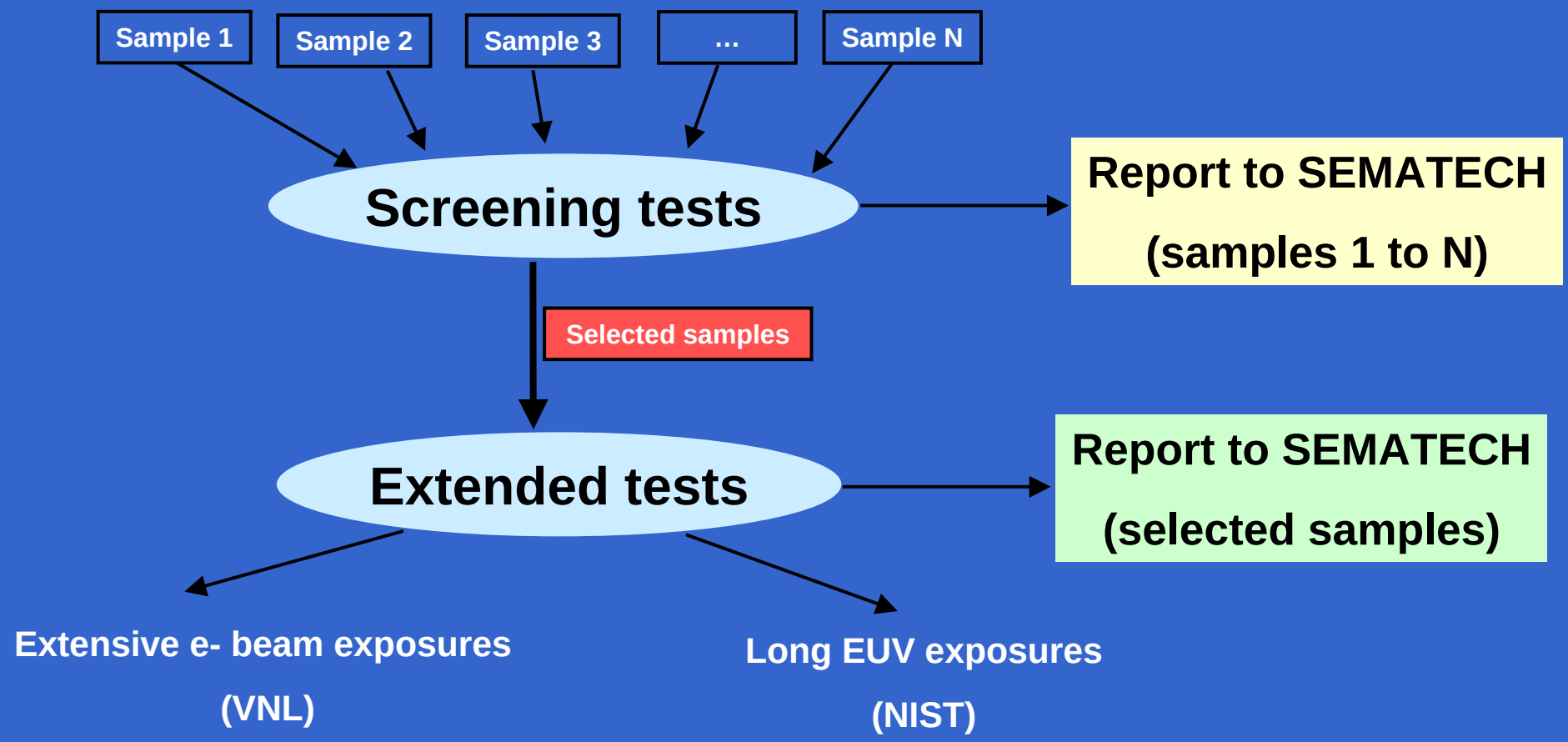
- **Robustness of reflectivity under electron beam and thermal testing must be considered as well**

Oxygen 1s peak from XPS spectra is very sensitive to presence of different oxides and changes in oxidation state

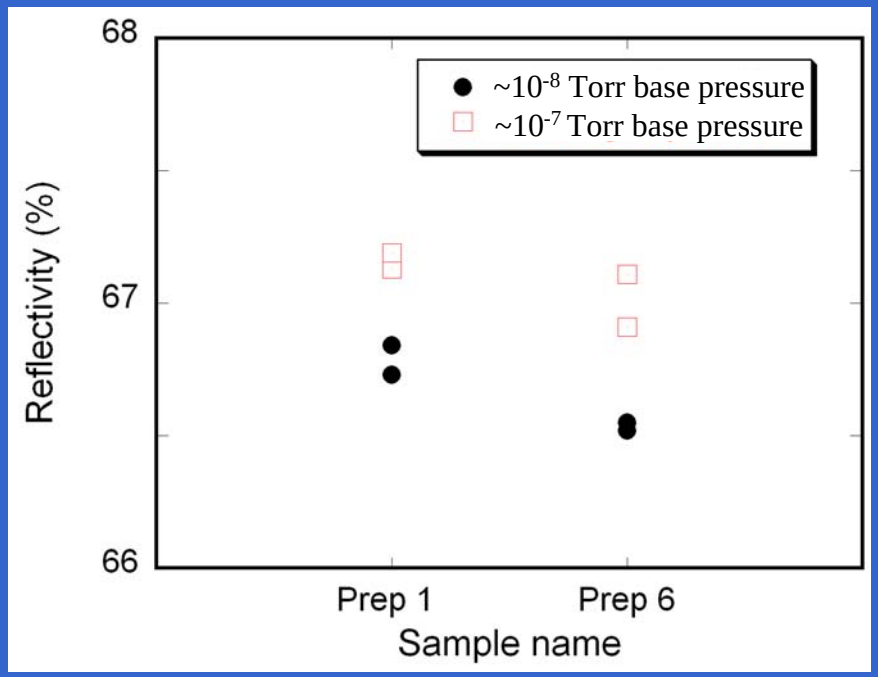


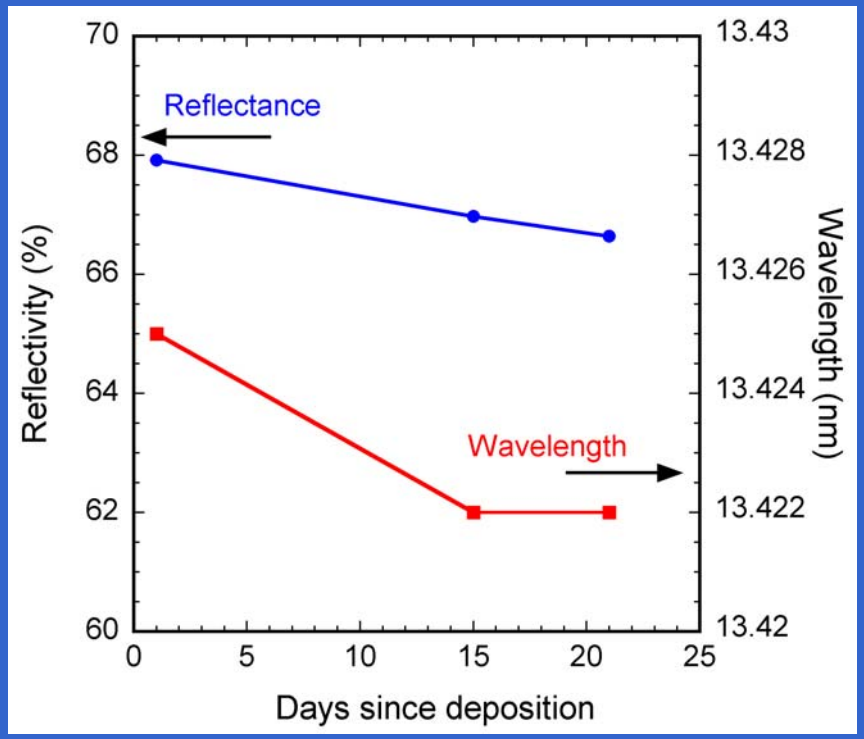


The best samples identified by the screening tests will be further tested under relevant environmental conditions



Additional Learning to Establish Traceable Standards and Metrology Infrastructure

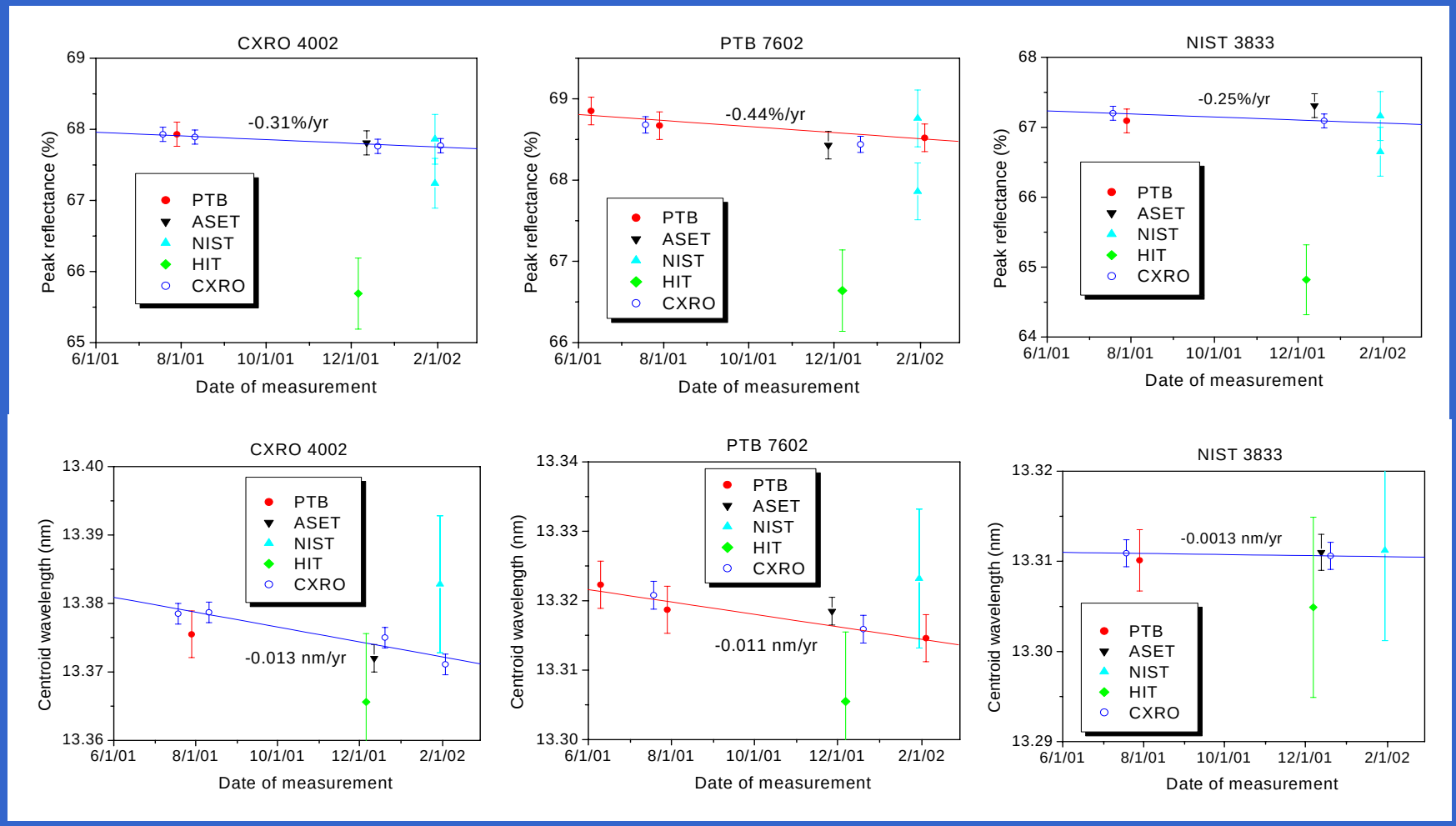




Error bars

Standardization

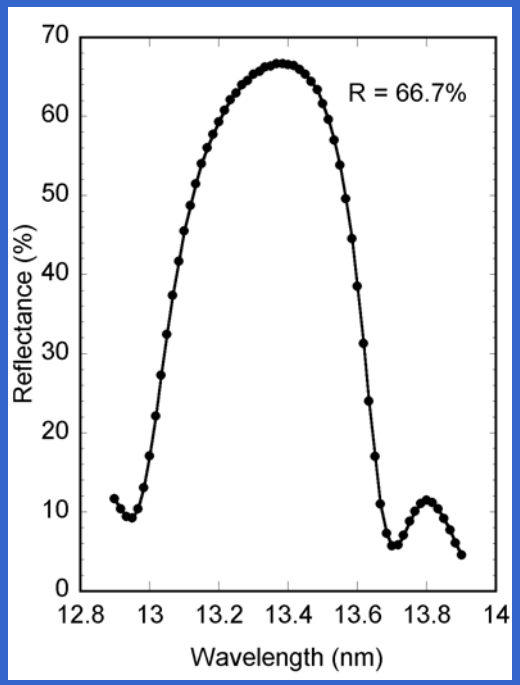
Some Aging was Observed for all Samples (round-robin experiments on Si-capped MLs)



Coated 5/01 **Coated 3/01** **Coated 3/98**

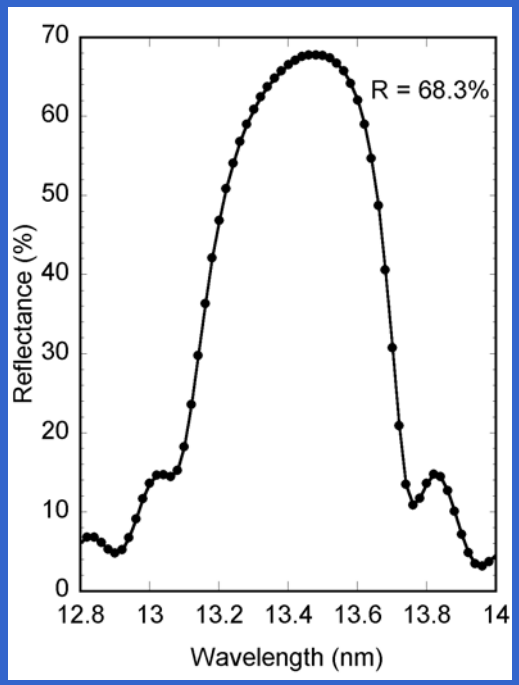
These Reflectivities Were All Measured the Same Way

R= 66.7%



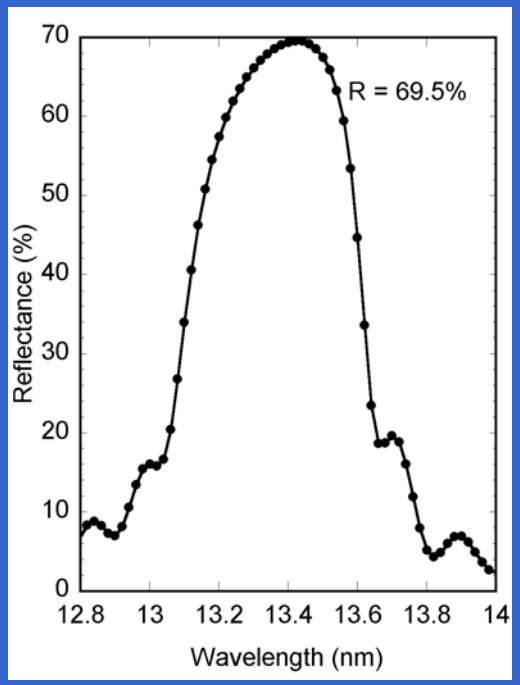
Past work (EUV LLC)
with diffusion barrier

R= 68.3%



Multilayer 1
no diffusion barrier

R= 69.5%



Multilayer 1
with diffusion barriers

Summary

- An extensive set of multilayers with modified Ru-capping layers has been fabricated
- Different deposition parameters strongly influence the EUV multilayer reflectivity and capping layer microstructure
- Selecting the best candidates for lifetime testing is not trivial and a high initial reflectivity is not necessary a good indicator for lifetime stability
- Preparation 1 was selected as the best candidate for further scaling and parametric studies

This work was performed under the auspices of the U.S. Department of Energy by University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.