EUV and e-beam exposures of Ru-capped multilayer mirrors

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Degradation of EUV projection optics

Industry Problem

Lifetime of Mo-Si multi-layer mirrors (MLM) under anticipated projection-tool conditions *much* too short.

Requirements: ΔR<1-2% over 30,000 hr lifetime

Conditions: EUV intensity, I_{EUV} = 10 mW/mm^2
Unbaked vacuum, $P_{H_2O} \sim 2\times10^{-7}$ Torr

NIST/Sandia Goal

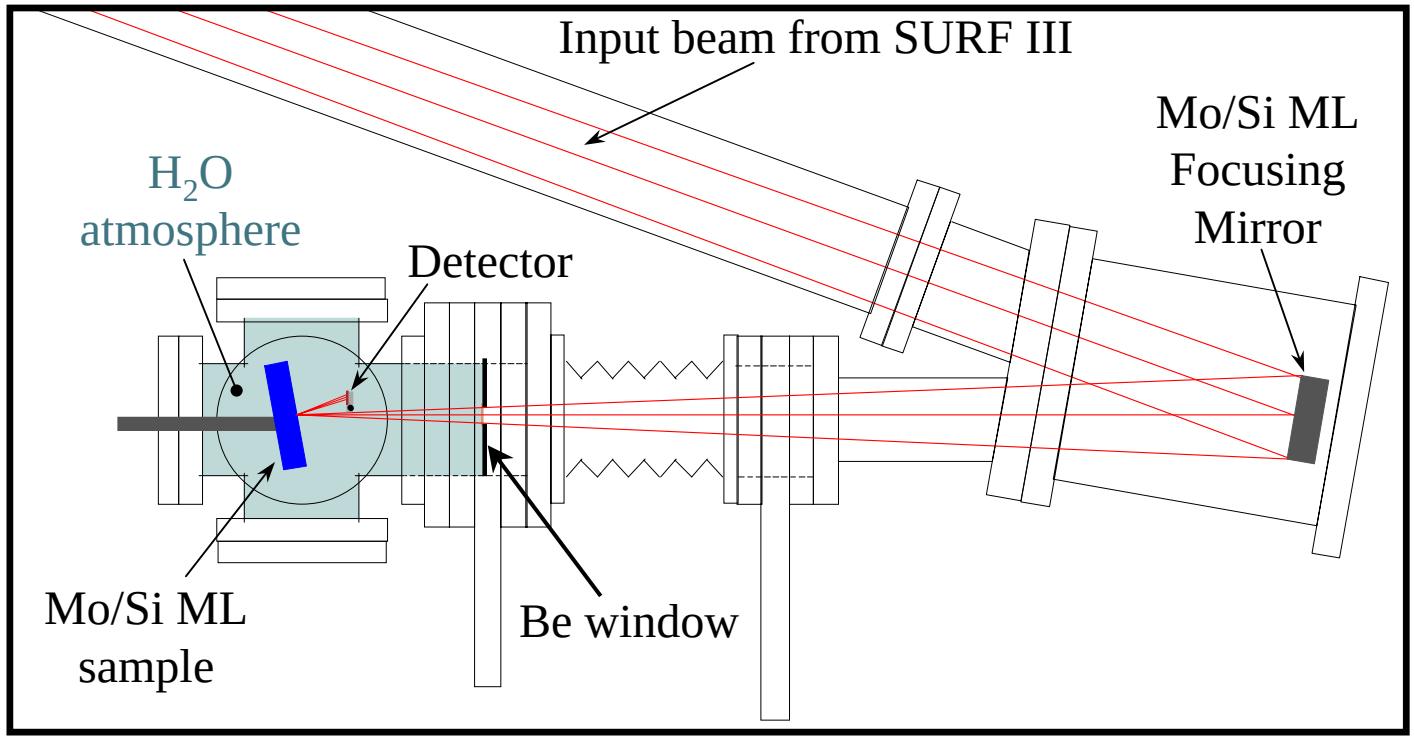
Develop metrology techniques to estimate lifetime of new, more robust MLs under anticipated projection-tool conditions.

- Find scaling laws relating ΔR to I_{EUV}, P_{H_2O}, and $T_{Exposure}$
- Predict ML lifetime in tool (~10^4 hrs) from ~10^2 hrs of accelerated testing under aggressive I_{EUV} and P_{H_2O} conditions

Outline

- EUV and e-beam exposure conditions
- Oxide growth on Si-cap ML for EUV and e-beam exposures
- Reflectivity decrease, ΔR, for Ru-cap ML exposed to EUV and e-beam
- Correlation of oxide thickness and ΔR for Ru-cap ML
- Development of sensitive *in situ* monitor of ΔR

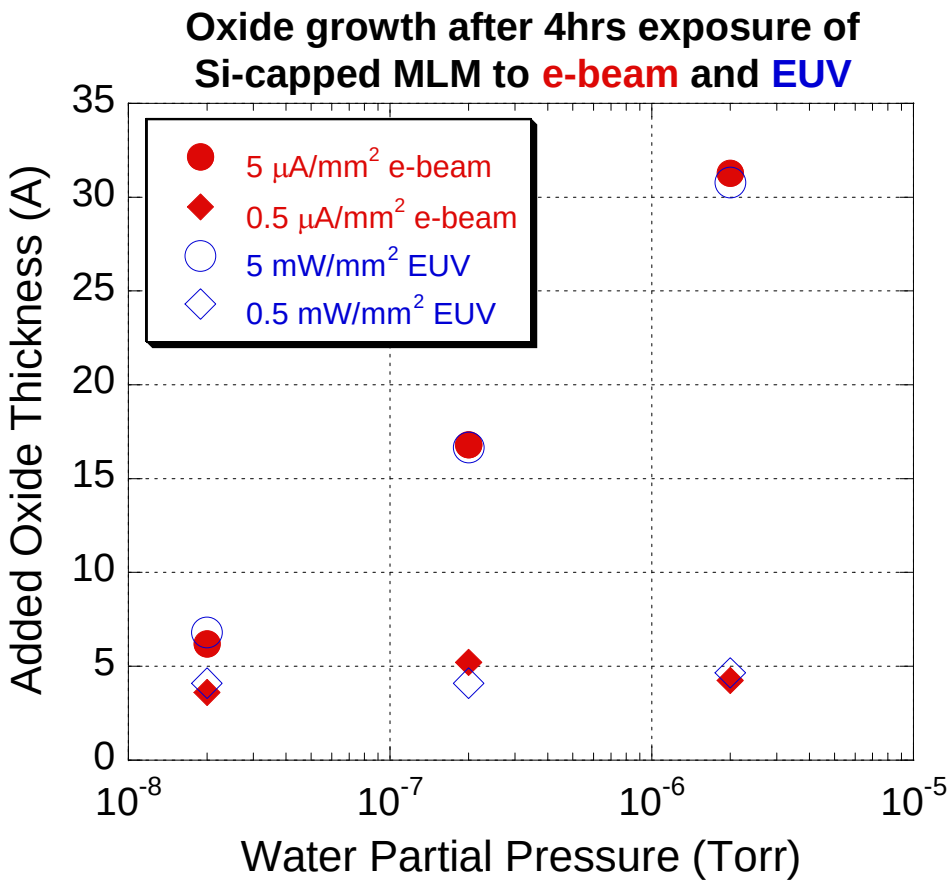
EUV Exposures at NIST



- Spot size ~ 600 μm × 850 μm (FWHM) at sample
- Average, in-band (13.0-13.5nm) intensity ~5 mW/mm^2
- Be window permits large water vapor pressures: $P_{H_2O} = 10^{-5}$ Torr
- Detect large reflectivity changes *in situ* with photodiode

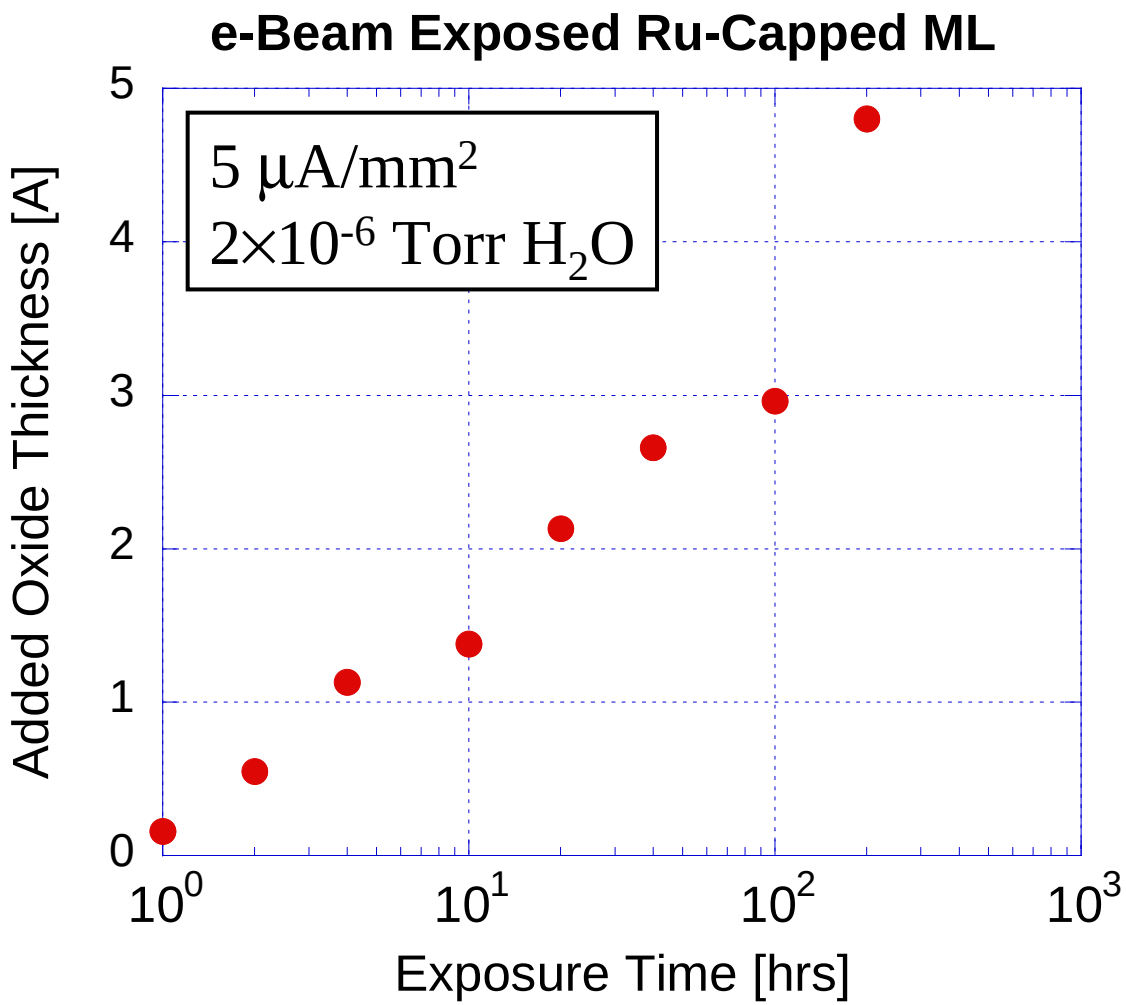
Electron-beam Exposures at Sandia

- Reflectivity decrease of Si-cap ML correlated to SiO_2 growth
- Equal oxide growth on Si-cap ML exposured to:
  - ➢ **1 μA/mm²** 1 keV e-beam
  - ➢ **1 mW/mm²** 13 nm EUV
- e-beam is convenient proxy for EUV exposure of Si-capped ML



Decreased Oxide Growth on Ru-capped ML

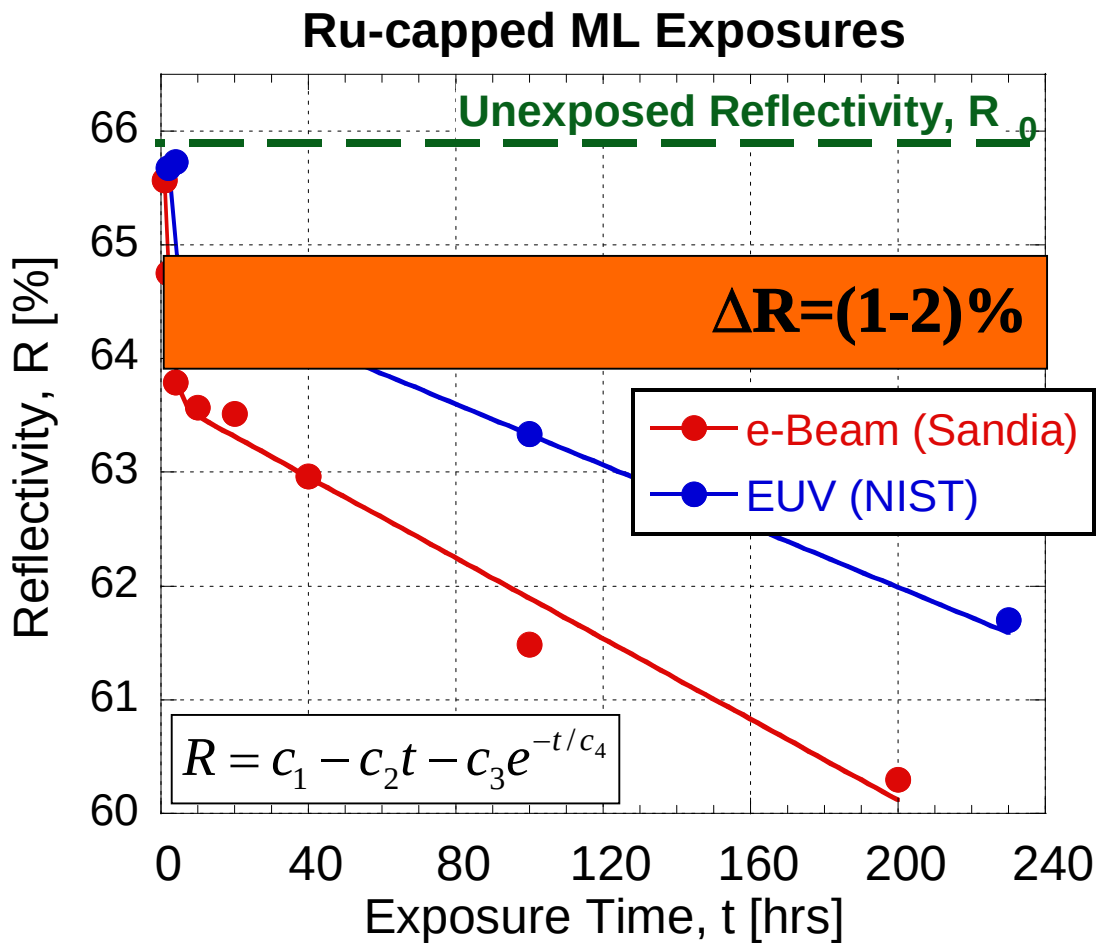
- Si-cap ML added **20Å** oxide after only 4hrs
- Auger measurements for EUV exposures underway…
- Ru-cap appears ~20x more resistant than Si-cap



Reflectivity Degradation of Ru-capped ML

- Exposure conditions:
  - ➢5 μA/mm^2 e-beam
  - ➢5 mW/mm^2 EUV
  - ➢2×10^{-6} Torr H_2O

- 1 mW/mm^2 EUV ***not*** equivalent to 1 μA/mm^2 e-beam for Ru-cap ML



Reflectivity Degradation of Ru-capped ML

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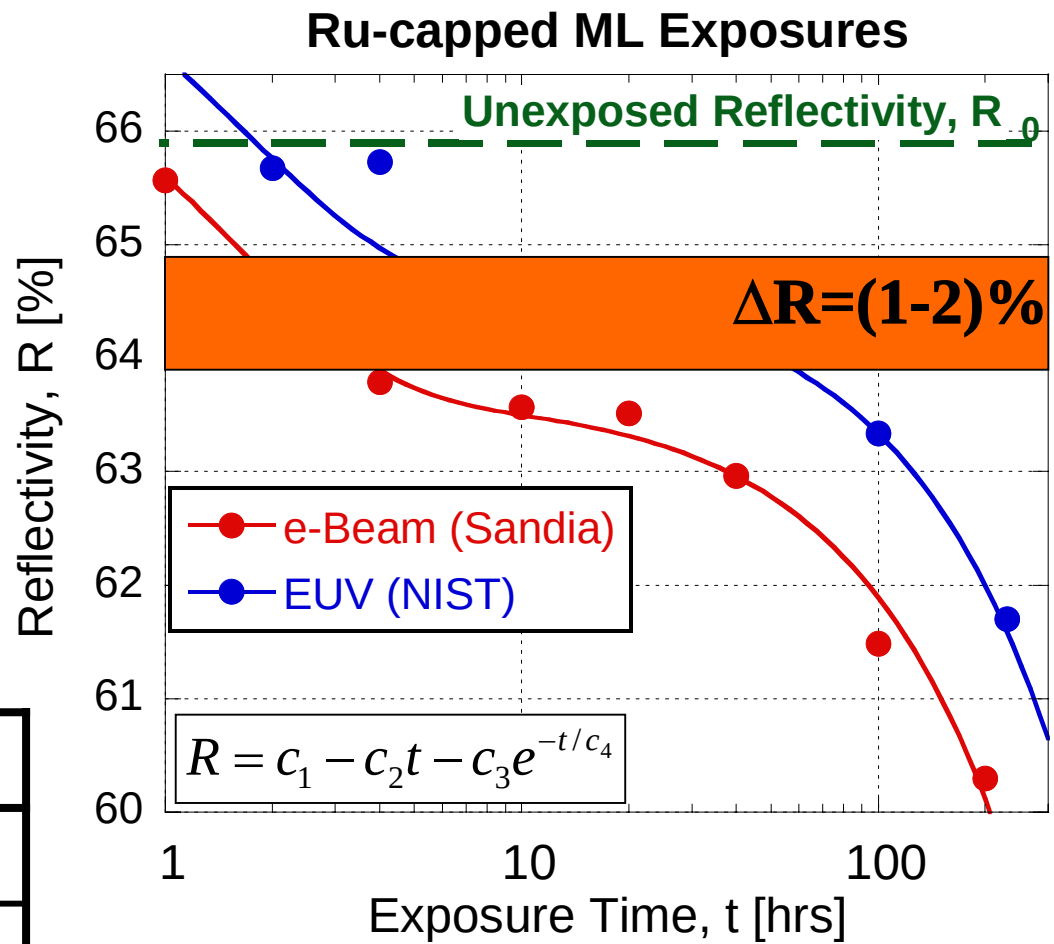
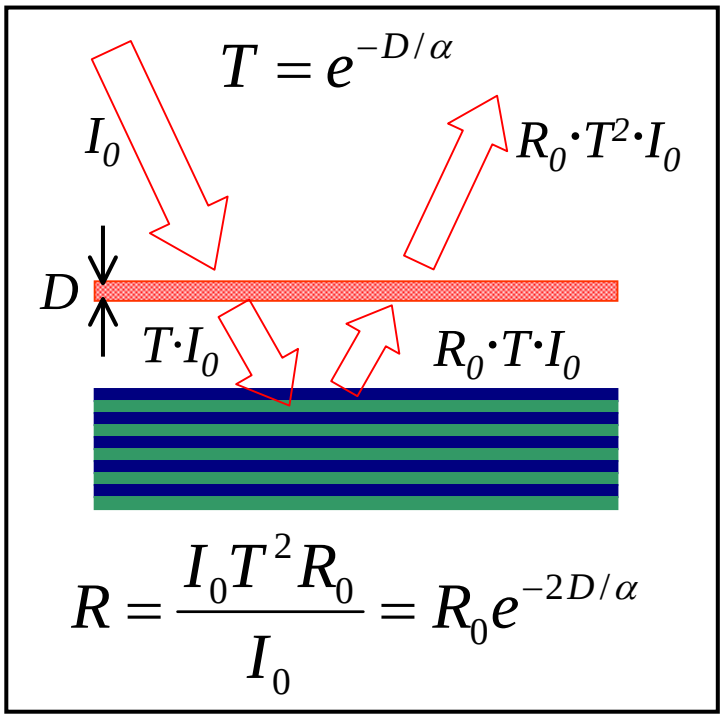
ΔR	EUV	e-beam
1%	~4 hrs	=2 hrs
2%	60 hrs	~4 hrs



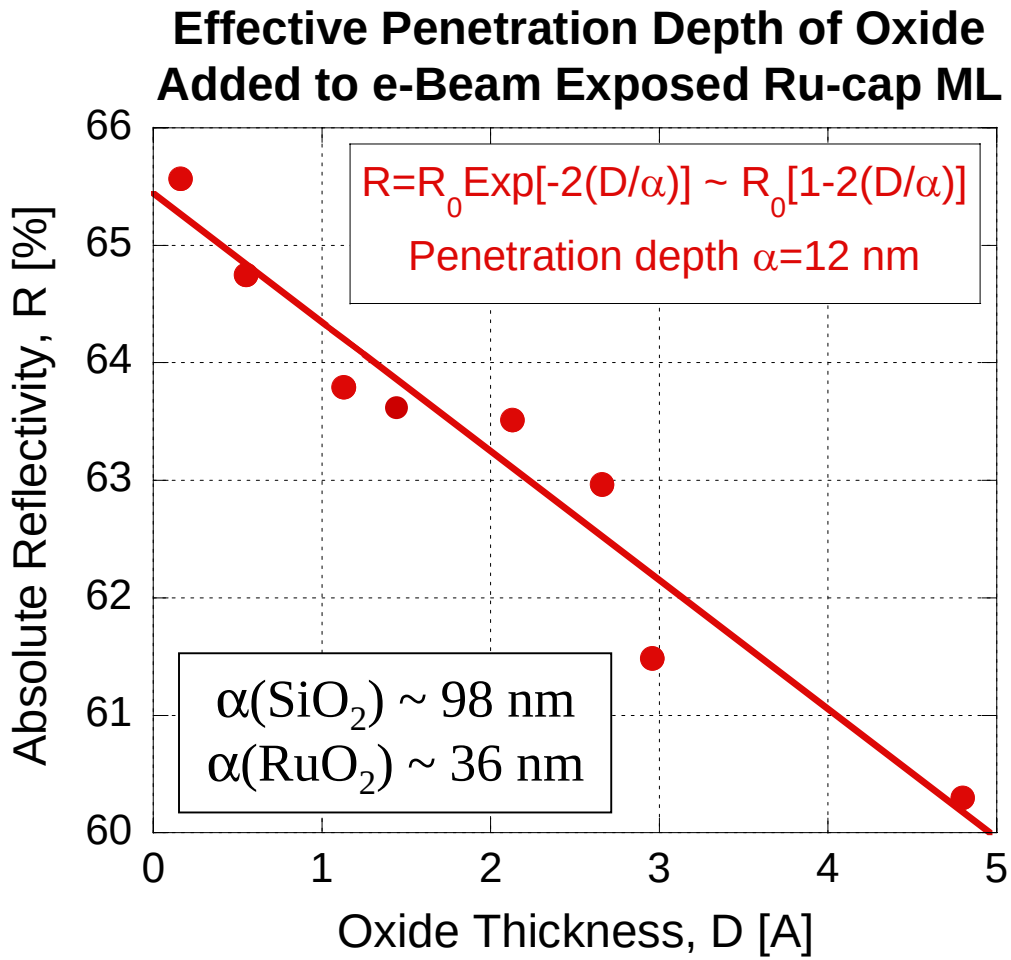
Ru-cap ML Reflectivity and Oxide Thickness



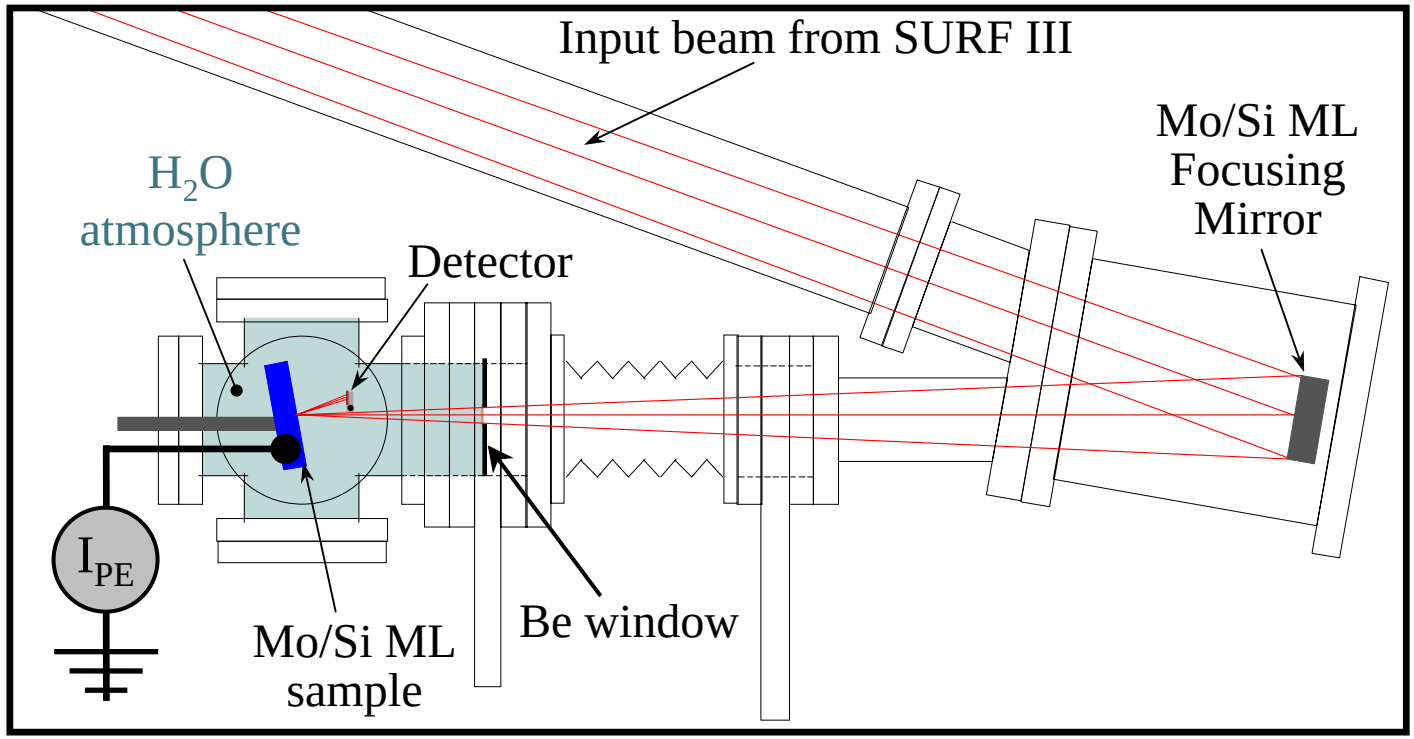
Attenuation of added oxide **not** primary cause of ΔR.

Interfacial roughening?

Diffusion?



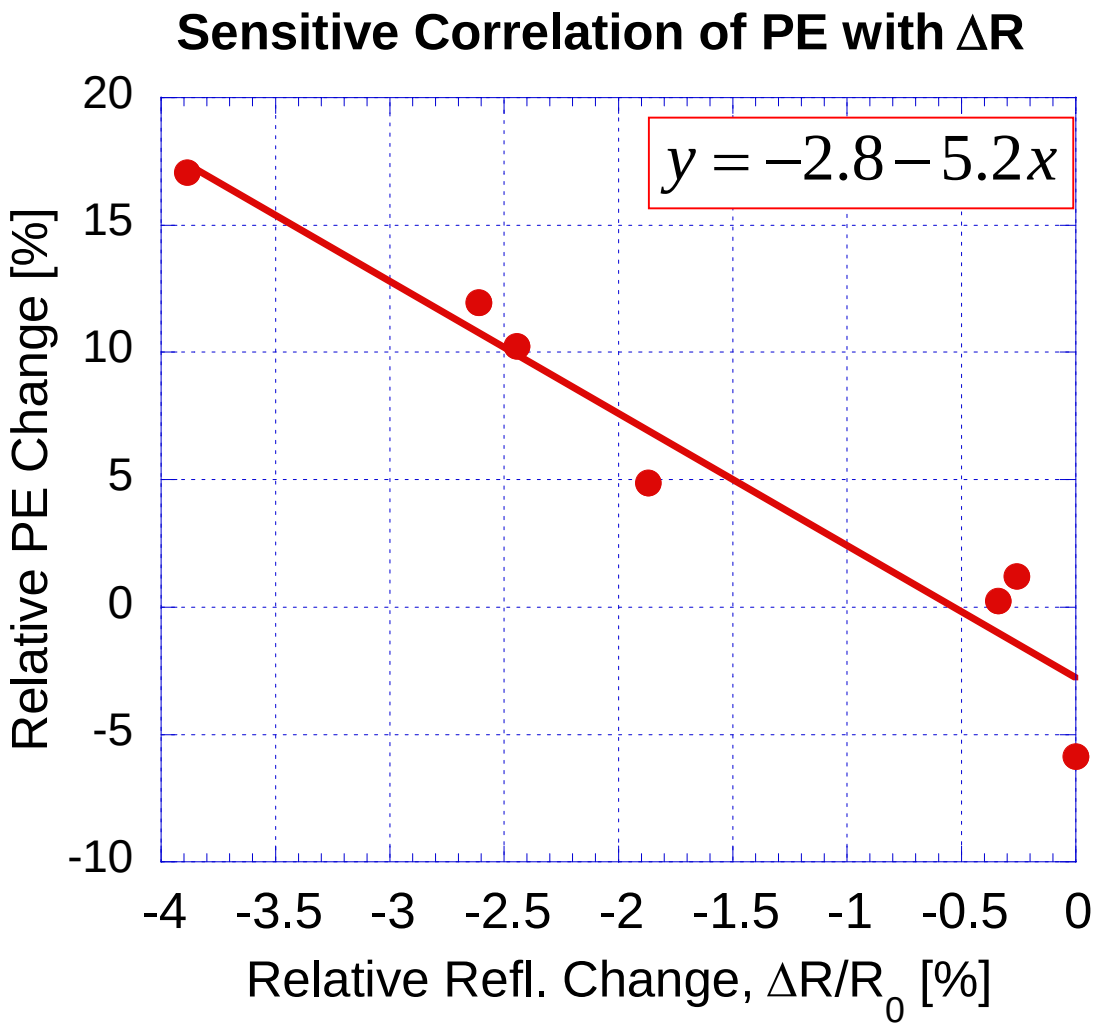
Precise *in situ* ΔR Measurements Difficult



- Measured *integrated* (13.0-13.5nm) reflectivity R_{int}< 45%
- Need reproducibility < 0.5% (absolute) for R_{int} measurements
- Could photoemission current (I_{PE}) be indicator of ΔR @ 13.4nm?

Reflectivity and Photoemission Changes Correlated

- Compare *in situ* PE with ALS measured *ΔR* @ 13.4nm
- A 1% relative *ΔR* produces a 5.2% change in PE
- PE may serve as sensitive *in situ* proxy for *ΔR* @ 13.4nm.



Conclusions

- Equivalence between e-beam and EUV exposures is different for Ru- and Si-capped MLs:
  ΔR (1 mW/mm^2 EUV) < ΔR (1 μA/mm^2 e-beam)

- 1% ΔR occurs after ~4 hrs of EUV exposure
  2% ΔR occurs after ~60 hrs of EUV exposure

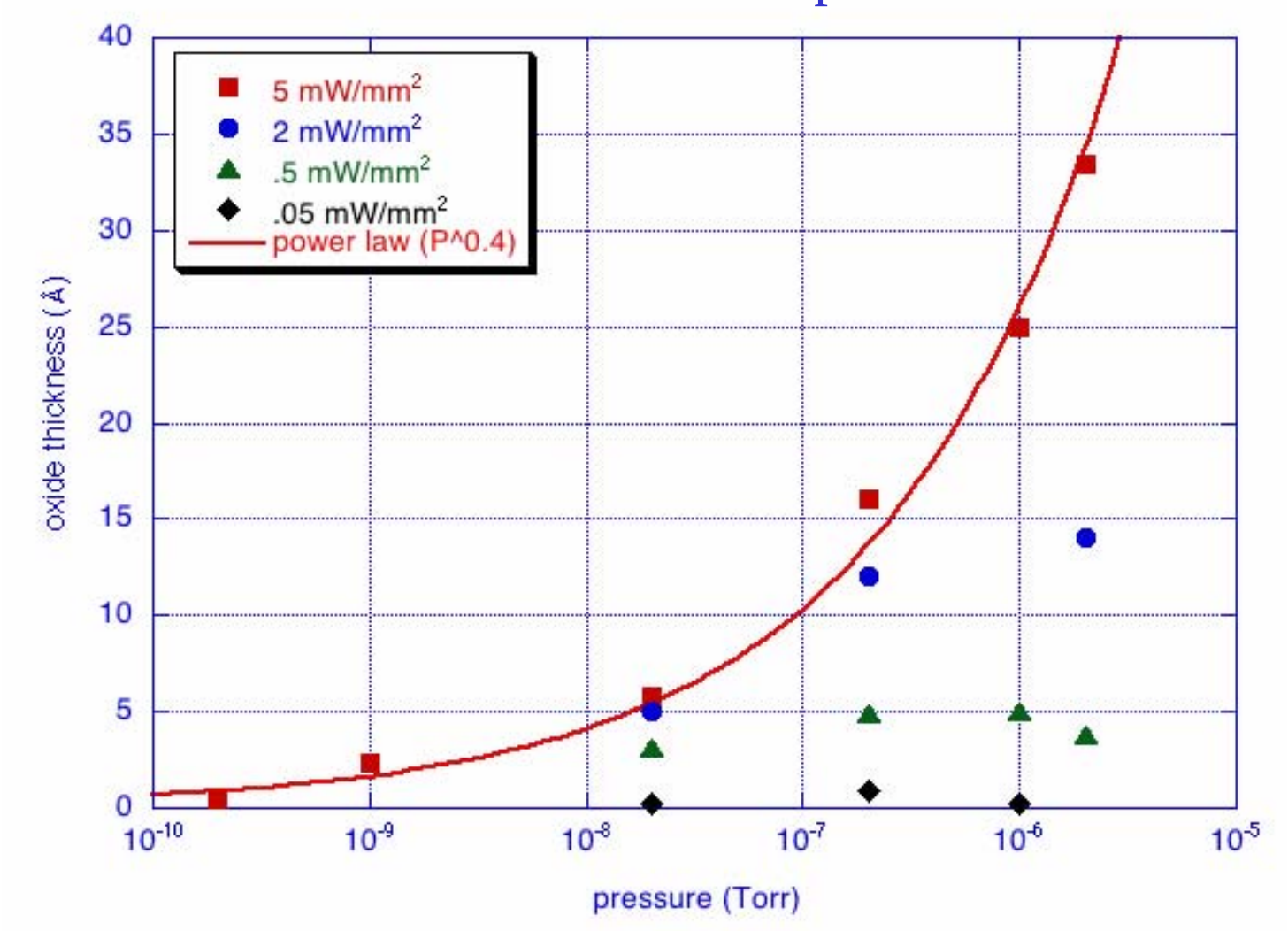
Future Plans

- Develop photoemission current as *in situ* monitor of ΔR with sensitivity to detect 1% relative changes during EUV exposures.

- Expose Ru-cap ML over range of H_2O pressures and EUV/e-beam intensities to determine scaling behavior of ΔR.

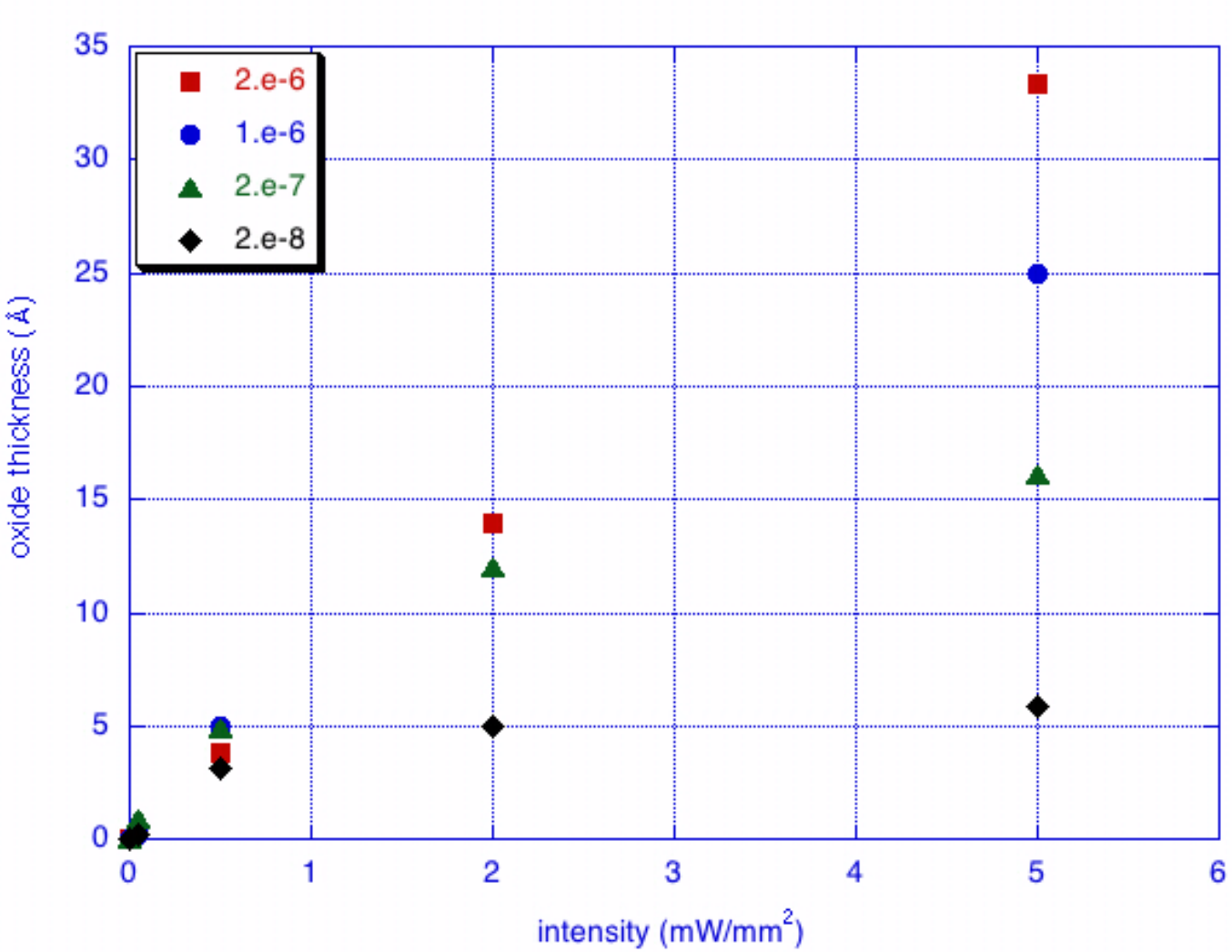
Photon Limited Oxidation of Si-cap ML

4hr EUV & e-beam exposures

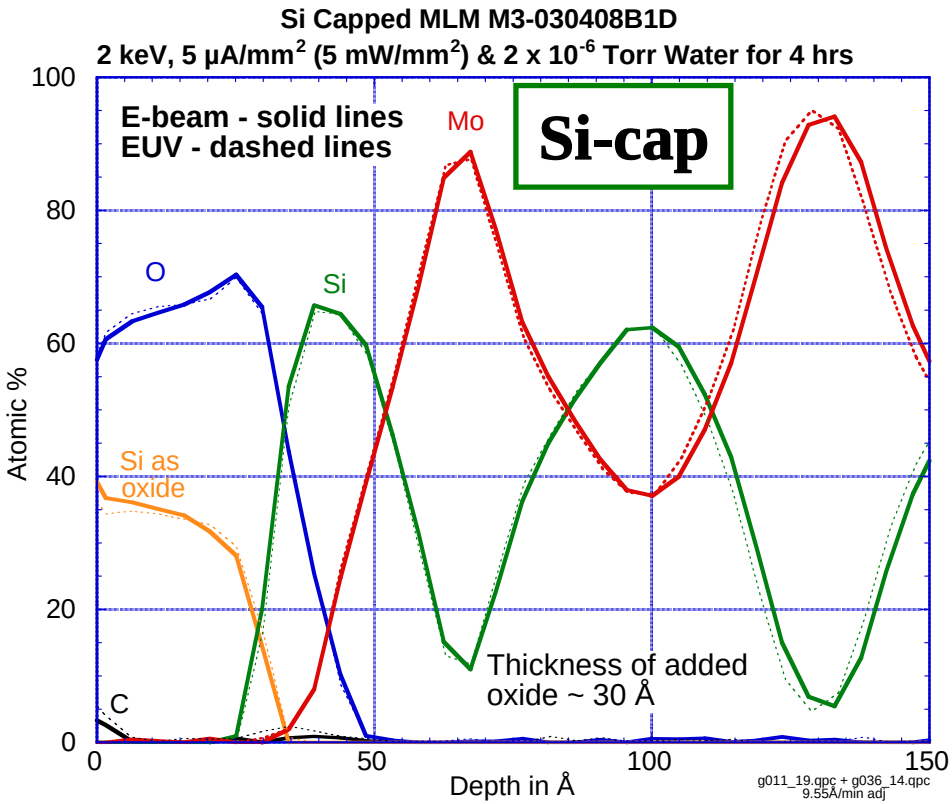


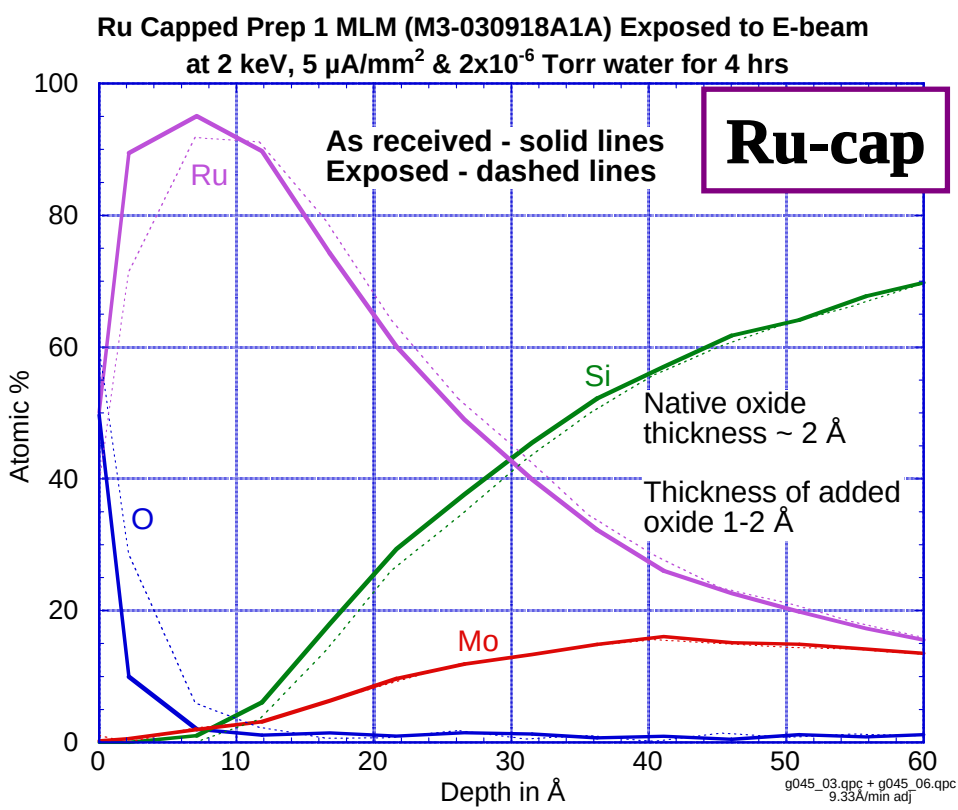
H_2O Limited Oxidation of Si-cap ML

4hr EUV & e-beam exposures



Auger depth profiles: 4hr e-beam exposures of Si- & Ru-capped MLs





Auger depth profile of 100hr e-beam exposure of Ru-capped ML