Improving X-Ray Optics Through Differential Deposition

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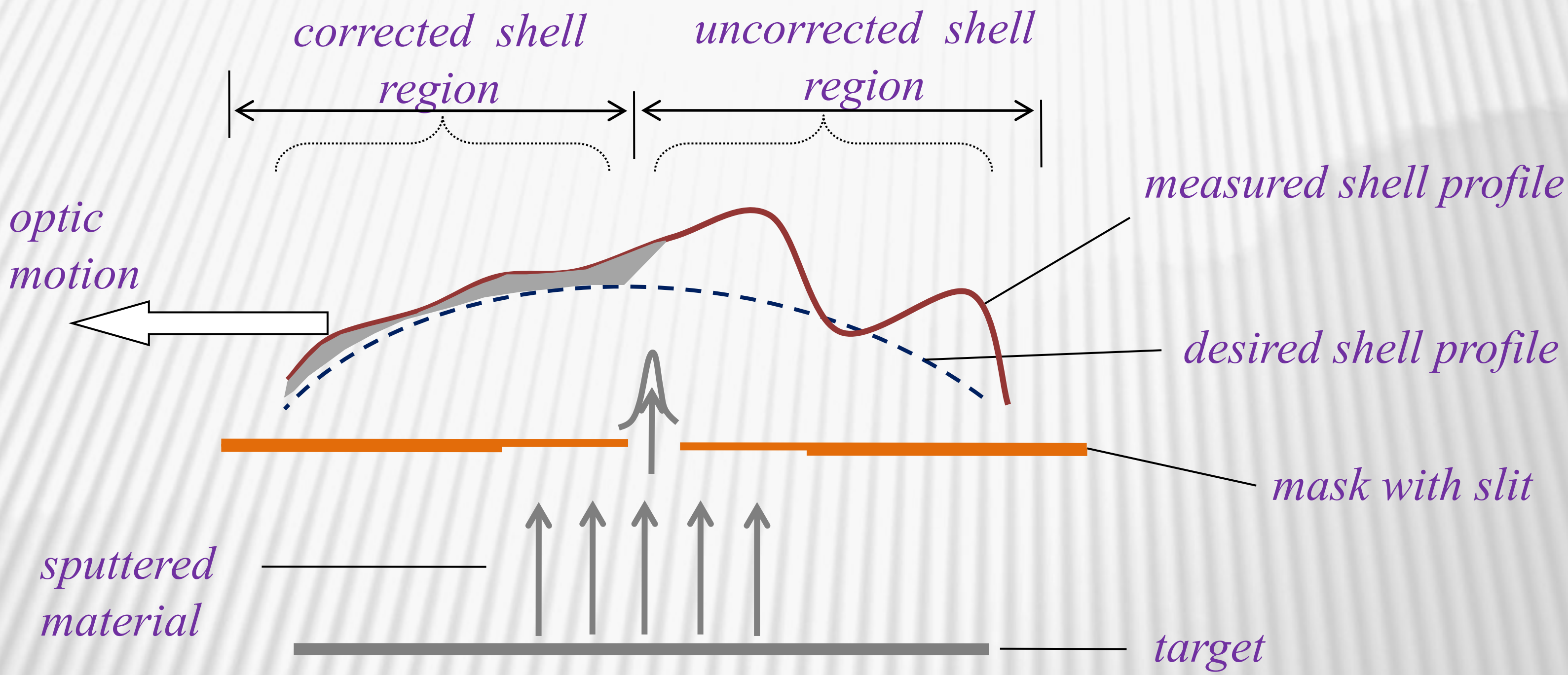
Workshop on X-Ray Mission Concepts

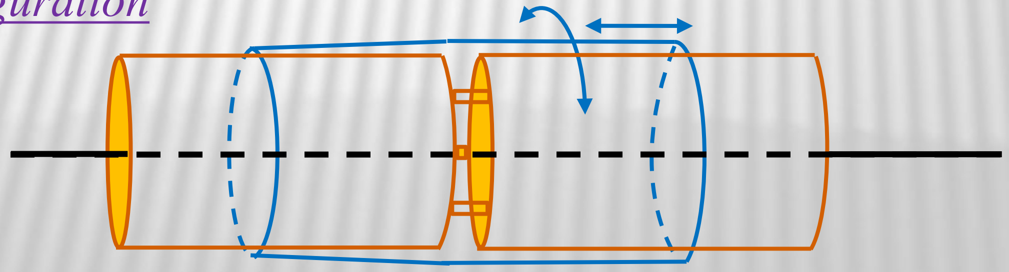
Differential deposition

- ***What***
  - Differential deposition is a technique for correcting figure errors in optics
- ***How***
  - Use physical vapor deposition to selectively deposit material on the mirror surface to smooth out figure imperfections
- ***Why***
  - Can be used on any type of optic, mounted or unmounted
  - Can be used to correct a wide range of spatial errors
  - Technique has been used by various groups working on synchrotron optics to achieve sub-μradian-level slope errors

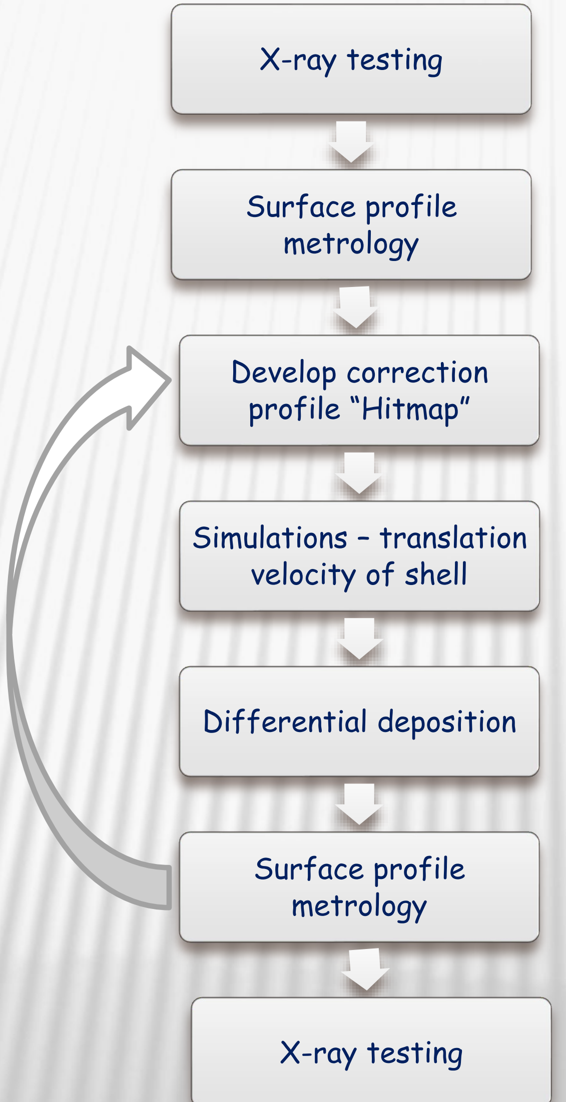
Addressing profile deviations through differential deposition



Full Shell Configuration



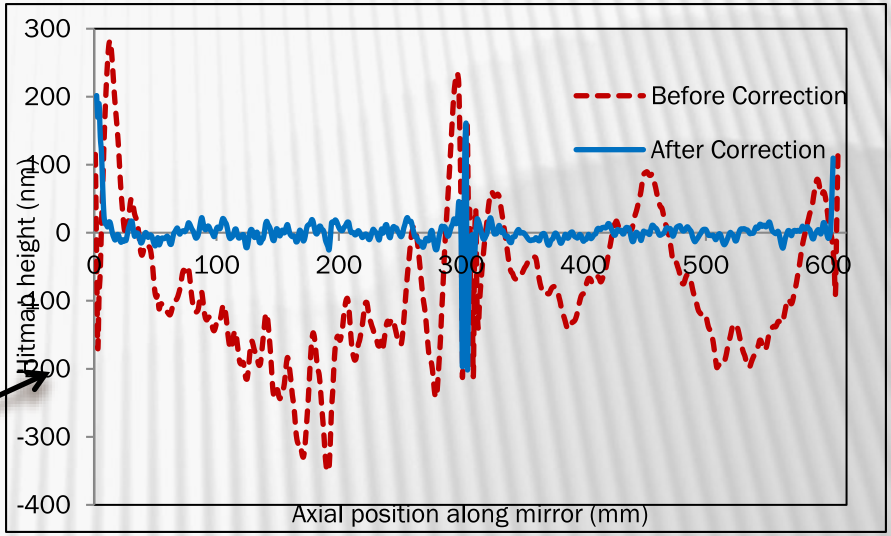
Process sequence - differential deposition

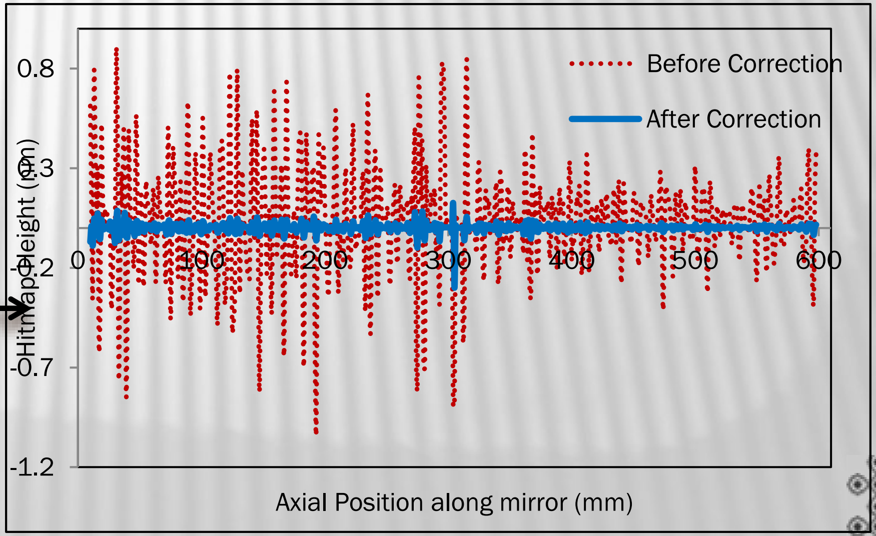


Theoretical performance improvement

Simulations performed on X-ray shell profile of 8 arc sec simulated HPD

Correction stage	Average deposition amplitude (nm)	Slit-size (mm)	Angular resolution (arc secs)
1	300	5	3.61
2	40	2	0.68
3	4	1	0.22
4	1	0.25	0.14





Possible practical limitations

- *Variation of sputtered beam profile along the length of mirror – particularly for short focal length mirrors*
- *Deviation in the simulated sputtered beam profile from actual profile, beam non-uniformities, etc*
- *Positional inaccuracy of the slit with respect to mirror*
- *Stress effects*
- *Metrology uncertainty*

Metrology limitation

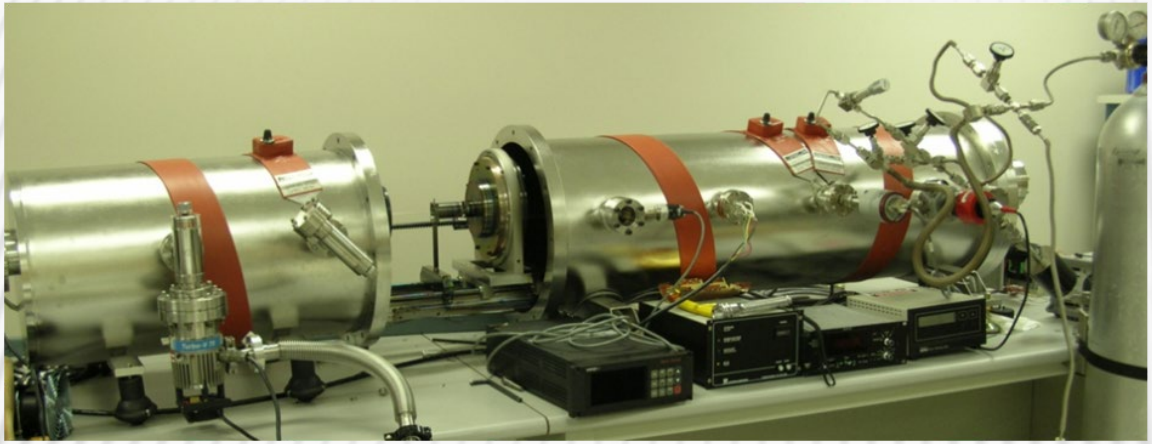
Simulations performed on X-ray shell of

8 arc sec simulated HPD

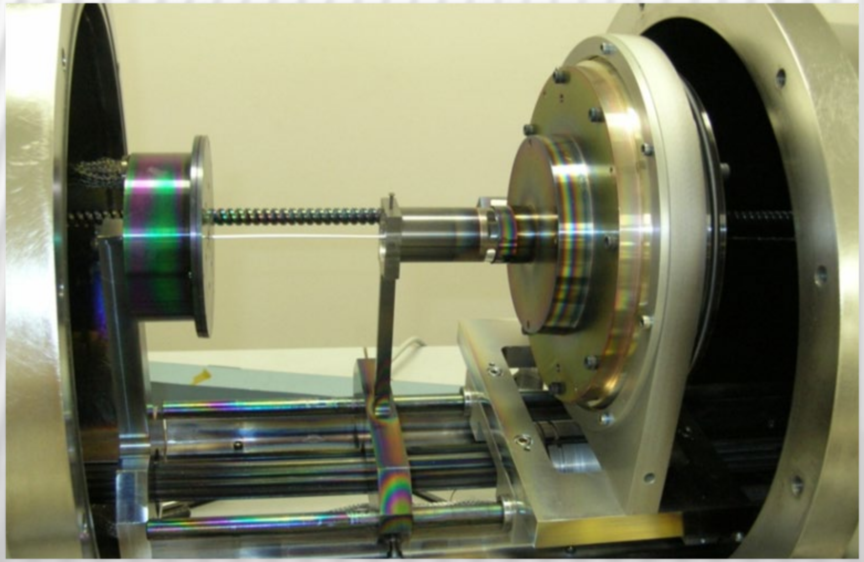
Correction stage	Average deposition amplitude (nm)	Slit-size (mm)	Metrology uncertainty (nm)	Angular resolution (arc secs)
1	300	5	± 0	3.6
			± 10	3.6
			± 50	7.3
2	40	2	± 0	0.6
			± 1	1
			± 5	2
			± 10	3.5
3	4	1	± 0	0.2
			± 0.5	0.2
			± 1	0.5
			± 2	0.8

- *Potential for ~arc-second-level resolution – with MSFC's metrology equipment*
- *Sub-arc sec resolution could be possible with the state-of-art metrology equipment*

Proof of concept



Modify an old coating chamber



Miniature medical optics

Material and process selection

Platinum-Xenon				Platinum-Argon			
power	pressure	roughness	deposition rate	power	pressure	roughness	deposition rate
75	15	1.950	0.130	75	15	2.060	0.140
90	15	2.043	0.230	90	15	1.933	0.190
75	30	1.895	0.170	75	30	1.868	0.160
90	30	1.810	0.250	90	30	2.083	0.220
Nickel-Xenon				Nickel-Argon			
power	pressure	roughness	deposition rate	power	pressure	roughness	deposition rate
75	**15**	**1.915**	**0.290**	75	15	1.995	0.180
90	15	2.070	0.360	90	15	1.778	0.240
75	30	3.093	0.240	75	30	2.260	0.220
90	30	3.630	0.310	90	30	2.210	0.290
Tungsten-Xenon				Tungsten-Argon			
power	pressure	roughness	deposition rate	power	pressure	roughness	deposition rate
75	15	1.965	0.300	75	15	1.900	0.120
75	30	1.805	0.290	75	30	2.125	0.290
90	30	1.993	0.370	90	30	-	-
75	50	2.075	0.290	75	50	1.998	0.310
90	50	2.423	0.370	90	50	1.868	0.370
Units: power-Watts, pressure-mTorr, roughness- Å rms, deposition rate – Å/sec							

Proof of concept on few-cm-scale medical imaging optics

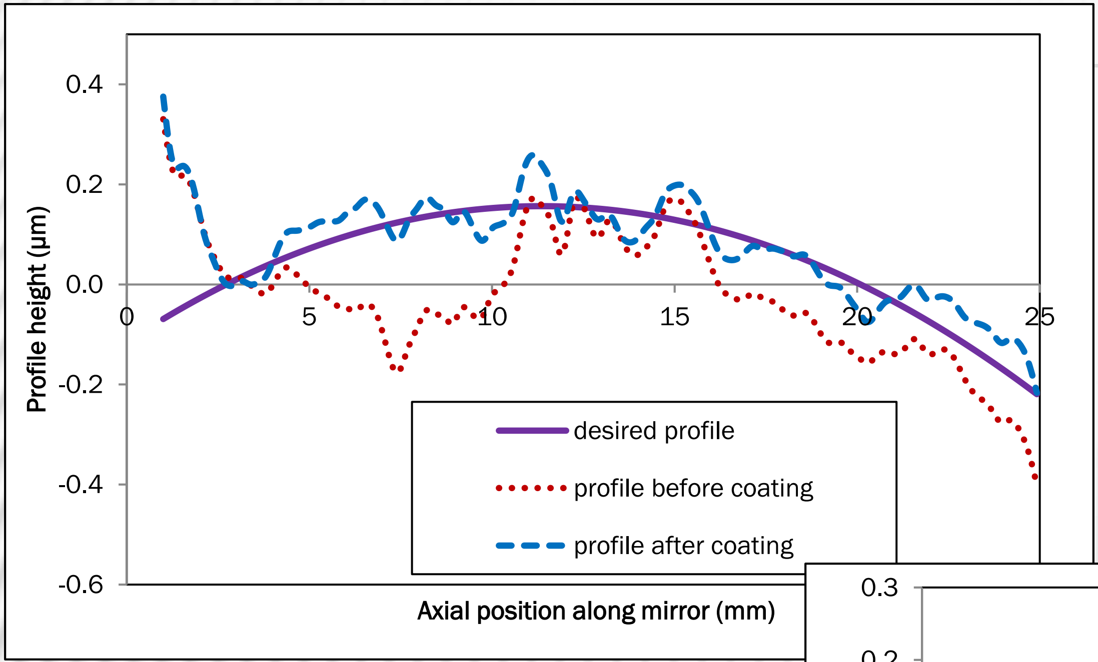
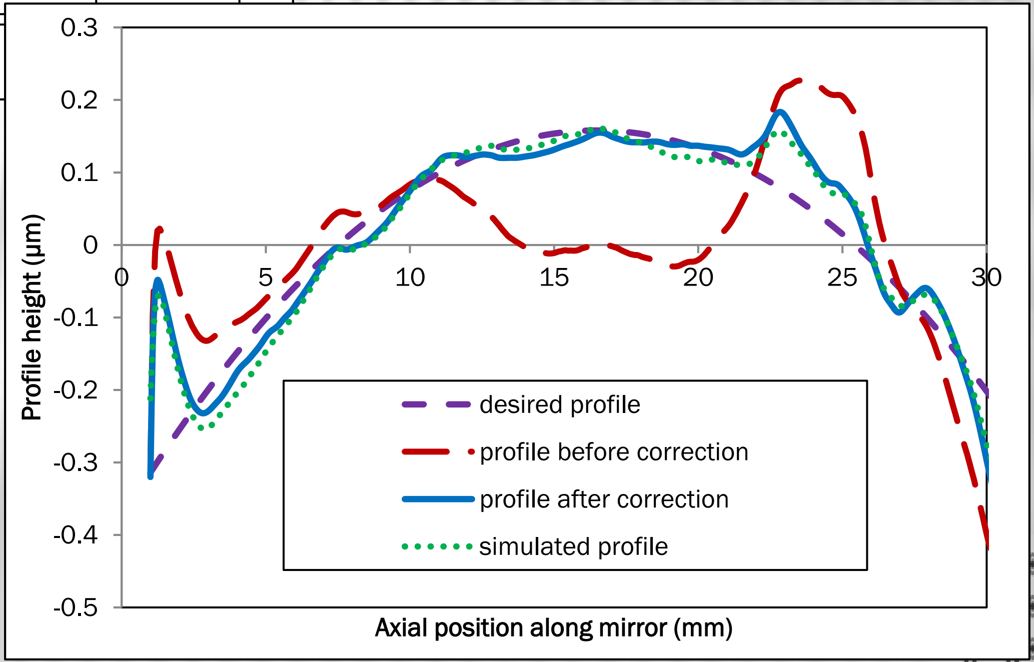


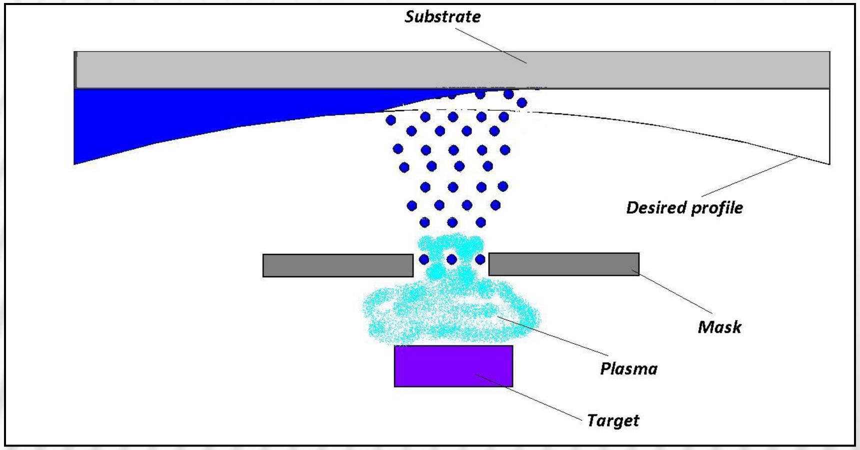
Figure error improvement from 0.11 µm to 0.058 µm rms

Slope error improvement from 12 arc sec to 7 arc sec rms



Other X-ray optics

- *Technique equally applicable to the planar geometry of segmented optics*



- *Can correct deviations low-order axial-figure errors and azimuthal axial slope variations in slumped glass mirrors*
- *WFXT – maintaining high angular resolution - 5 arc sec over wide field of view - avoiding shell end effects and mounting errors, mid-spatial-frequency errors*

Current Status

• Since submitting this RFI response we have been notified of APRA /ARA funding

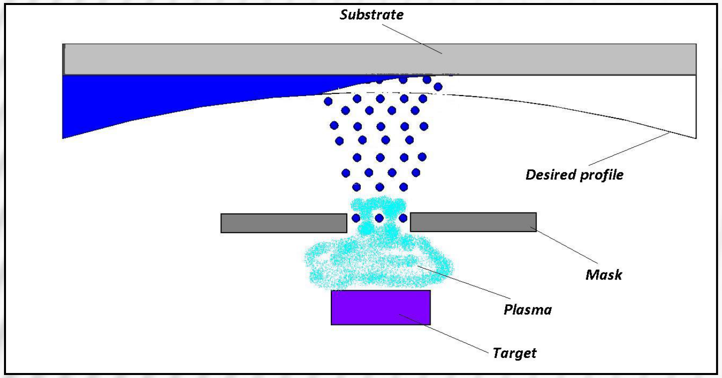
• This will allow us to build a custom system and demonstrate the technique on larger full shell (MSFC) and segmented (GSFC) optics

• We hope to be able to demonstrate < 5 arcsec performance in 3 years

•To go beyond this, (arcsecond level) is very difficult to judge as we have not yet discovered the problems.

- May necessitate in-situ metrology, stress reduction investigations, correcting for gravity effects, correcting for temperature effects
- Some of this will become obvious in early parts of the investigation
- Top-of-head estimate – ~ 5 years total and additional $2-3M

Conclusion



On planar segmented optics

Differential deposition

applicable to

Any reflecting configuration

Cylindrical full shell optics

Segmented optics

to correct

Low and mid order axial figure errors

Azimuthal axial slope variation

Profile generation on conical approximated surfaces

Shell edge effects

Mounting effects