Multilayer mirror coatings for high numerical aperture extreme-ultraviolet lithography systems

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Outline

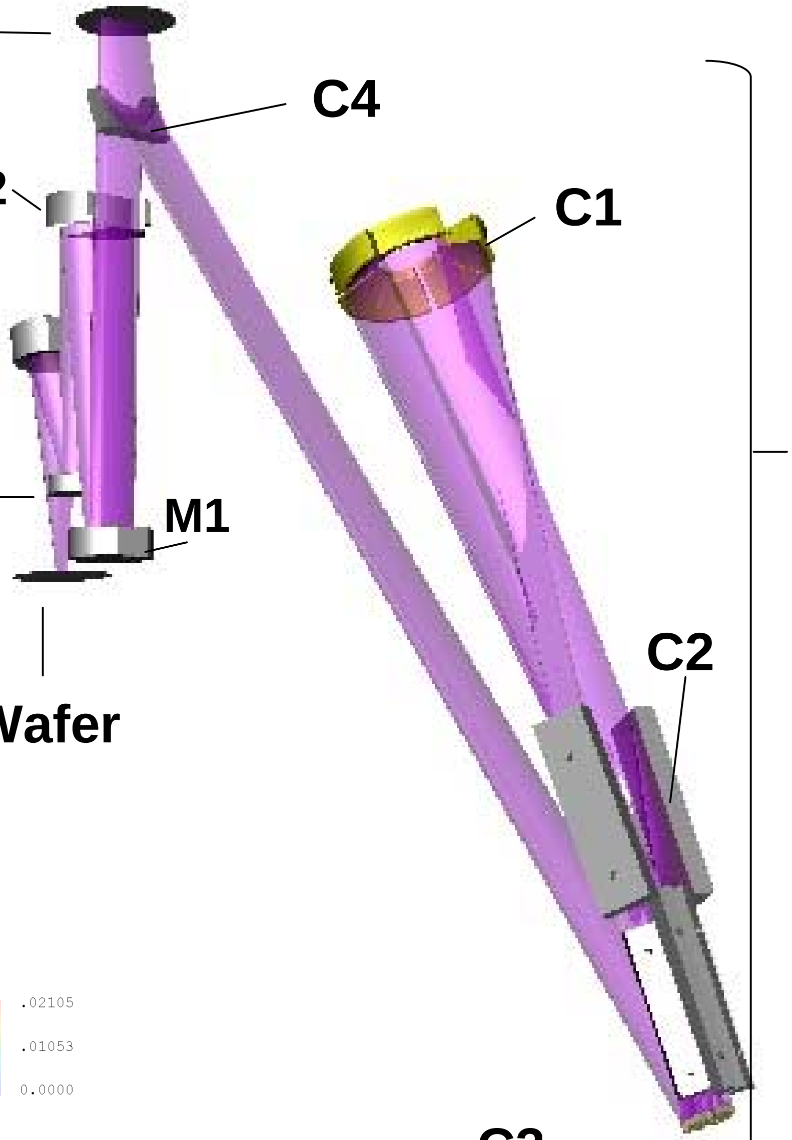
1) ETS projection optics — 0.1 NA
    - uniform coating results

2) High NA beta-class design

3) Deposition system for high NA optics
    - graded thickness coating results
    - wavelength matching

4) Microexposure tool (MET) coatings

The Engineering Test Stand has a numerical aperture of 0.1



Mask

C4

M2

C1

Projection Optics

M4

Condenser

M3

M1

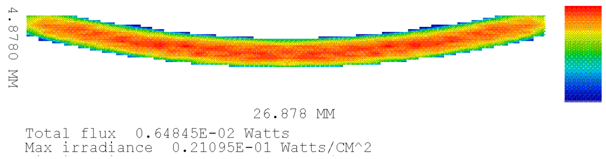
Wafer

C2

C3

NA = 0.1
Resolution = 70 nm L/S

Ring field:
104 mm at mask
26 mm at wafer



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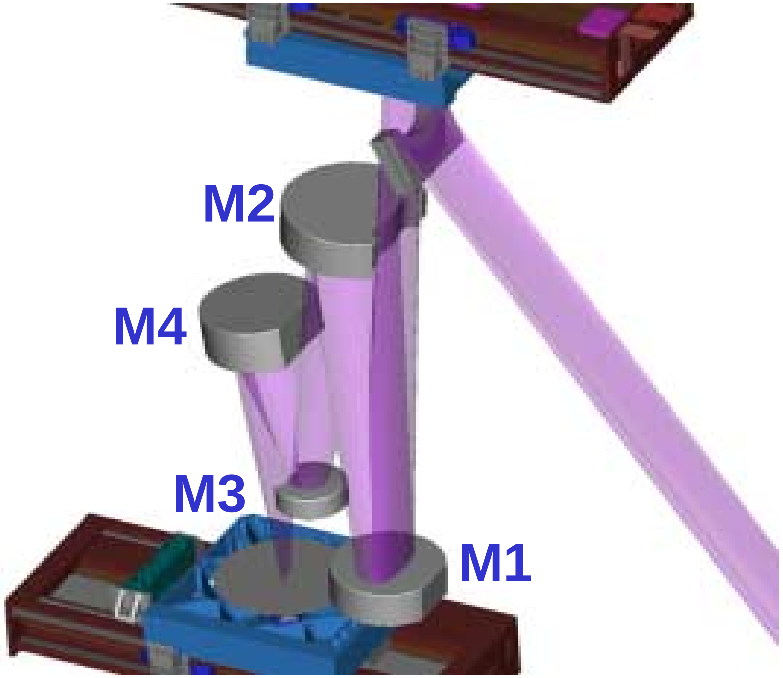
The ETS projection optical system was designed to work with uniform coatings



Coating non-uniformity contributes to figure errors

PO set	Figure spec	ML-added
1	0.5 nm rms	0.15 nm rms
2	0.25 nm rms	0.1 nm rms

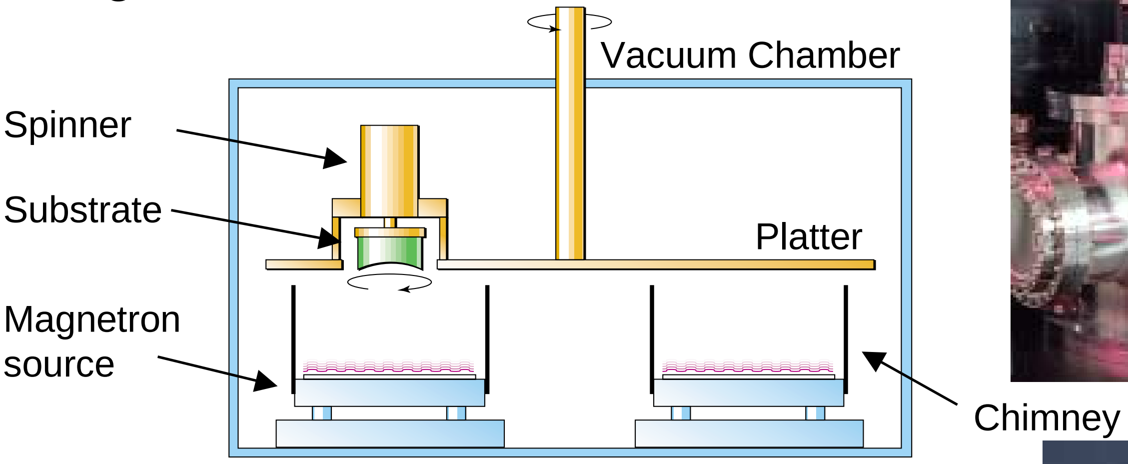
Estimate of uniformity required across a 160 mm projection optic:
Mo/Si: 0.1 nm/280nm = 0.04% rms

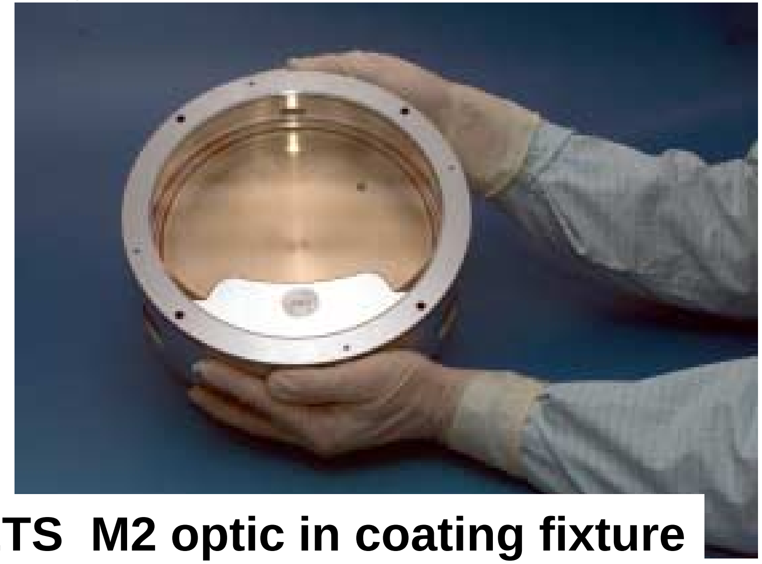
Linear or spherical non-uniformities are compensable.

Largest optic is 200 mm diameter with a 160 mm clear aperture

The Set 1 ETS optics were spun around their own center during coating

Mag-1 - Side View

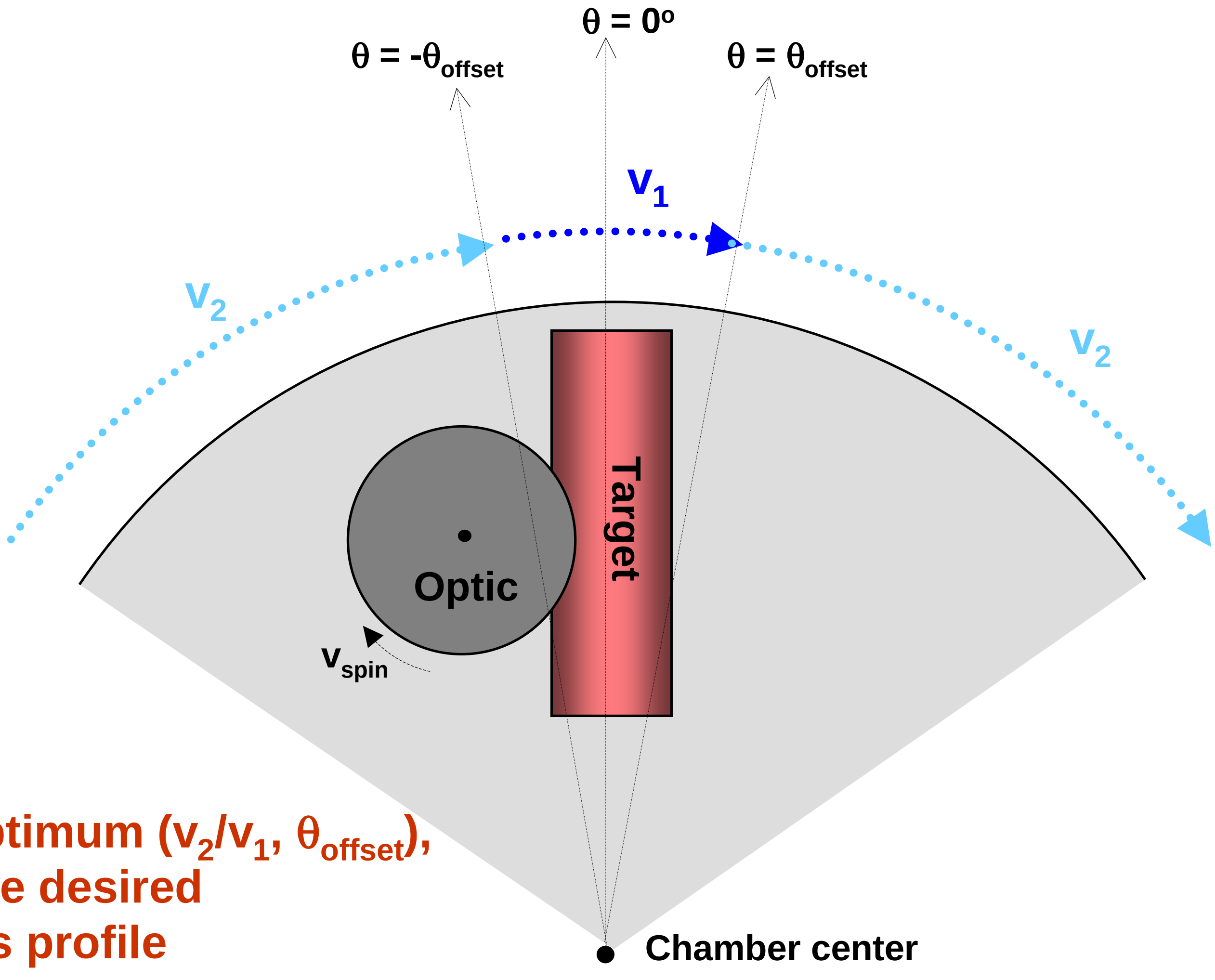




ETS M2 optic in coating fixture

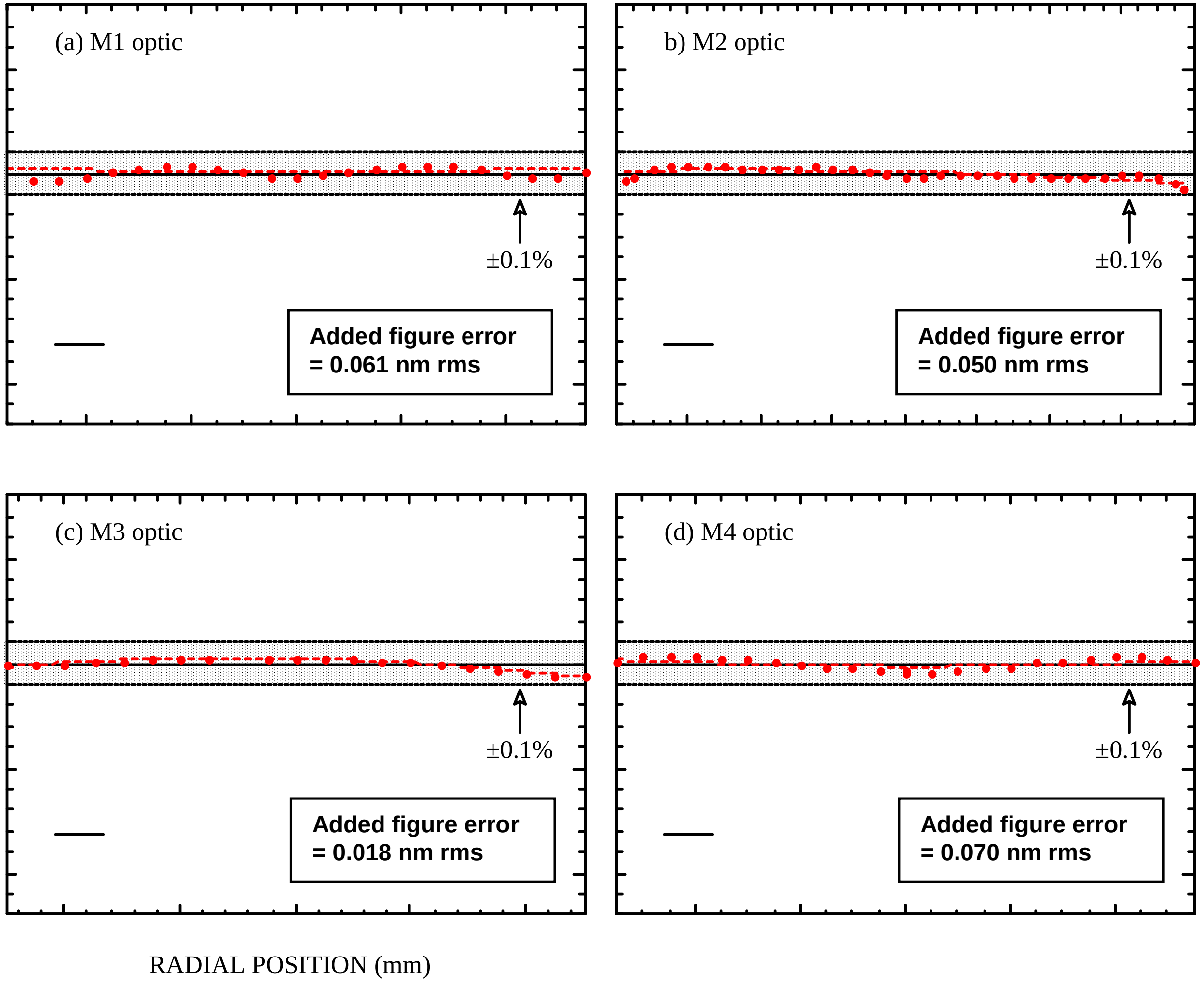
- DC magnetron sputtering with Ar plasma
- Substrates mounted on a large platter that rotates to deposit alternating layers
- Substrates are spun fast about their axis for azimuthal uniformity
- Layer thicknesses are determined by <u>platter</u> rotation velocity

Platter velocity modulation allows control of the radial thickness profile



Select optimum (v_2/v_1, θ_{offset}), to achieve desired thickness profile

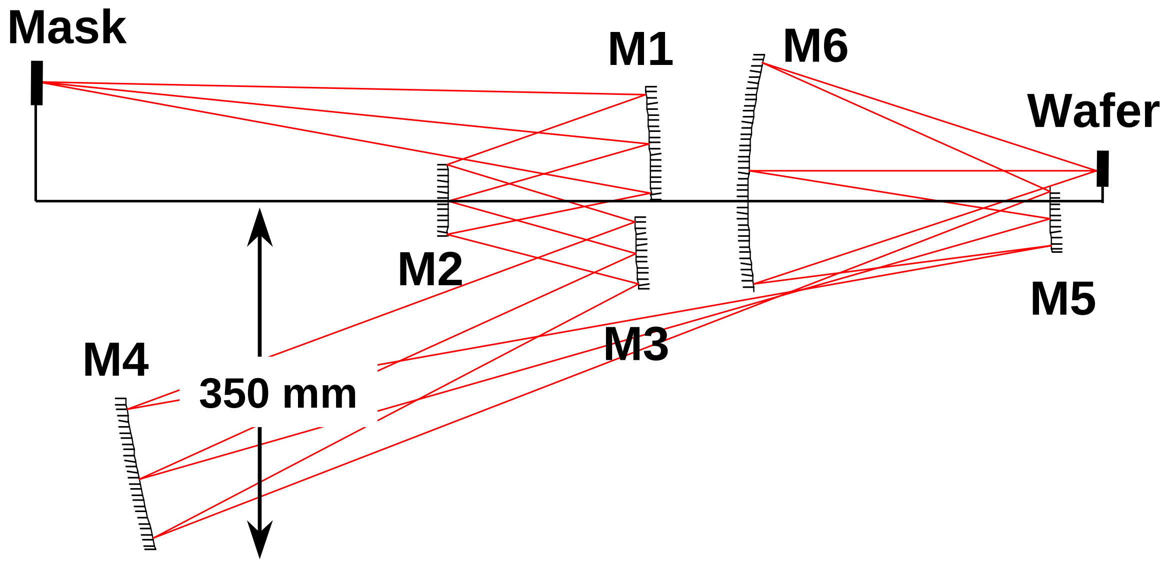
The uniformity of the ETS Set 1 optics achieved Set 2 specifications



Solid lines represent the targeted prescription, the data points are the measured values

Large-field, high NA projection systems require large optics with gradients symmetric about the optical axis

Example: __Six-mirror high NA EUV projection system__



Reduction = 4x

NA = 0.25

RFW = 2.0 mm

Dist. < 0.25 nm

RMS = 0.012λ (λ = 13.4)

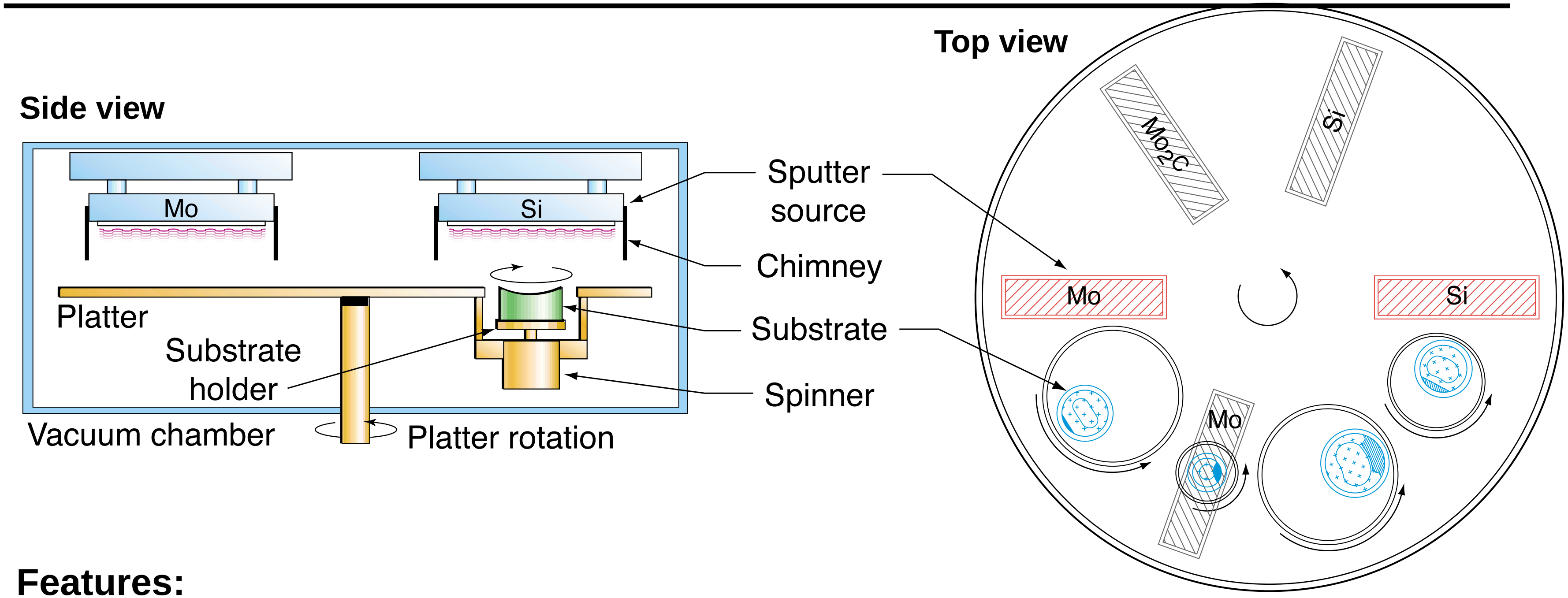
courtesy of Russ Hudyma
US patent 6,033,079

Understanding the limitations of ML coating technology is *__prerequisite__* to optimizing the optical design and building a Beta system

We designed a new deposition system for coating large high NA optics

“Mag-4” multilayer deposition system

Mag-4 spins the optics off-center for graded-thickness coatings

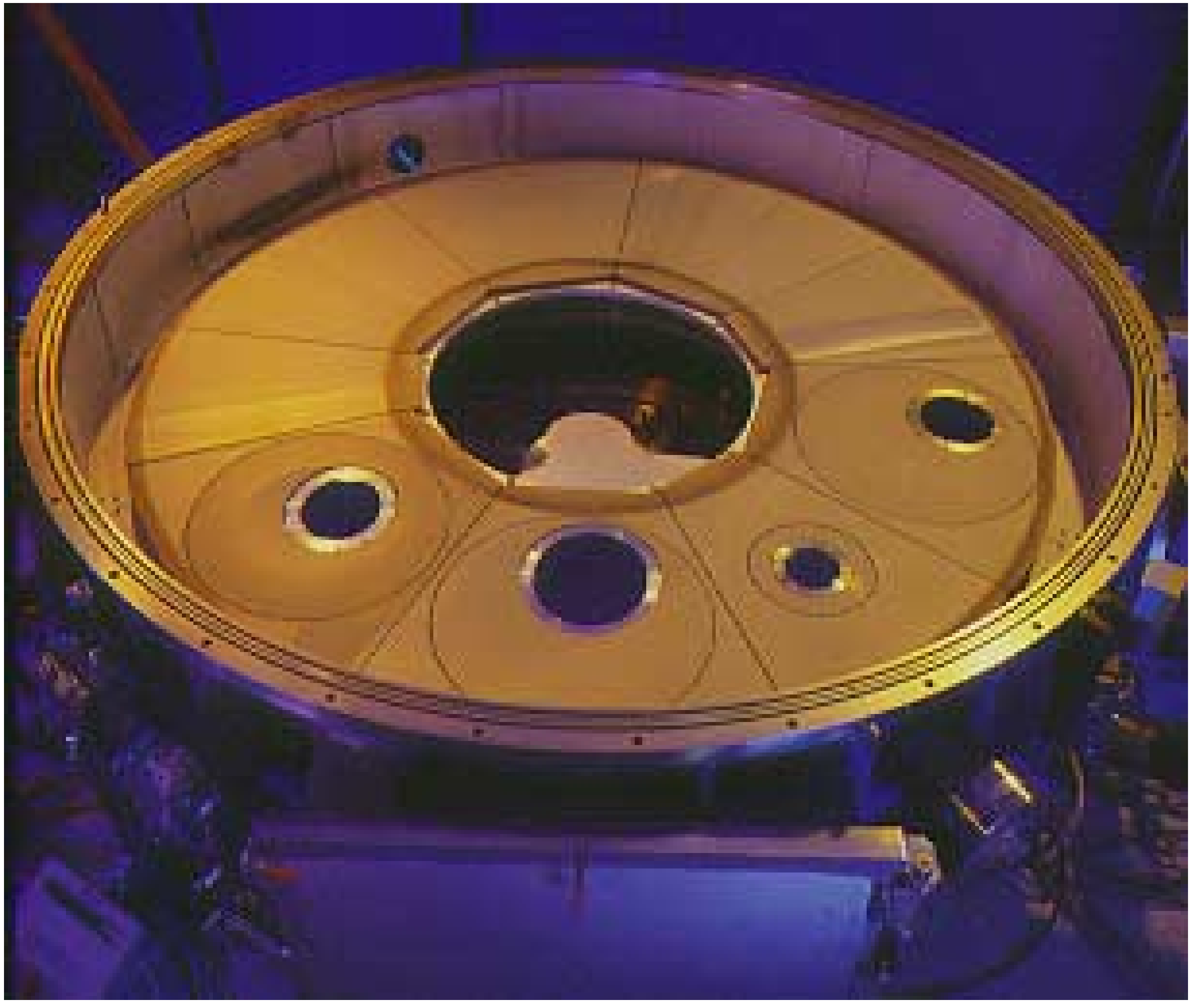


Features:

- optics can be spun off-axis for graded-thickness coatings
- fast spinning of substrates (to 500 rpm) provides azimuthal uniformity
- improved wavelength matching by coating 4 optics in the same run
- only 1 optic is passed over only 1 source at any given time—> independent control of all layers
- precision platter rotation velocity (~ 1 rpm) controls film thickness and uniformity
- deposition time = ~ 40 minutes

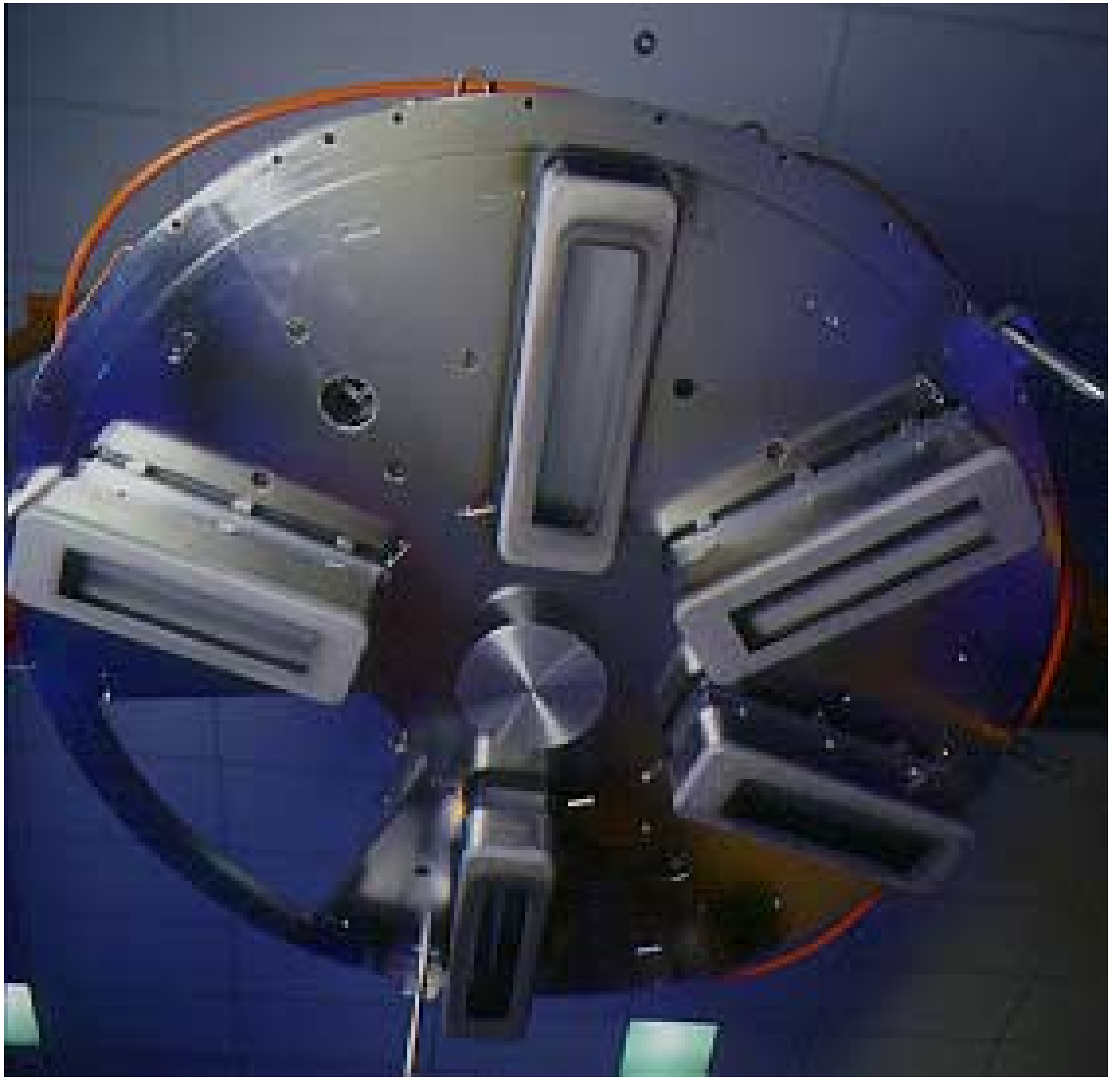
Mag-4 is configured to coat 4 optics up to 470 mm diameter

View of substrate platter,
with 4 ETS projection optics spun around the optical axis



The system can be modified to coat fewer, but larger optics up to 600 mm

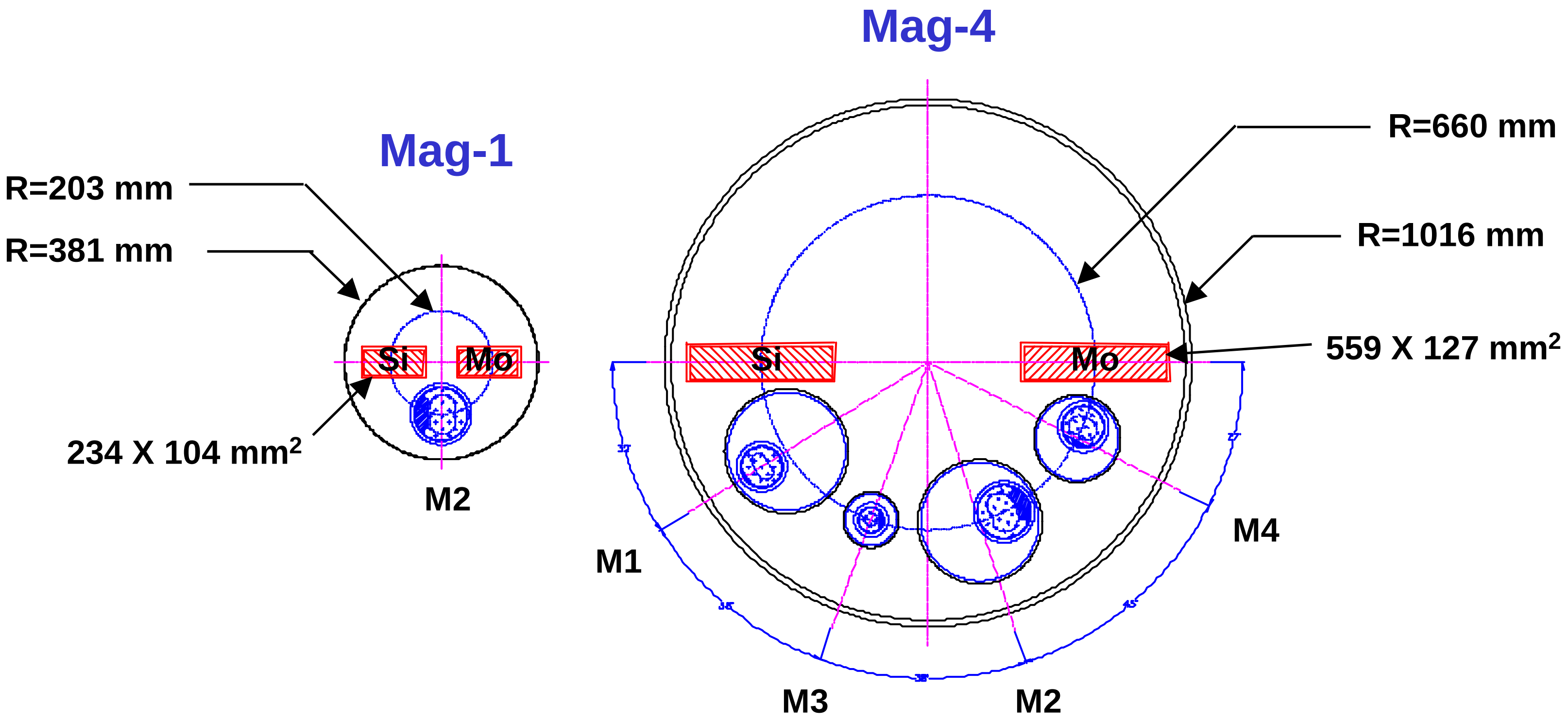
Five sputter sources provide process flexibility



Underneath view of chamber lid with 5 sputter sources

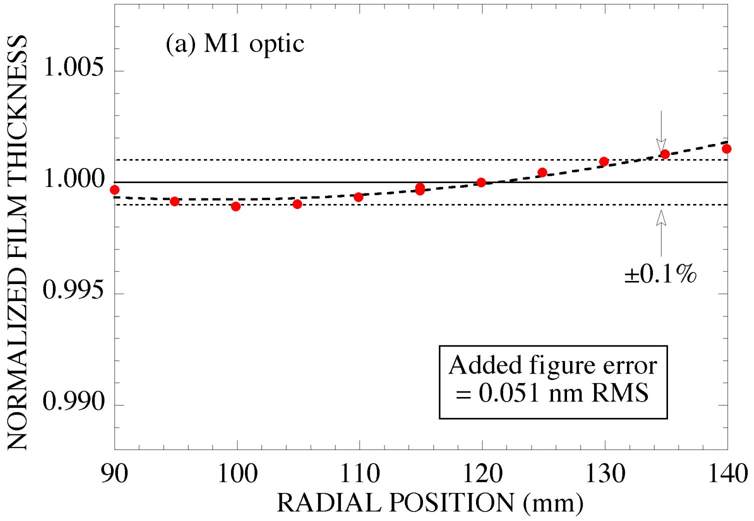
- 2 sources used for coating curved optics
- 2 sources used for process development
- 1 source for new materials, e.g., capping layers

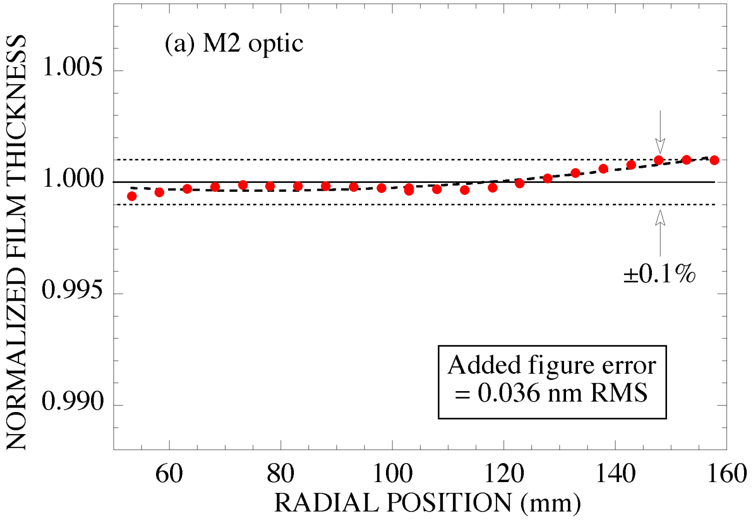
Comparison of Mag-1 and Mag-4 coating systems

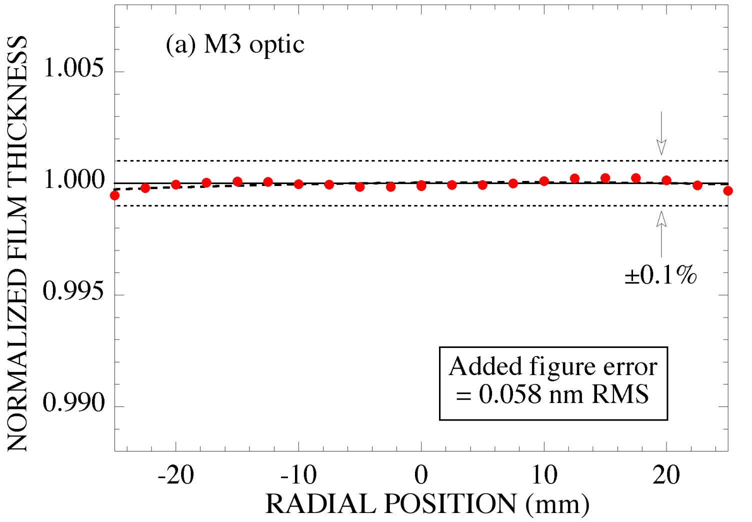


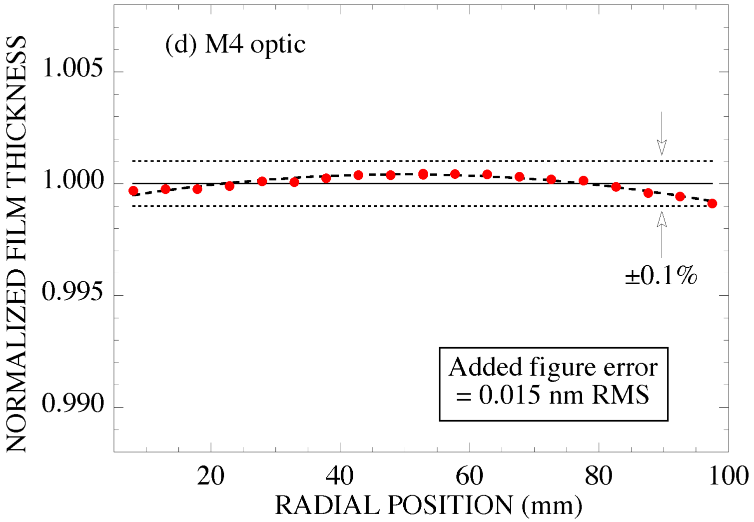
The new deposition tool can accommodate larger substrate tilts, larger substrate-to-target distance variations and larger coating areas.

ETS PO Set 2 Results

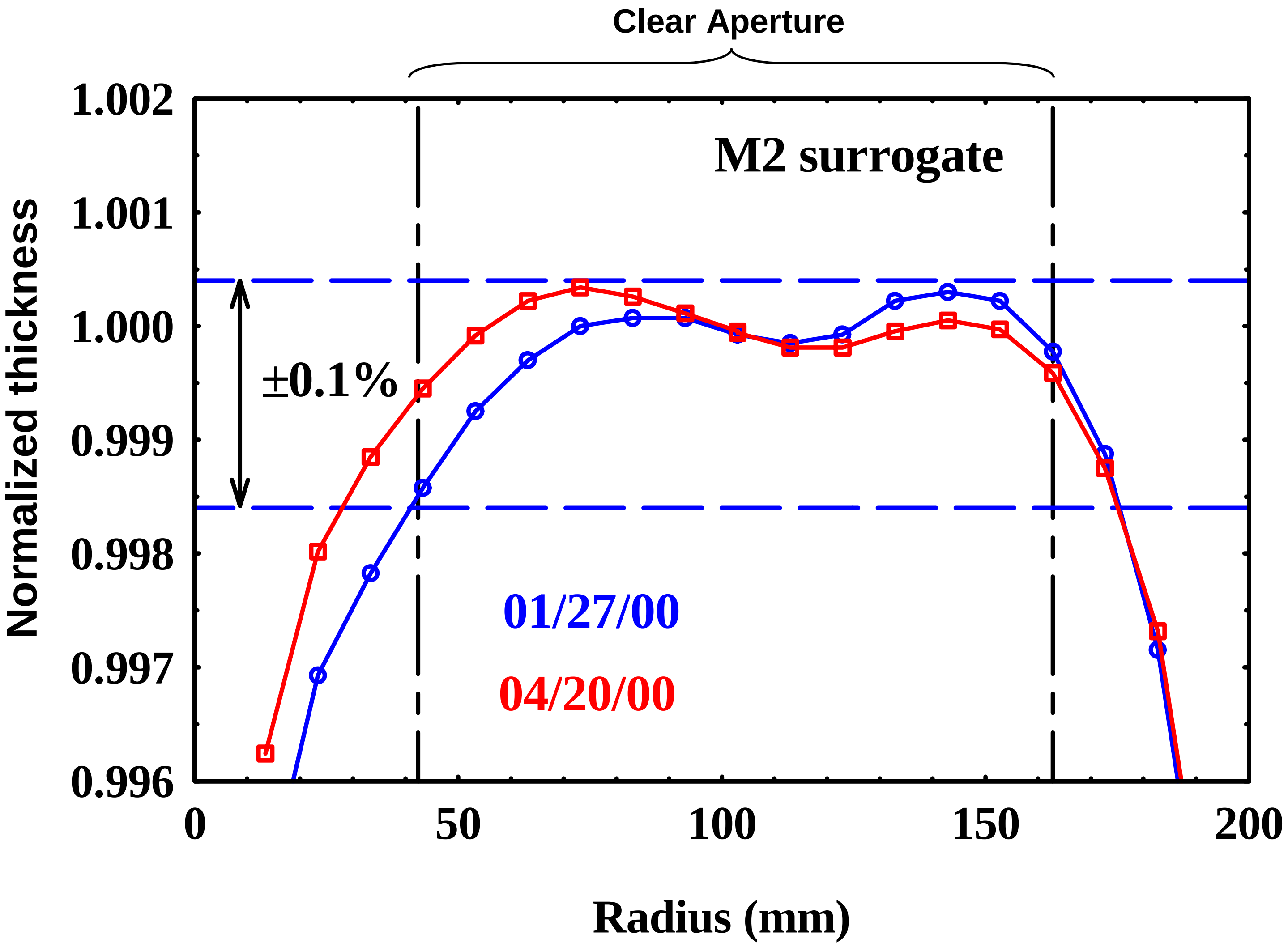






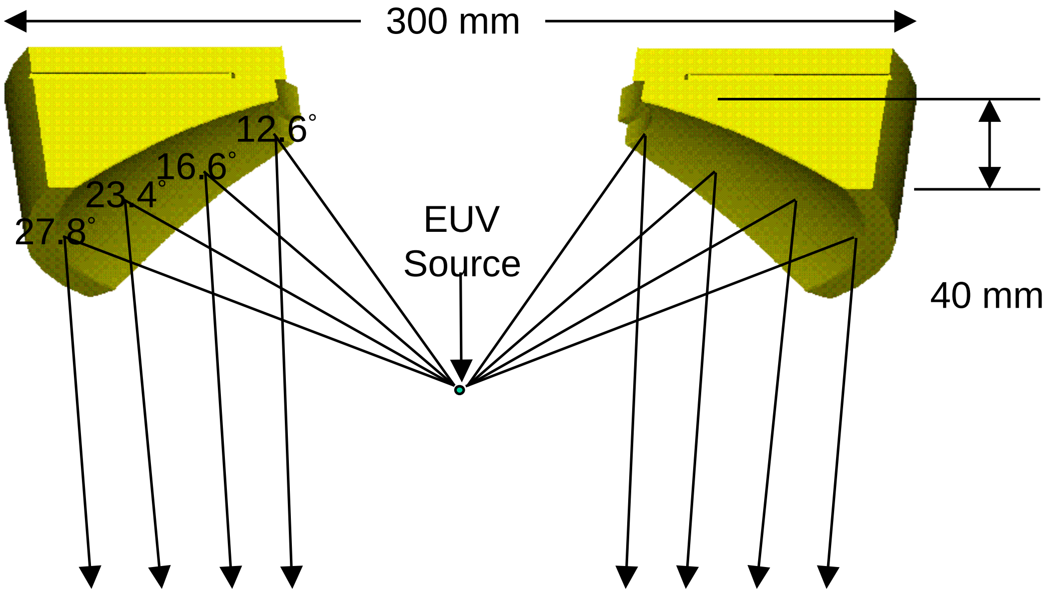


The uniformity of the M2 process is stable over a 3 month period



Condenser optic C1 is large, deeply concave and has a wide range of incidence angles

Condenser optic C1
in the deposition fixture

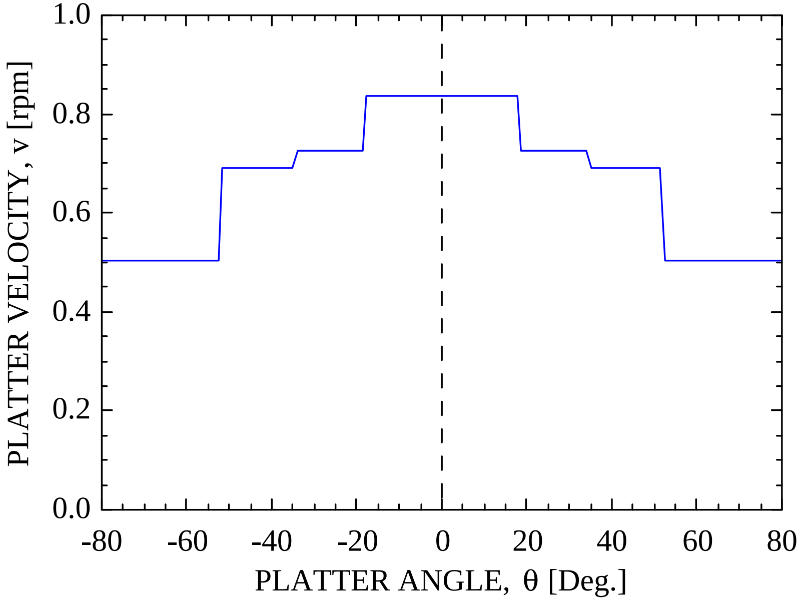


C1 requires a graded coating thickness to compensate the variation in incident angle

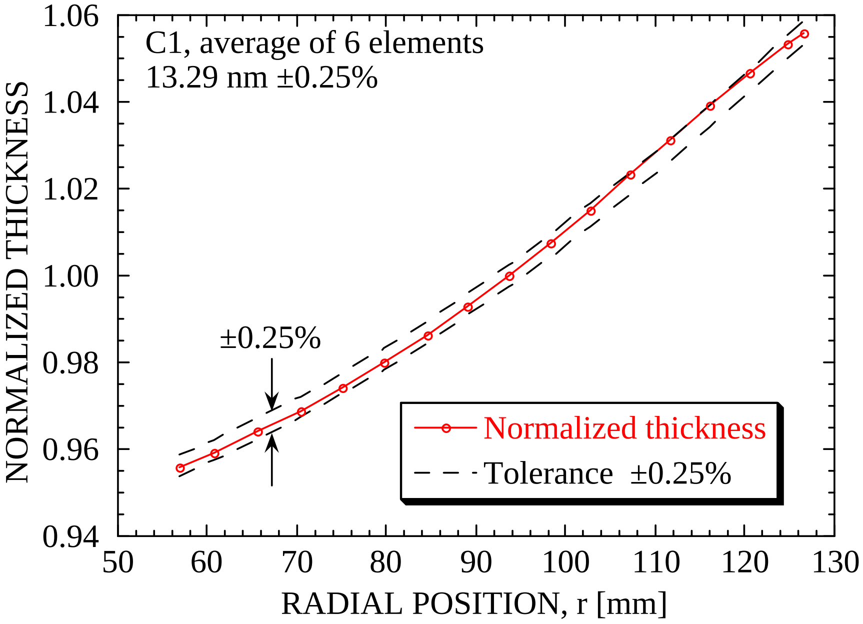
$$\lambda = 2\Lambda\cos\alpha\sqrt{1-\frac{2\bar{\delta}}{\cos^{2}\alpha}}$$

The graded coating for C1 was achieved with a 4-velocity recipe

Velocity profile used

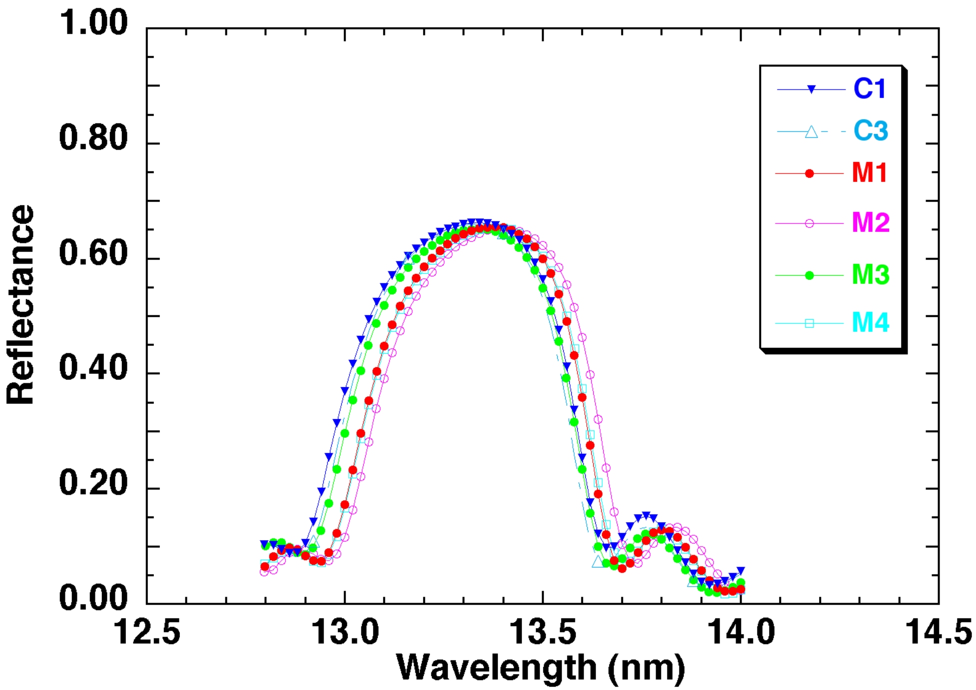


Thickness distribution achieved



Optic-to-optic wavelength matching is required to achieve high throughput

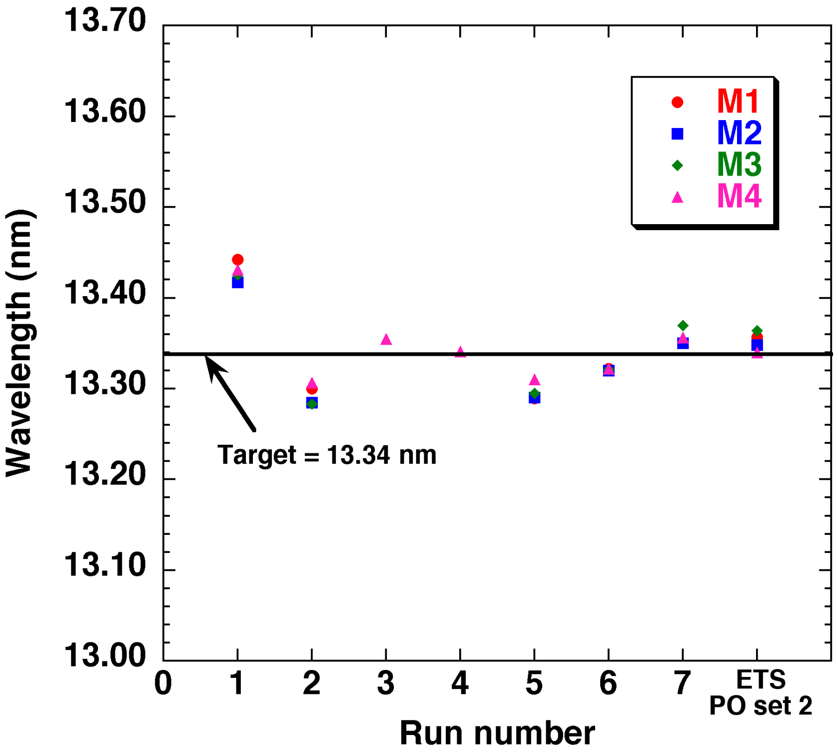
Results from ETS Optics Set 1 coated "0ne-at-a-time" in Mag-1



- **Wavelength matching was 1σ = 0.032 nm**
- **Yielded an integrated throughput of <u>96%</u> compared to ideal**
- **Resulting peak centroid = 13.339 nm**

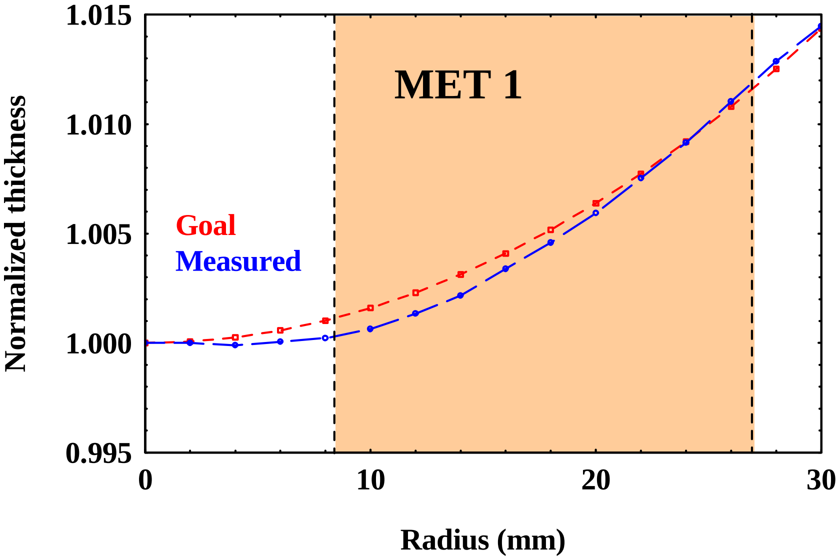
Coating 4 optics per run improves optic-to-optic wavelength matching

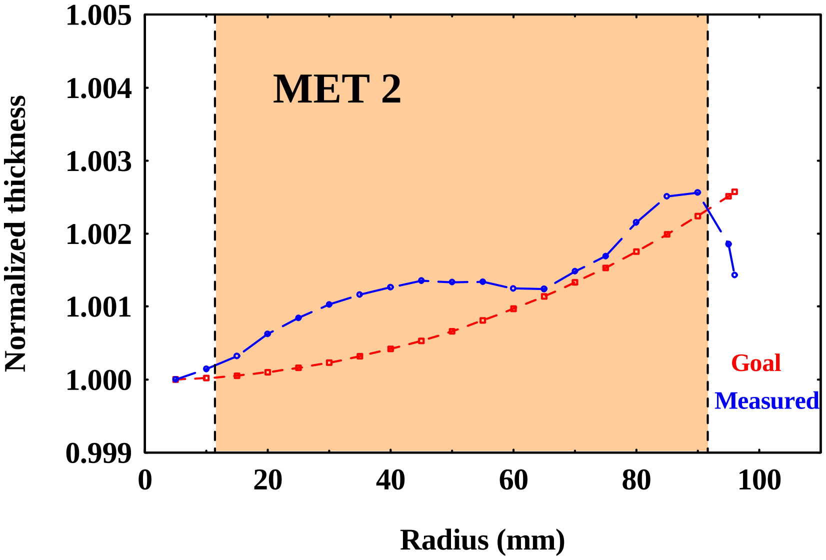
Recent results from Mag-4 coated "Four-at-a-time"



	Wavelength matching (nm, @ 1σ)	
	within a run	run-to-run
Mag-1	0.03	0.03
Mag-4	0.007	0.02

Coatings for the MET optics are nearly within specification





- MET 1 is within specification

- MET 2 has non-compensable added figure error
  — probably will require a 3 velocity recipe

Summary

1) Multilayers for high-NA beta-class systems require graded-thickness coatings on large optics

2) Achieving such gradient prescriptions typically requires spinning the optics off-center during coating

3) A new deposition system was developed for coating high NA beta systems

4) Results on ETS optics show that the system meets requirements

Plans for future work

1) Demonstrate the capability on surrogate beta-class optics

2) Continue improvements in thickness control for the more stringent figure specifications for beta systems