Multilayer mirrors for EUVL, progress status

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Outline

- Introduction
- Collector optics
- Illuminator optics
- SO optics
- Refurbishment
- ML for 6.X nm
- Conclusion

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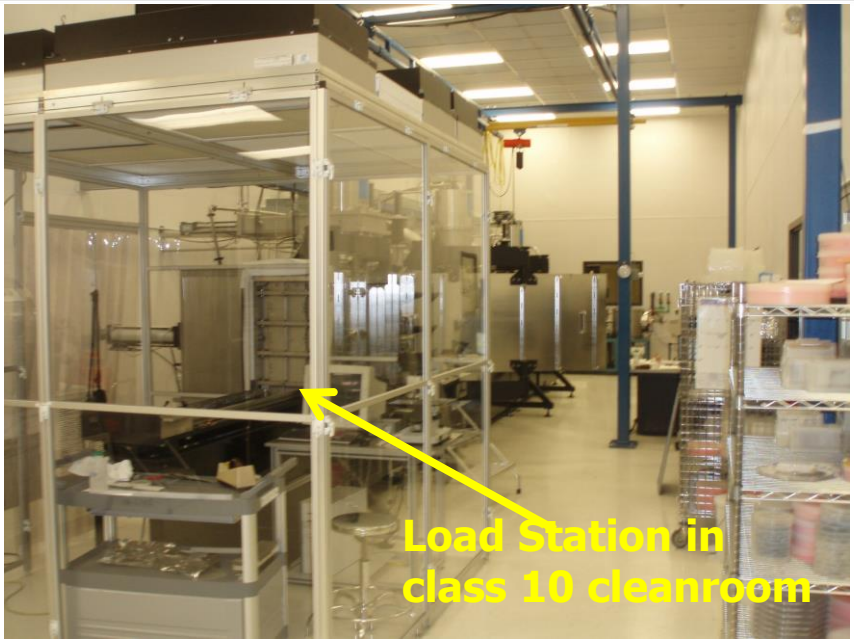
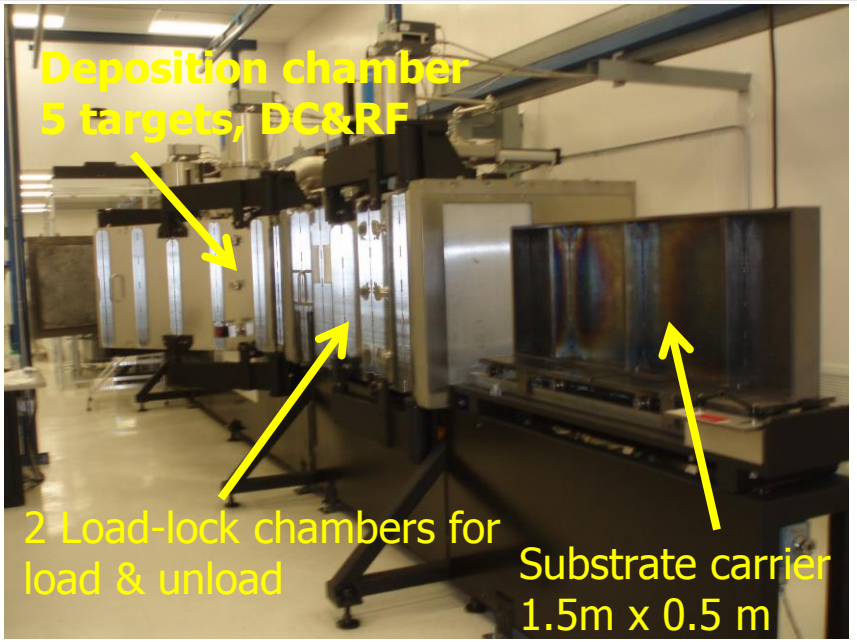
Current Inline Deposition Tool





Custom built system
(1997) – 16years old

Unique for multilayer production

24/7 operation

12m long, 2m tall

- Dual Spinning Capability
  - #1: 550mm dia x 220mm thick
  - #2: 175mm dia x 35mm thick
- Mechanical
  - 0.2mm accuracy
  - 1-133 mm/sec (±0.1%)
  - velocity profiling (6 pts/mm)

Need:

- Larger substrates capability
- Better run-to-run repeatability
- Reactive deposition capability
- More flexibility in velocity profiling
- ……

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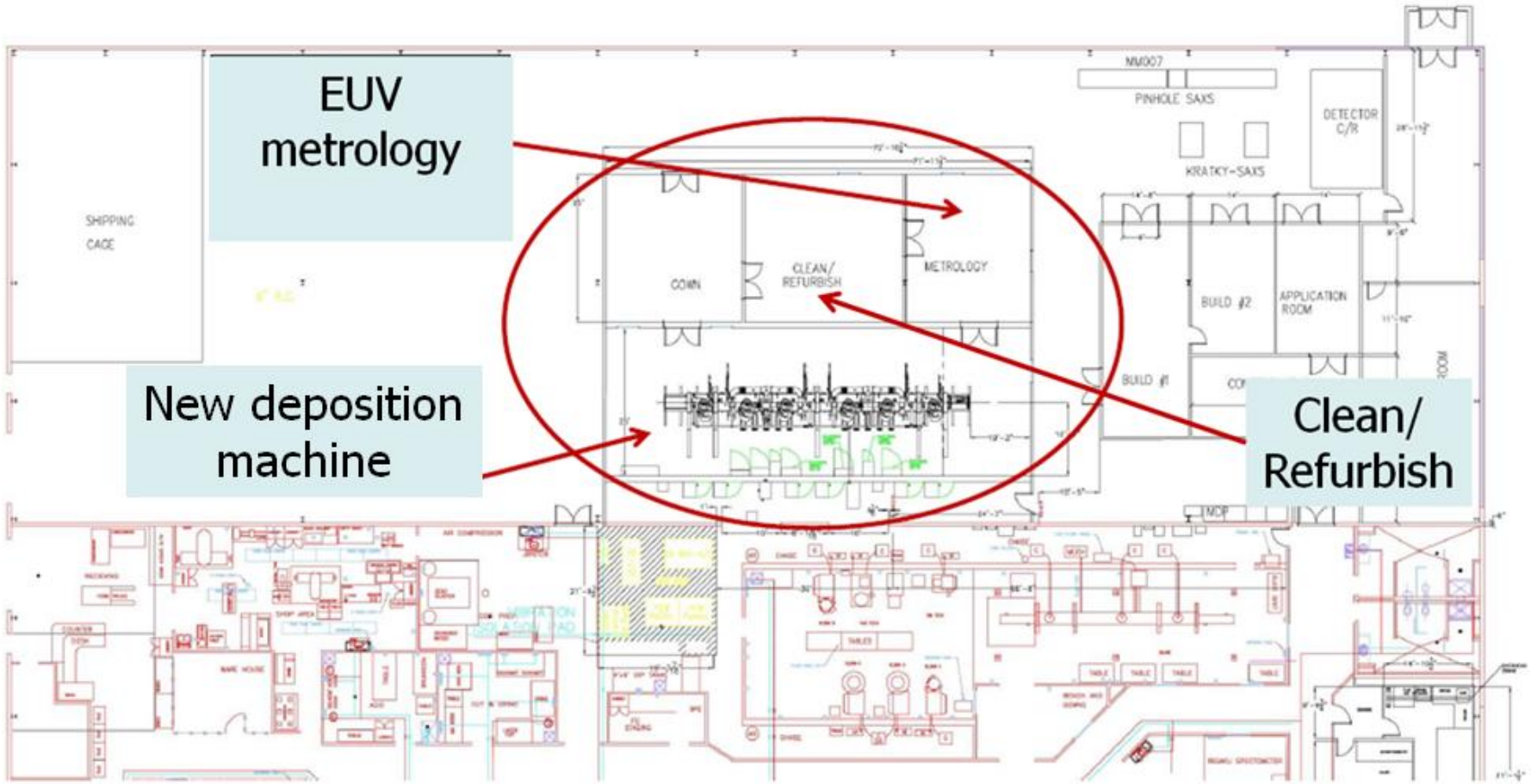
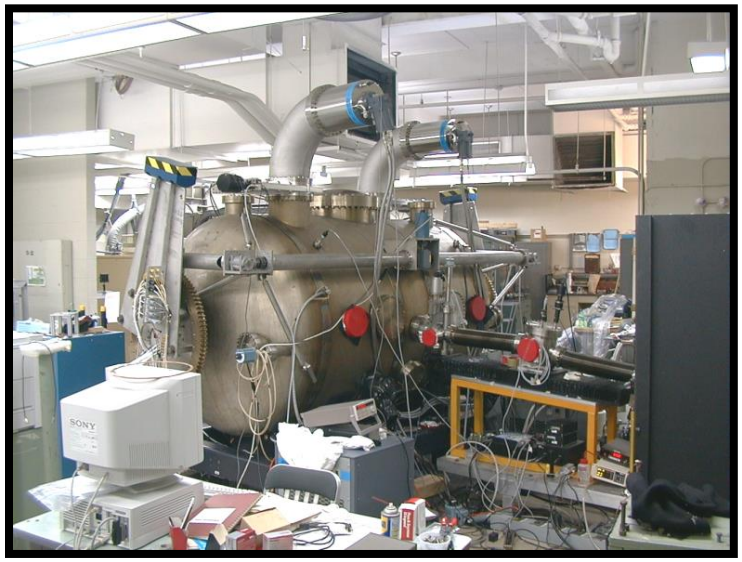
RIT Pilot Production – Phase 1 in 2013

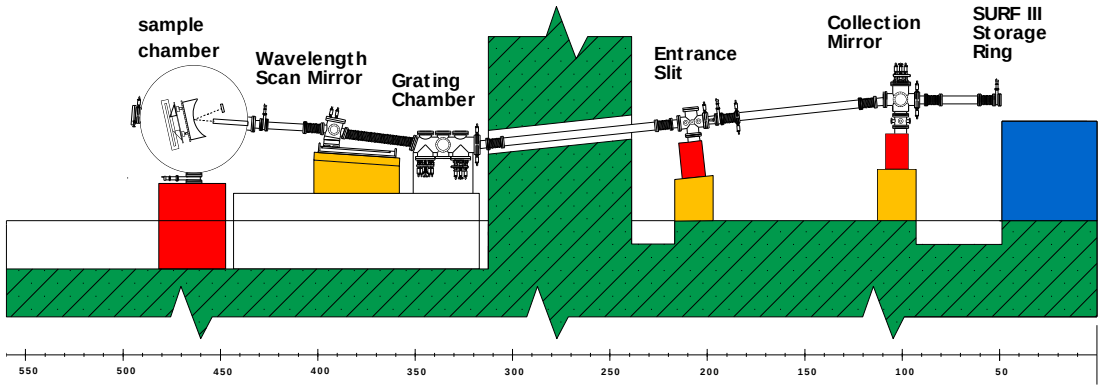


Coated 1st surrogate collector

Collector EUV testing at NIST



Challenges



Optic is larger (>440 mm), deeper (> 100 mm), and has larger slope (~49°) than the Beamline 7 reflectometer was designed to handle. Significant modifications have been completed in order to accommodate optic.

Goniometer can't be tilt far enough to make all measurements in vertical plane. Two angles should be set to add up to the incidence angle. It allowed to make measurements that simulate un-polarized light by setting reflection plane to 45° from vertical, thus converting of this into un-polarized light (as from a plasma source)

A Zemax model was developed to predict the performance of the optic at various angles and positions. This model was used to place the optic and detector and to confirm alignment of the optic.

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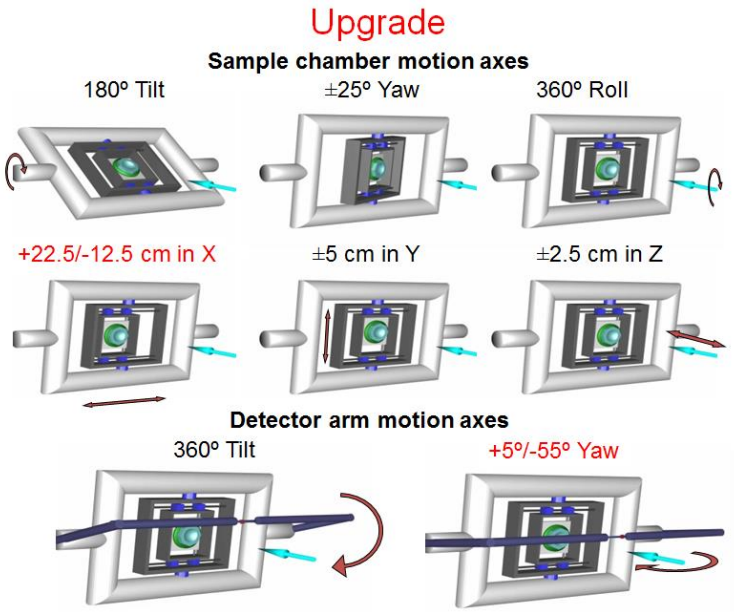
EUV Reflectometry Facility at NIST



Sample Chamber

- Samples up to 45 cm diameter, 40 kg mass.
- Six axes sample motion, three axes detector motion.
- UV spot size: 1mm x 1mm (FWHM)
- Can be fitted with external end-stations for assembled instrument calibration.

Monochromator

- VLS grating:
  - 600 mm^{-1}, 7 nm - 35 nm
- Wavelength Uncertainty: 0.01 nm
- High throughput (P_{EUV} > 1 μW)
- Fixed exit slit
- Reflectivity uncertainty: ~ 0.25% λ near 13.5 nm

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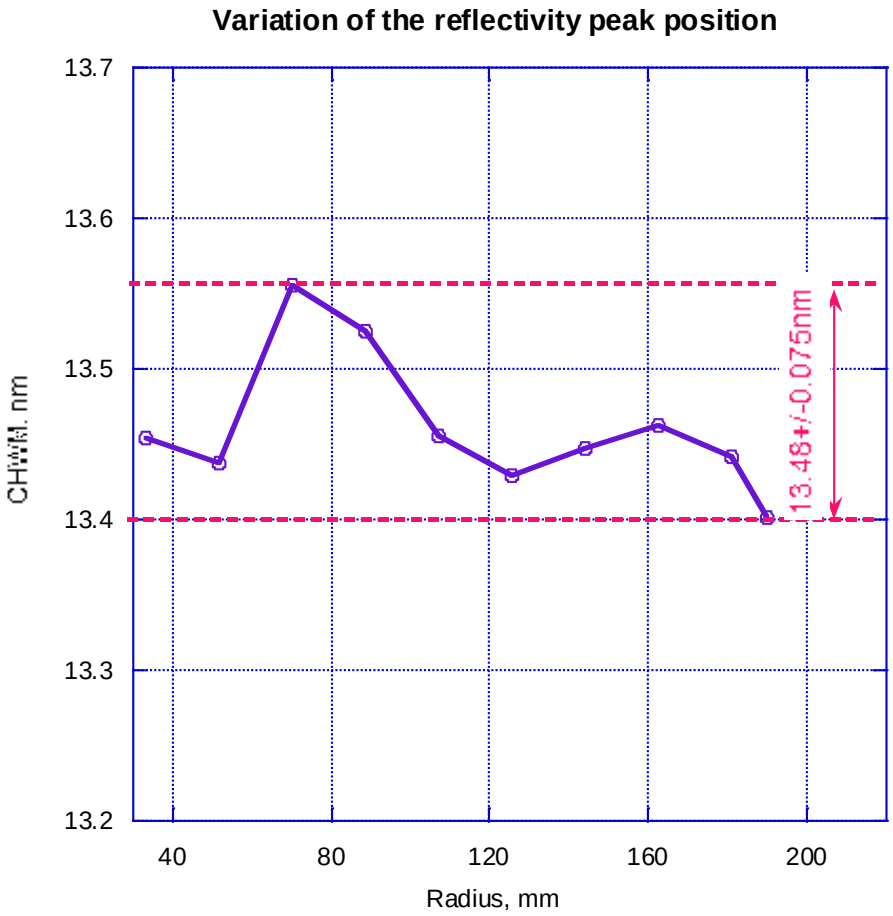
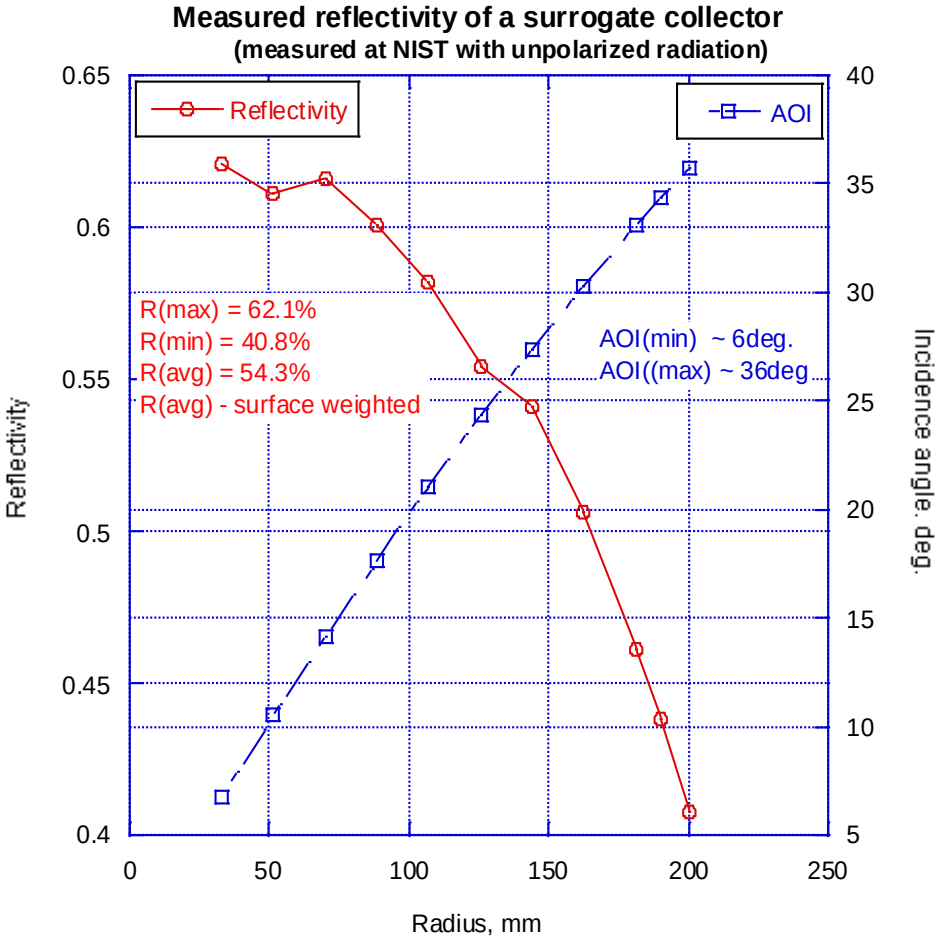
Surrogate collector: 1st EUV results





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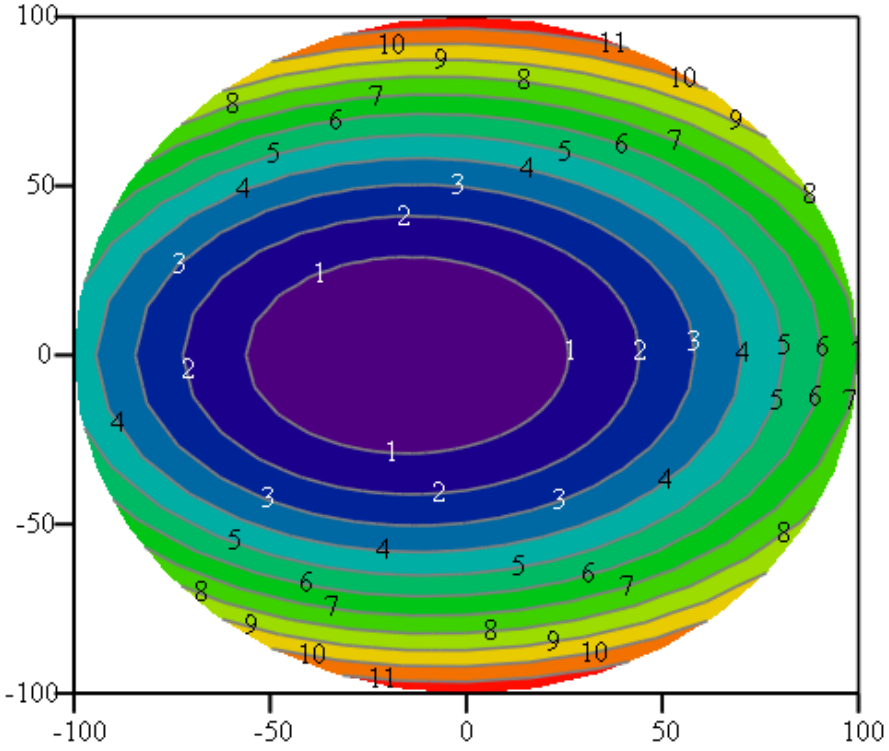
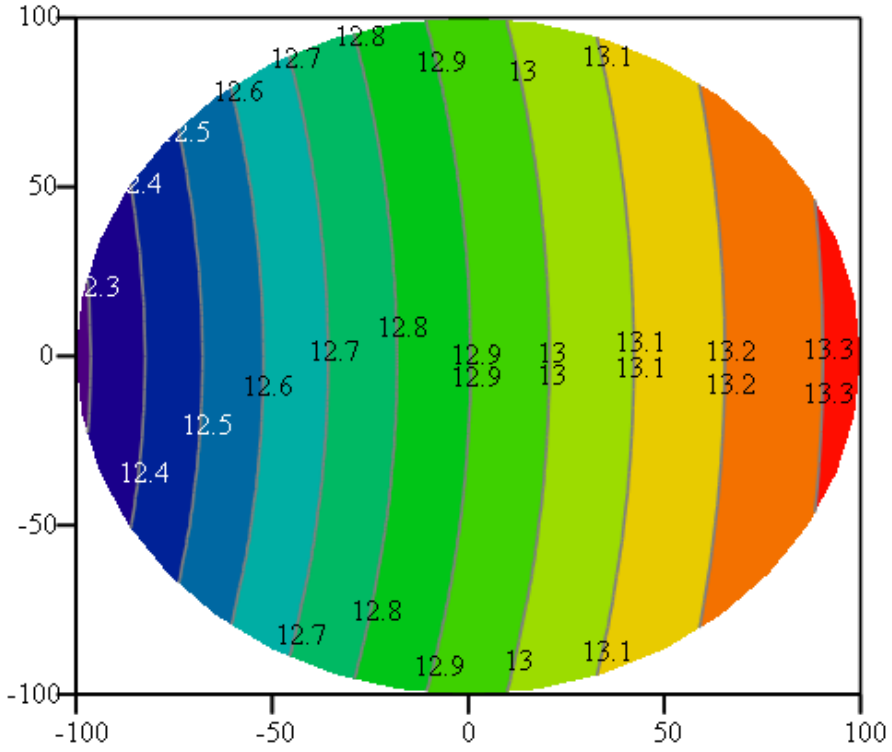
Illumination optics - I

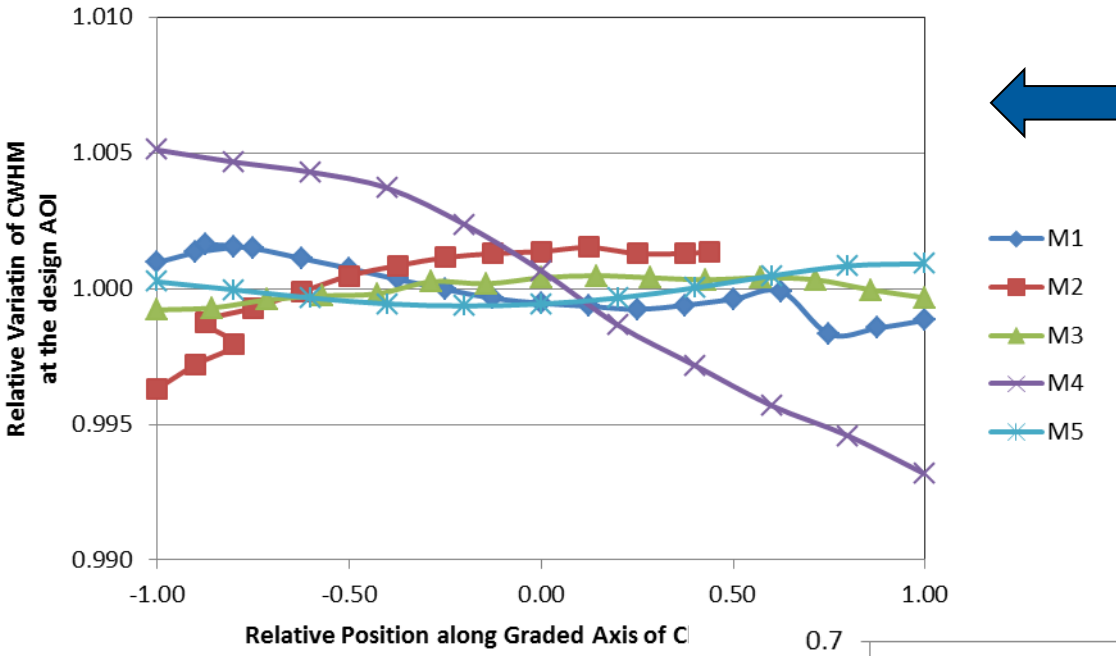
Surface is parabolic in shape,
with up to 9mm sag & 10º of angle



ML period gradient (due to AOI gradient)
is primarily linear to keep a constant
cwhm of EUV peak

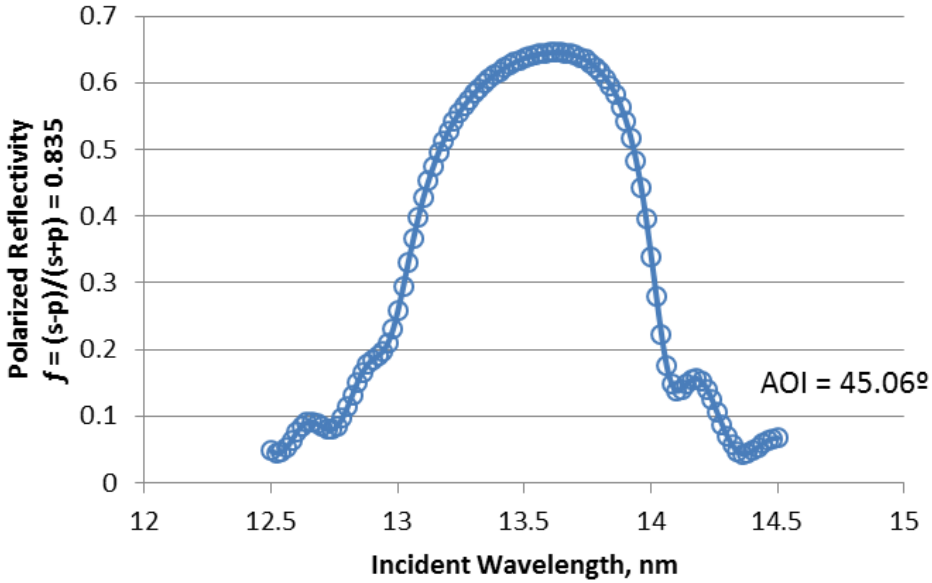


Illumination optics - II



Relative uniformity across the CA of each optic in the graded direction ranges from ±0.08% to ±0.7% (for the strongest gradient)

Incident beam at CXRO was 92% s-polarized; expect Rp = 70% at fully s-polarized



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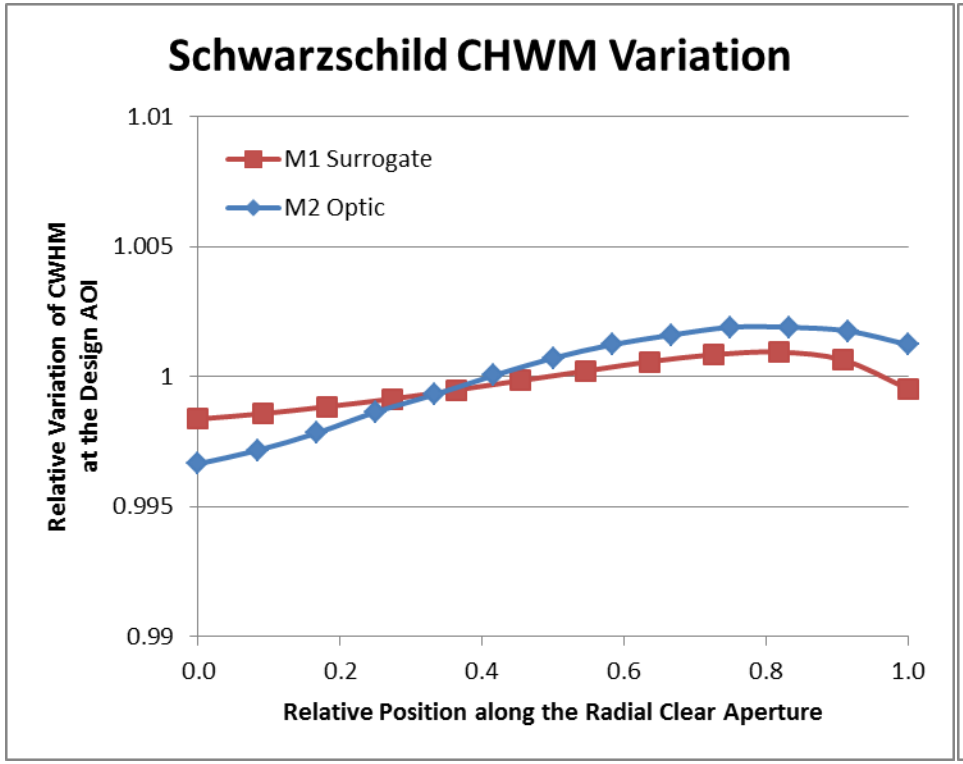
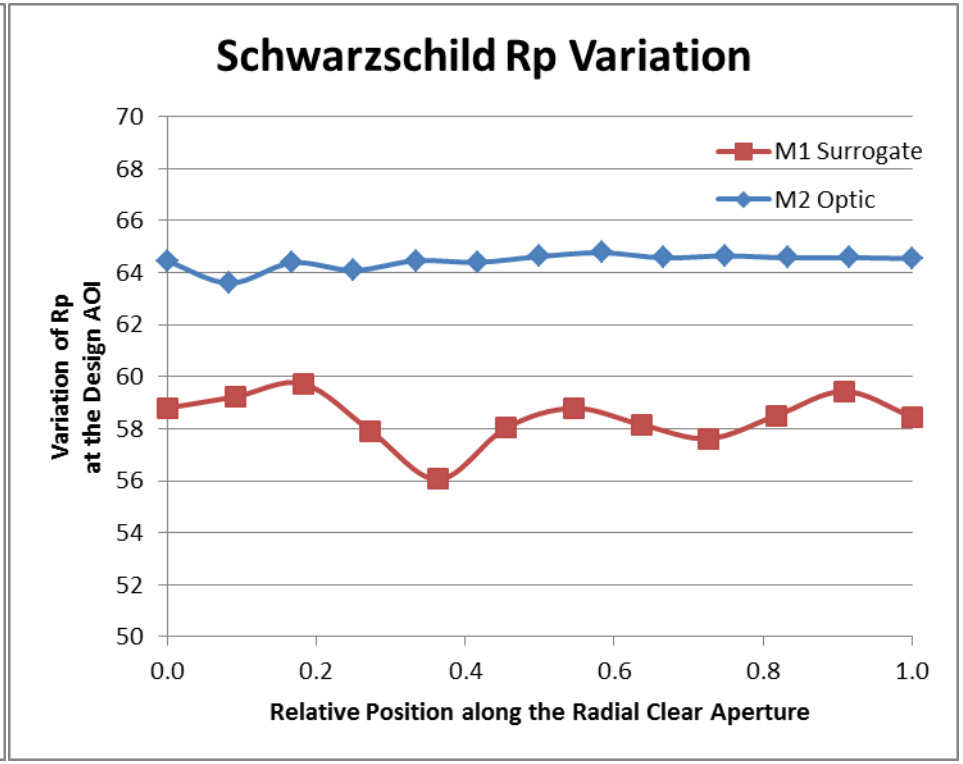
M1 Surrogate + M2 Final

(Zerodur substrates)

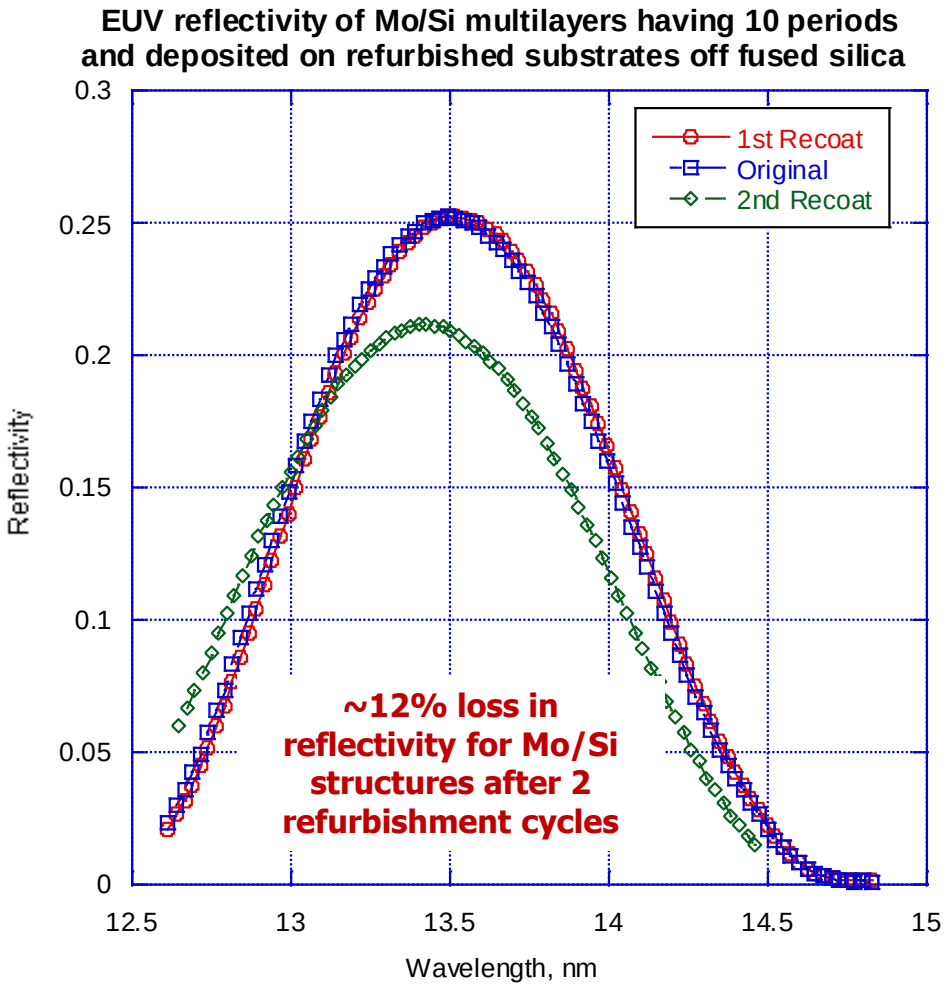


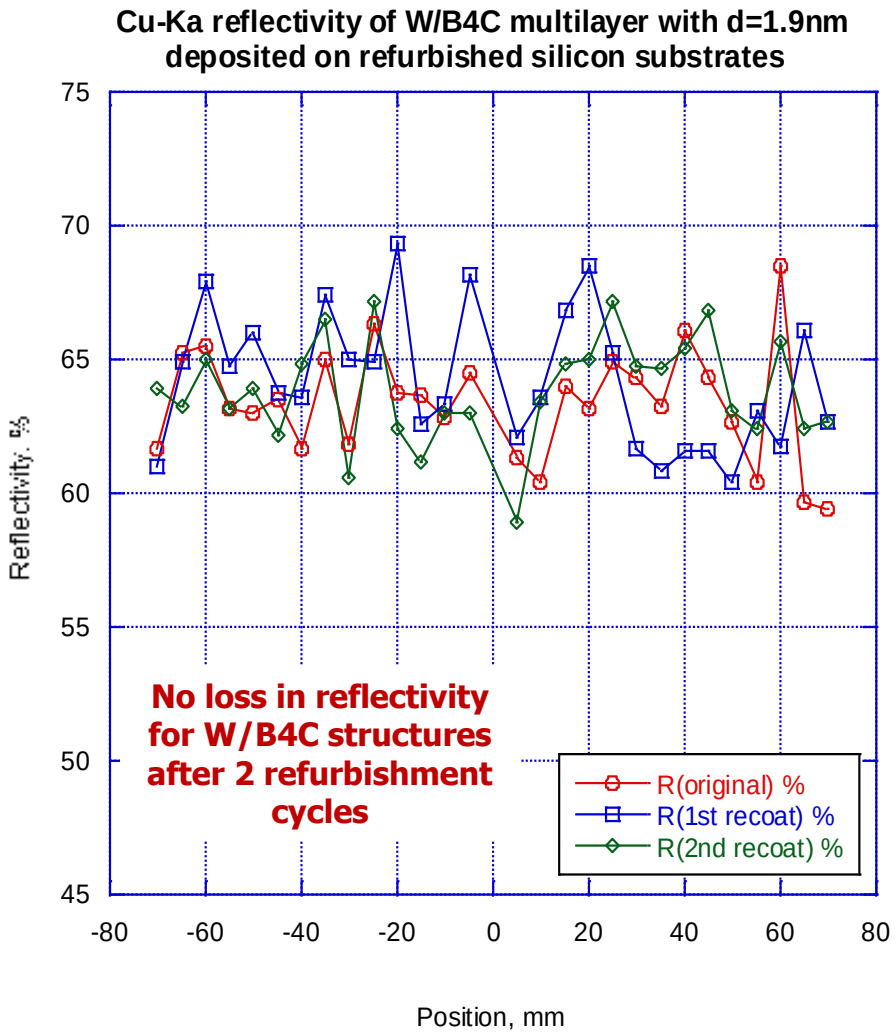


AFM roughness
M1 Surrogate = 0.37nm rms
M2 Optic = 0.19nm rms

Refurbishment

Refurbishment: previous results



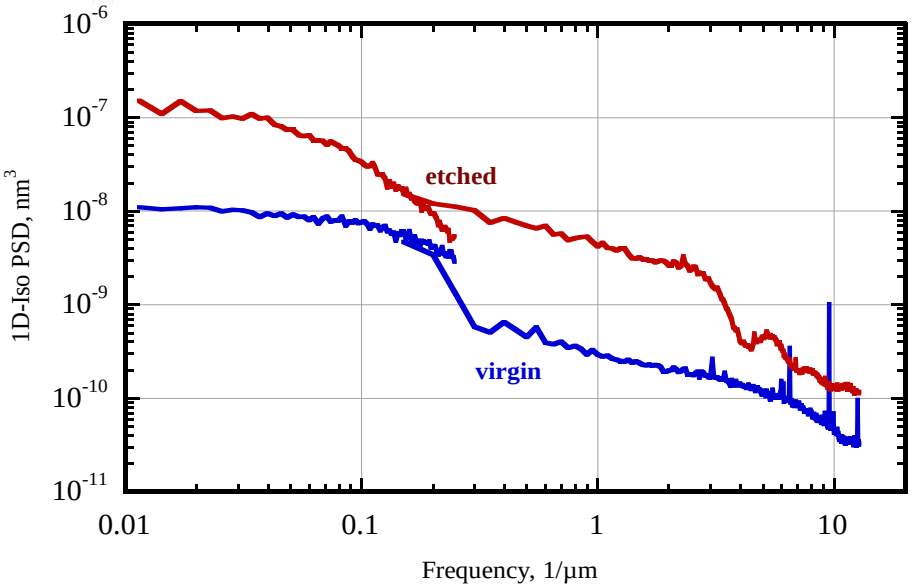


EUV performance after 2nd stripping cycle

R_p = 6-8%

Selective etching could destroy the surface

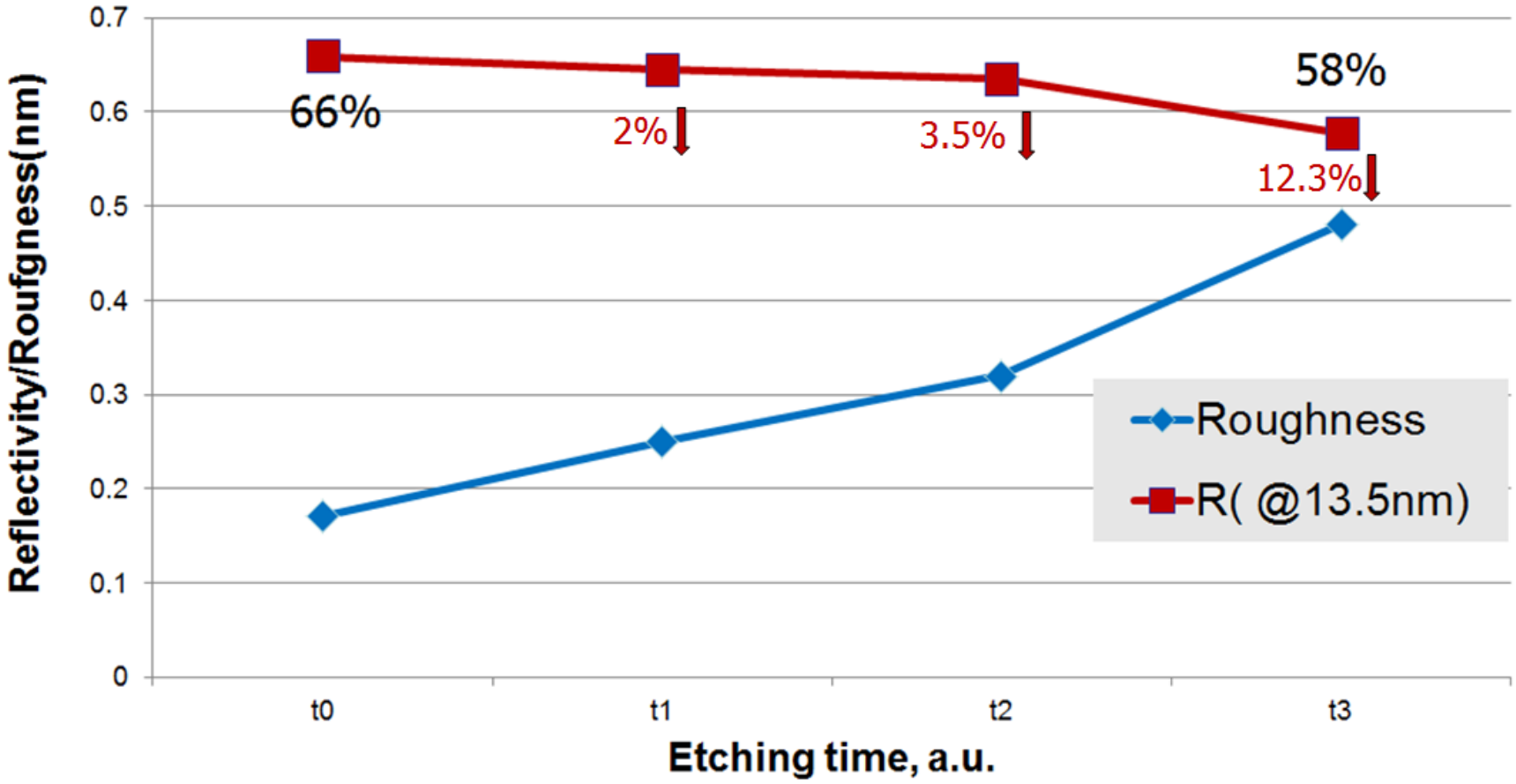
R_p = 13-16%



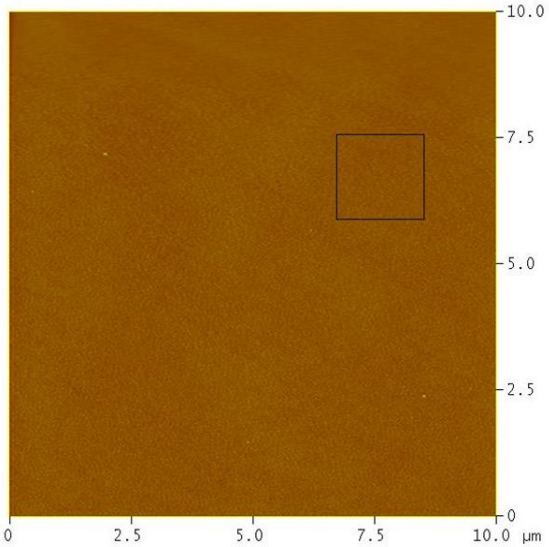
During etch, one region was removed quickly (while the remaining region etched more slowly), and thus had excessive exposure to the etching solution. This reduced the reflectivity in this region.

Mo/Si on Si substrate

Roughness and EUV reflectivity of Mo/Si multilayers deposited on Si substrates



Buffer layer and surface roughness



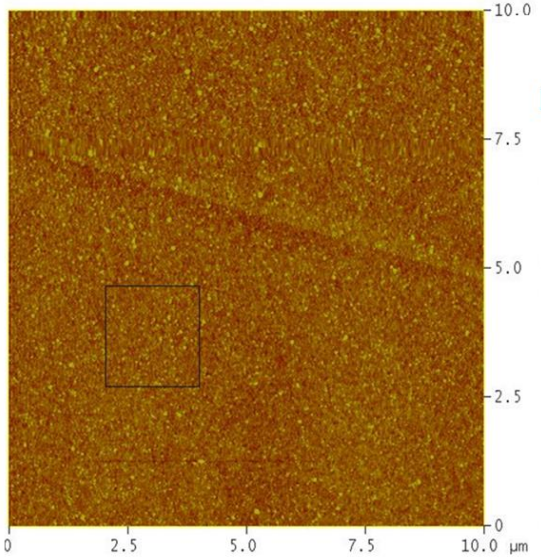
Uncoated wafer

Image Statistics

Img. Rms (Rq)	0.141 nm
Img. Ra	0.108 nm
Img. Rmax	5.312 nm

Box Statistics

Rms (Rq)	0.126 nm
Mean roughness (Ra)	0.101 nm
Max height (Rmax)	0.964 nm
Max peak ht (Rp)	
Av max ht (Rpm)	
Max depth (Rv)	
Av max depth (Rvm)	
Box x dimension	1.800 µm
Box y dimension	1.683 µm



After 40x(Mo/Si) removal, Buffer #1

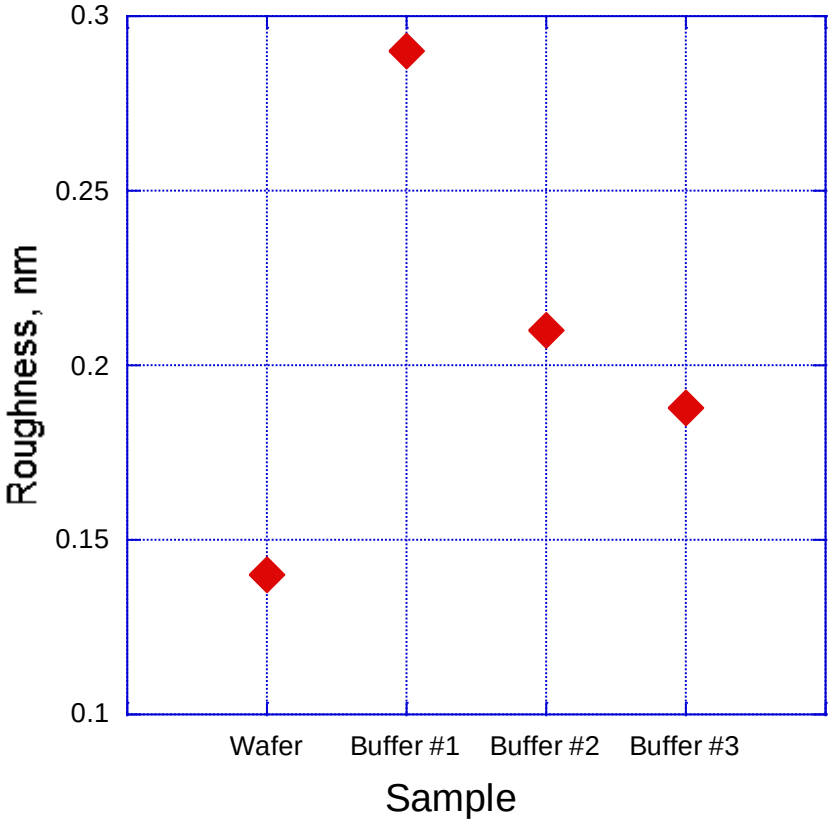
Image Statistics

Img. Rms (Rq)	0.290 nm
Img. Ra	0.206 nm
Img. Rmax	12.992 nm

Box Statistics

Rms (Rq)	0.270 nm
Mean roughness (Ra)	0.198 nm
Max height (Rmax)	2.744 nm
Max peak ht (Rp)	
Av max ht (Rpm)	
Max depth (Rv)	
Av max depth (Rvm)	
Box x dimension	1.977 µm
Box y dimension	1.957 µm

Surface roughness after ML removal



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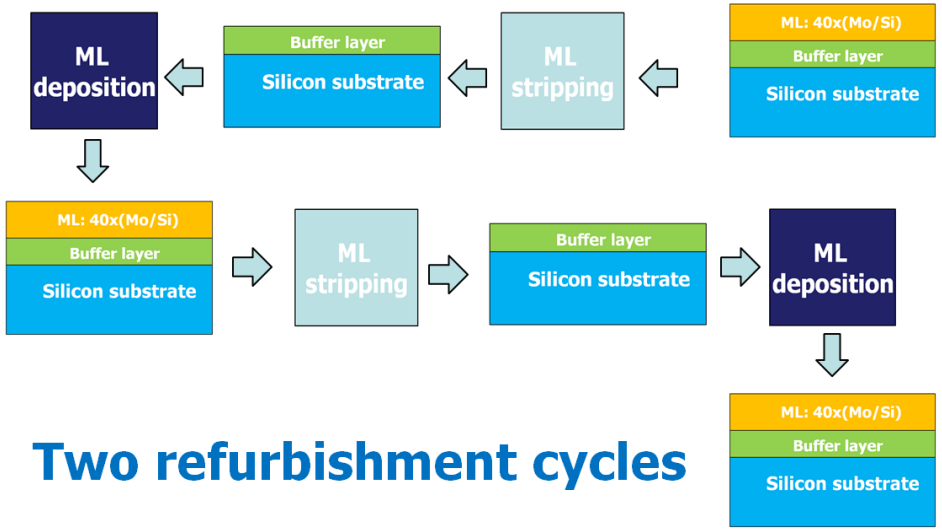
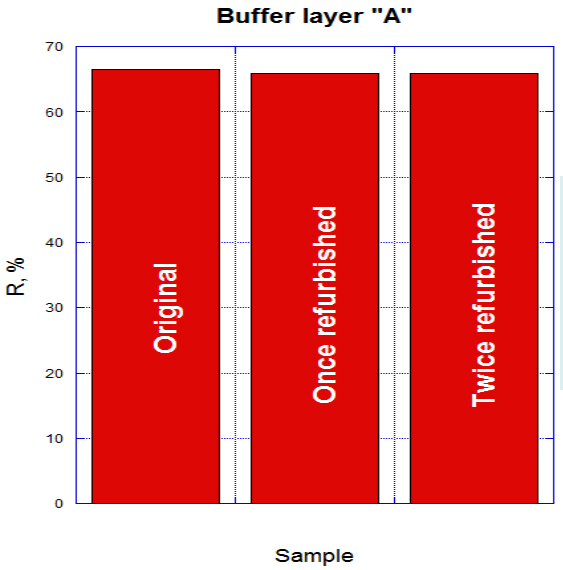
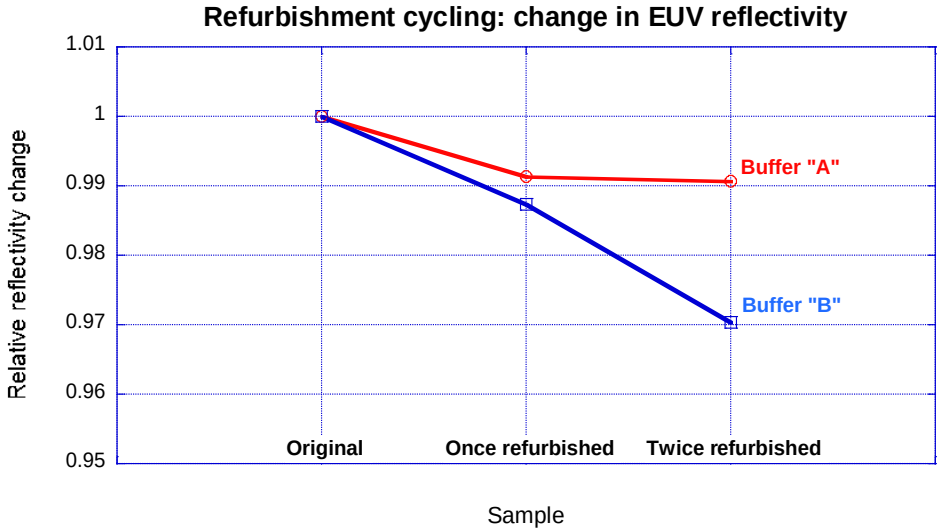
Buffer layer and EUV performance

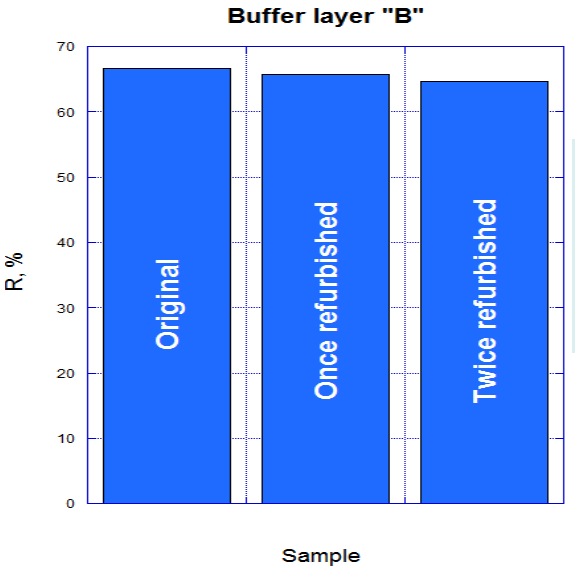


Two refurbishment cycles



Buffer layer "A" ~ 1% EUV reflectivity loss after 2 cycles





Buffer layer "B" ~ 3% EUV reflectivity loss after 2 cycles

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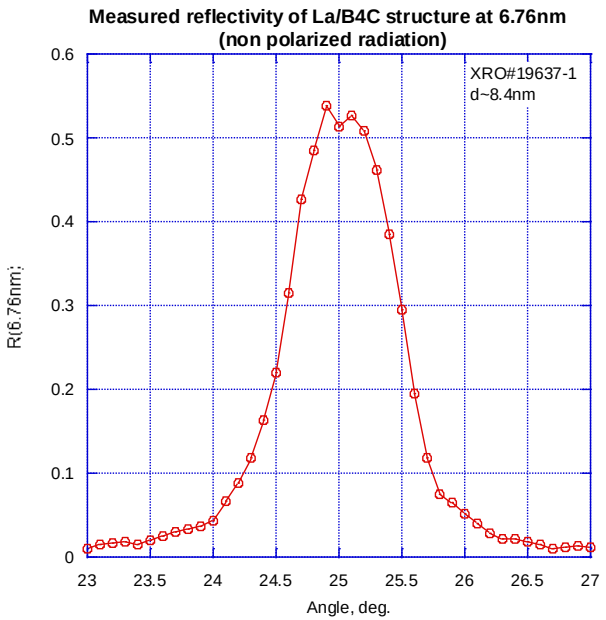
Multilayers for 6.X nm

R(max) @ 6.X nm with La/B4C

d=8.4 nm



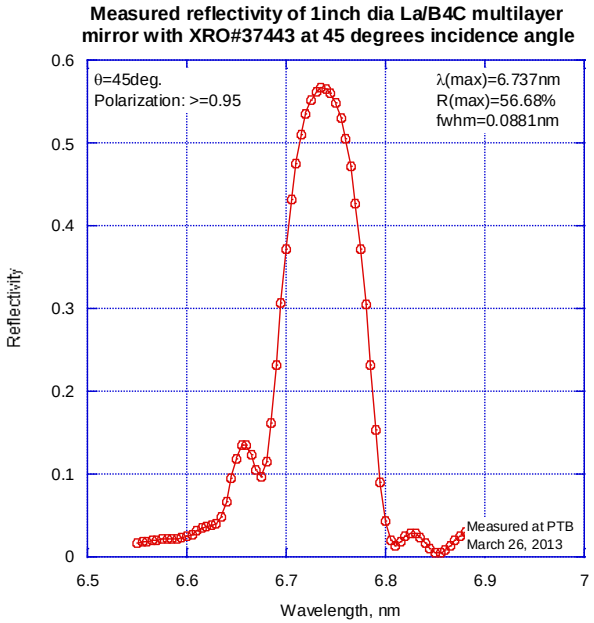
Polarization:
R(normal) vs. R(25deg.): +12%

Expected reflectivity @6.66nm:
52%*12% **= 58.2%**

Based on R. Soufli's B4C constants:
R(σ=0, θ=25deg.)≈**56%** @6.76nm

7.7% loss, σ(eff.)≈0.6nm

d=4.8 nm



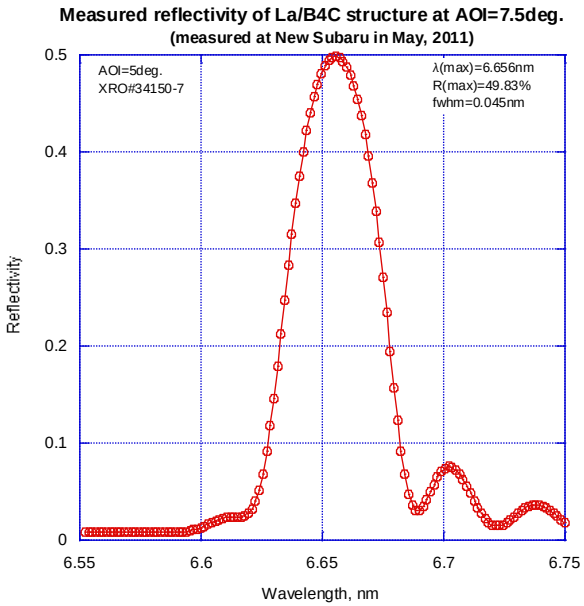
Dispersion:
R(@6.66nm) vs. R(@6.76nm): +10%

Expected reflectivity @6.66nm:
56.68%*10% = **62.3%**

Based on R. Soufli's B4C constants:
R(σ=0, θ=45deg.)≈**64%** @6.737nm

12.9% loss, σ(eff.)≈0.5nm

d=3.4 nm



R(meas.)≈**49.8%:**
~7% lower than expected
~35% lower than maximum possible

R(max)

Expected:
R(σ=0.45nm, normal)
≈53.2%

Maximum possible:
R(σ=0, normal)
≈67.2%

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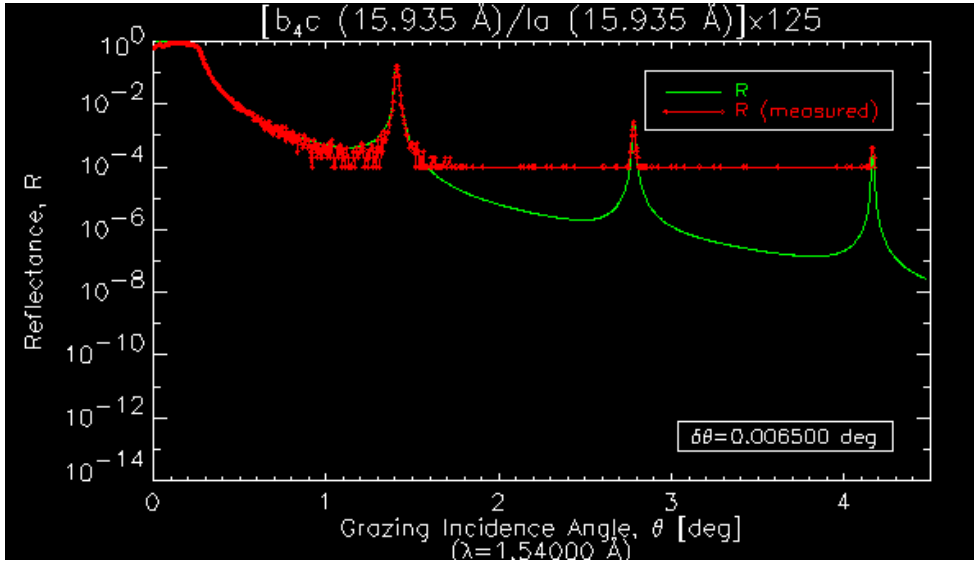
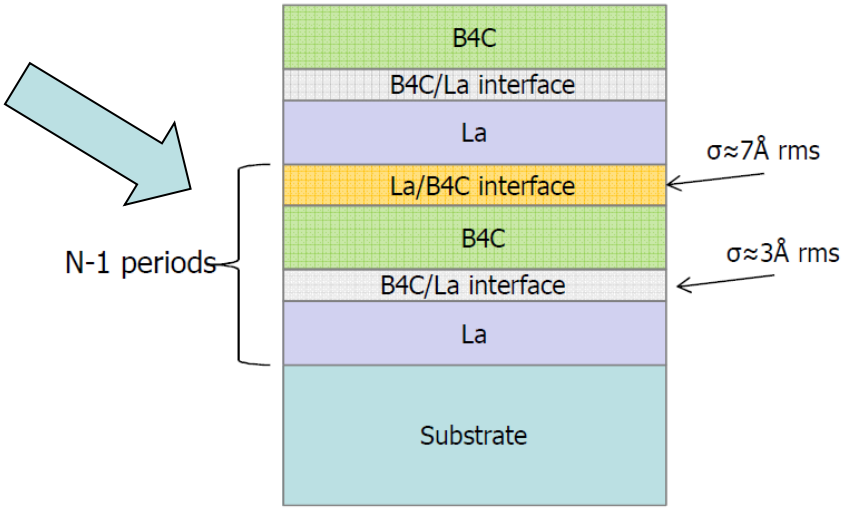
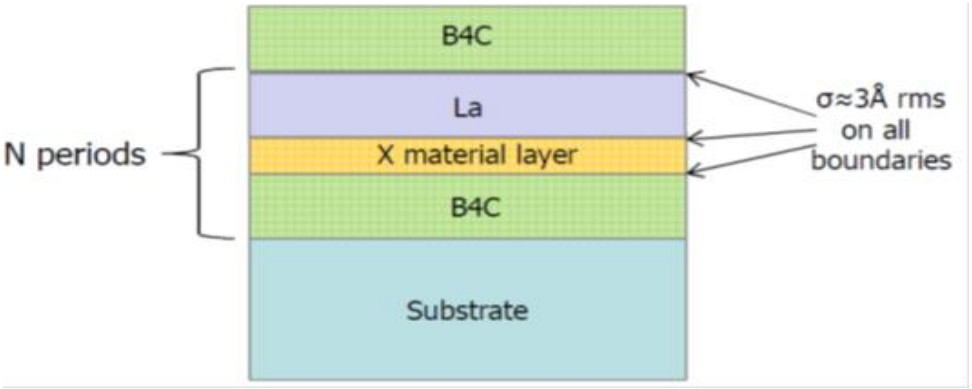
A typical La/B_4C structure

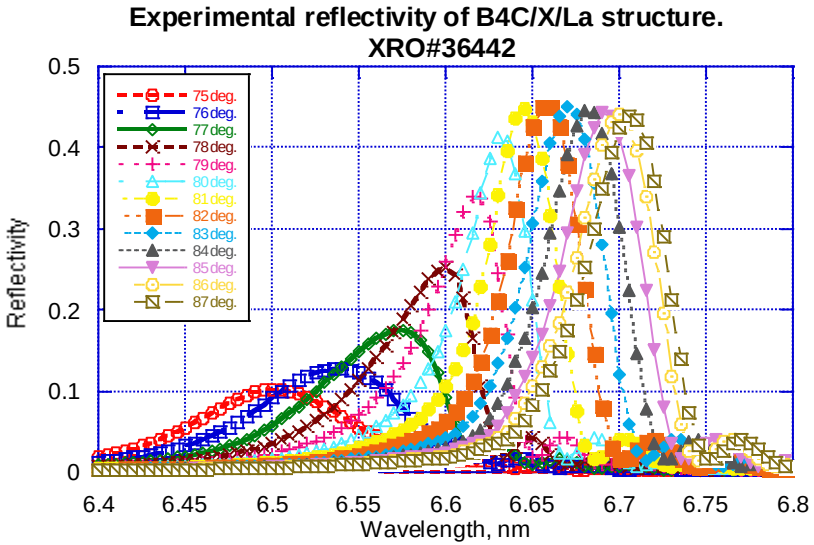
Cu-K_α (λ=1.54Å) fitting





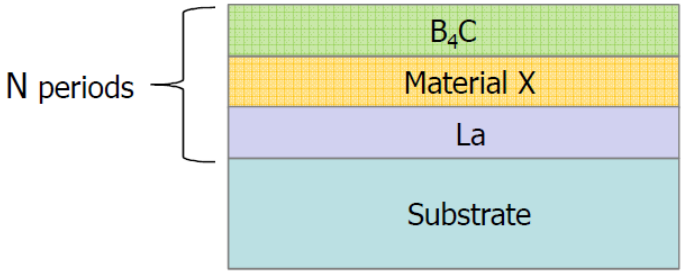
La/B4C/X : last year results

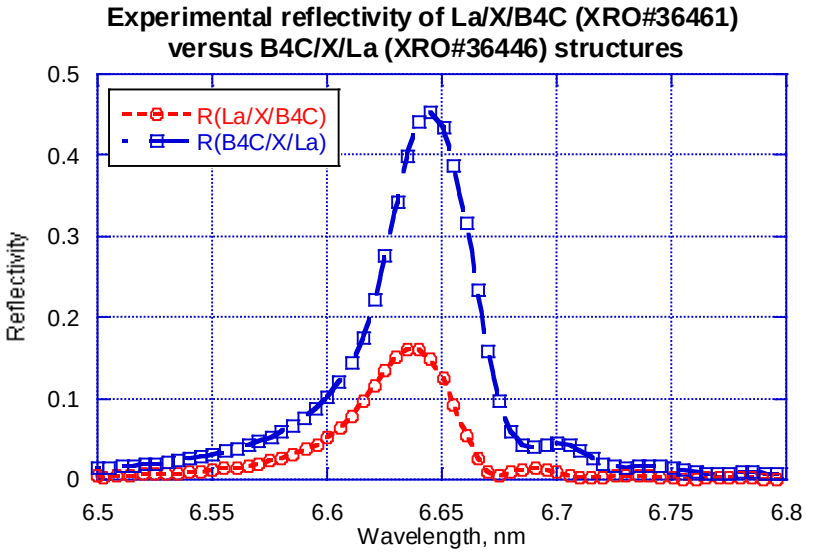




R_{max}=45.15% @ 6.656nm

vs. 49.83% with La/B4C





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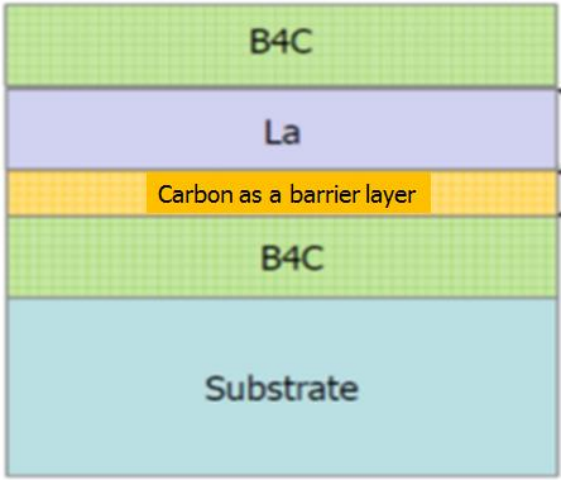
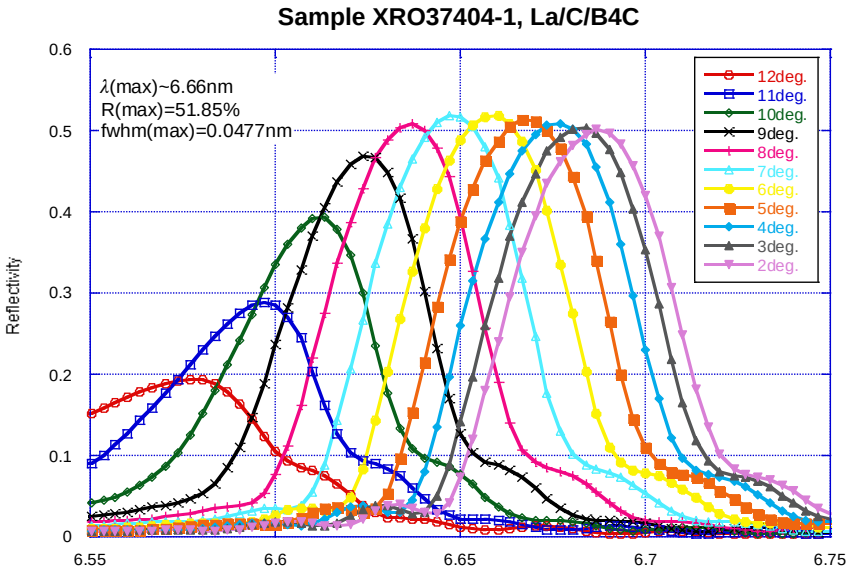
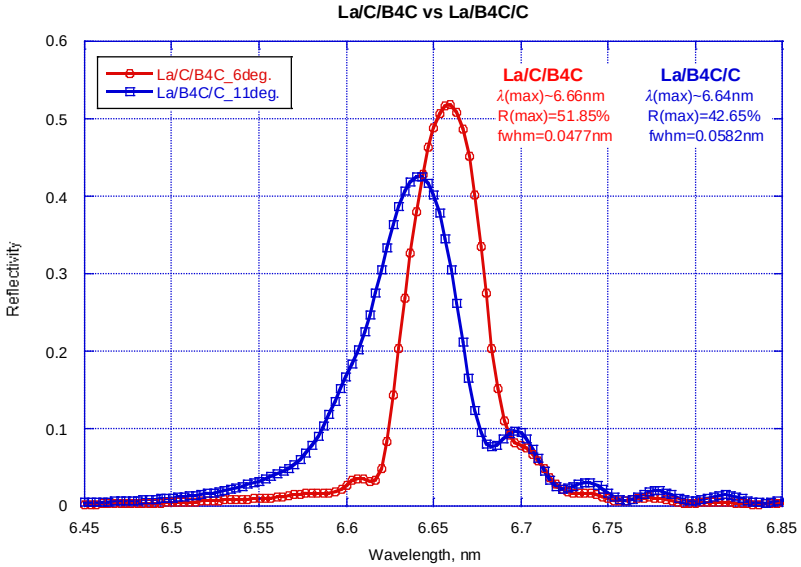
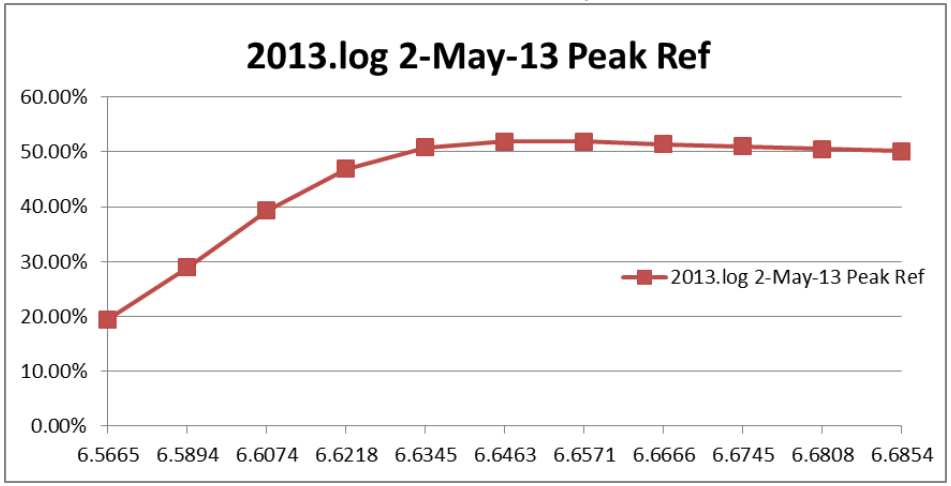
La/B4C/C structures



R(max) ~52%







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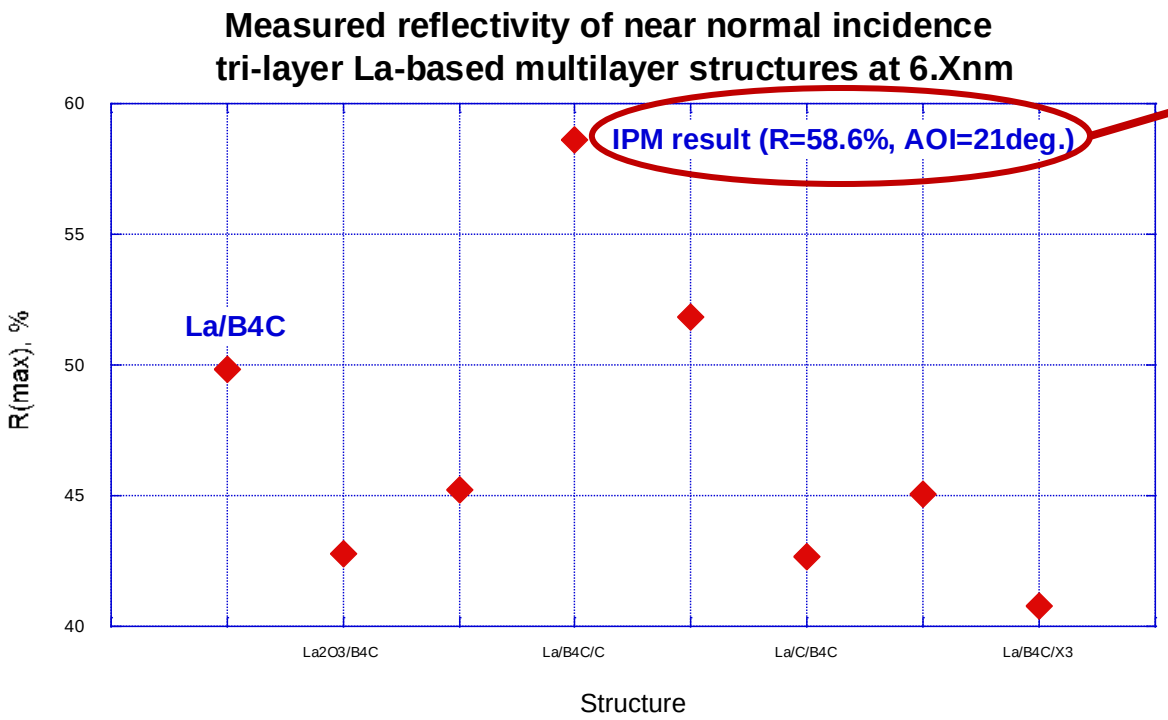
Reflectivity of La/B4C/X structures



Expected Rm~55%
at normal incidence
H(C) ~ 0.5nm

Expected maximum reflectivity R(La/C/B)~61%

Structure	AOI, deg.	λ(chwm), nm	R(max), %	fwhm, nm
La/B4C	5	6.655	49.83	0.043
La2O3/B4C	15	6.628	42.8	0.053
La/B4C/X1	8	6.656	45.2	0.049
La/B4C/C	6	6.66	51.85	0.0477
La/C/B4C	11	6.638	42.65	0.0582
La/B4C/X2	8	6.66	45.08	0.0462
La/B4C/X3	6	6.66	40.76	0.0456

Can be increased with a lower thickness of carbon barrier layer (this structure has H(C)~0.9nm)

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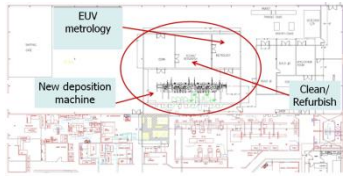
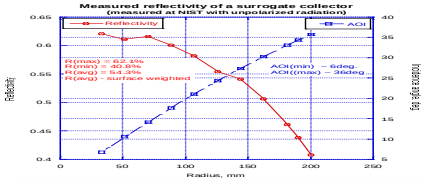
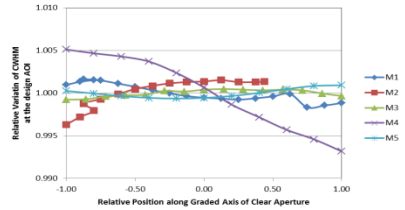
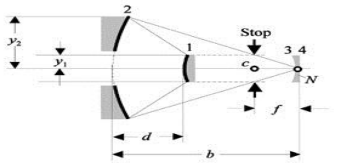
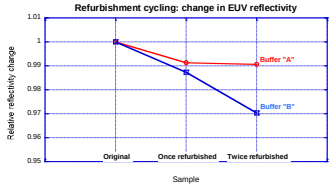
Conclusion

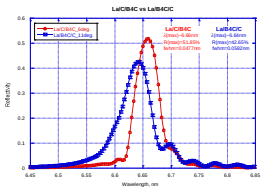












- **New deposition tool**
  - Dual deposition chamber, commissioning in Sept'13
- **Collector optics**

  NIST upgraded reflectometer for up to 450mm optics

  1st surrogate: R(avg)≈54.3%, CWHM=±0.75% - un-polarized beam
- **Illuminator optics**

  CWHM for all 5 optics is within +/-0.8%

  Reflectivity at 45deg for s-polarized beam reaches 70%
- **SO optics**

  CWHM: +/-0.3%, R(M2 optics) ≥ 64%
- **Refurbishment**
  - Mo/Si on bare Si: ~2% loss per cycle,
  - Mo/Si on a buffer layer: ~1% after two refurbishment cycles
- **ML for 6.X nm**
  - ~52% reflectivity at AOI=6deg.
  - Expected: R(La/B4C)~ 54%, R(La/C/B)~61%

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Acknowledgement

- **RIT**

  G. Fournier, J. Hummel, C. Coffel, T. Camitan

- **CXRO**

  E. Gullikson

- **NIST**

  C. Tarrio, S. Grantham, T.B. Lucatorto

Thank you

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