Next Generation X-Ray Optics (NGXO)

Reflective Coating for Lightweight Segmented X-ray Optics

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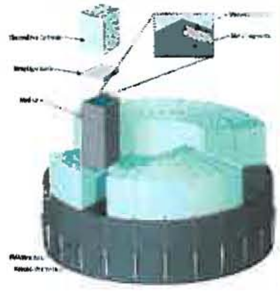
X-Ray Optics for Astronomy

- Next generation x-ray optics for astronomy will require segmented, lightweight optics
- Compact, thin shell => low cost (~ Suzaku)
- High angular resolution is the frontier (~ arc-second)

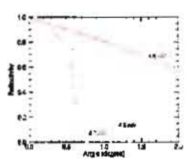
Segmented Thin-Shell Mirror

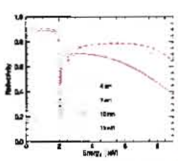


Modular X-ray Telescope

Mirror = Substrate + Reflective Coating

- Precise, thin, large, glass substrates (a few arc-seconds) are now developed and resolution is improving
- Low stress, high-Z coating is needed for x-ray reflection for E < 10 keV. Multi-layer for harder x-ray.
- Requires about 20 nm of single layer film of high-Z metal (e.g., Ir, Pt)

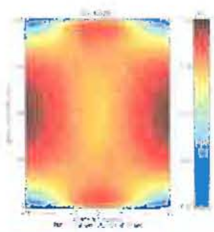




Coating and Angular Resolution

- Does coating matter structurally? For arc-second resolution optics, yes.
- Coating stress ~ GPa (20 nm film) is high enough to distort thin shell mirror
- Example: Sag of ~ 1 µm from 3 Gpa, 20 nm film on 0.4 mm glass substrate of 200 mm long

$$K = \frac{6(1-\upsilon)\sigma\tau_f}{E\tau_s^2}$$

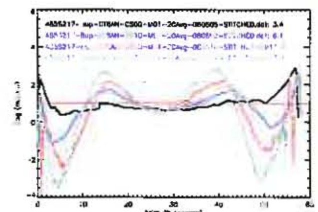


Coating with Magnetron-Sputtering

- Film stresses are high:
  - Ir: ~ 4 GPa (compressive)
  - Cr: ~ 2 GPa (Tensile)
- Successively depositing thicker films on mirrors progressively worsens it axial curvature

Two approaches to eliminate film stress-induced distortion:

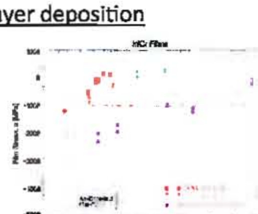
1. Low stress Ir/Cr bi-layer
2. Conformal front and back side deposition

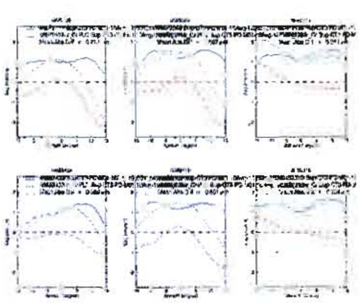


Film	Sample/Method	Thickness (nm)	Stress (GPa)
Ir	[illegible] wafer	20 - 40	-3.5 ± 0.2
Ir	Si wafer	15 - 30	-3.8 ± 0.14
Pt	glass	10 - 30	-3.5 ± 0.5
Cr	glass	10 - 30	1.6 ± 1.1

Low stress Ir/Cr bi-layer deposition

- Take advantage of compressive Ir and tensile Cr
- Combined Ir/Cr bi-layer deposition will produce zero stress film
- Calibration of Cr film with variable thickness reduces the effective stress of Ir/Cr film to within ± 0.1 GPa





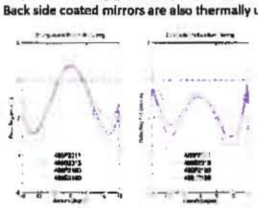
+221 MPa   -426 MPa   -887 MPa

- Direct deposition of Ir/Cr bi-layer film on full-size mirrors
- 3 different stress levels: ≈ +0.2, -0.4, -0.9 GPa
- Full surface heights of mirrors were measured with interferometer (with null lens generating cylindrical wavefront)
- Film-induced axial curvatures are not proportional to stress (issue with thickness calibration)

Sag variation of Mirror, as functions of Azimuths

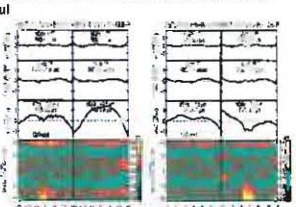
Conformal Front-side and Backside deposition

- Coating-induced distortion of mirror may be balanced by coating both front side and the back side of the mirror
- Requires matching (preferably uniform) thickness and stress distribution over mirror's surfaces
- Back side coated mirrors are also thermally useful



Front and Back side Deposition with Magnetron-sputtering

- Front-side deposition produces sag variation as expected
- Back-side deposition produces consistent, similar sag change
- But magnitudes do not match exactly, especially at middle azimuths
- Geometry difference of mirrors mounted in the coating chamber



Conformal Front and Back Coating with Atomic Layer Deposition (ALD)

- The case for ALD
  - Conformal coating on all surfaces
  - Uniform coat
  - Potentially lower stress
  - Dense and smooth films
- Preliminary results are encouraging
- Currently engaging local facilities and thin film equipment providers for further development

Further Information

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FMA/Modules: Ryan.S.McClelland@nasa.gov

References

[1] William W. Zhang, et al., "Next generation x-ray optics: high-resolution, light-weight, and low-cost", Proc. SPIE 8443-28, (2012).
[2] Ryan S. McClelland, et al., "Design and analysis of modules for segmented glass x-ray optics", Proc. SPIE 8443-144, (2012).
[3] Michael Biskach, et al., " Precise alignment and permanent mounting of thin and lightweight x-ray segments", Proc. SPIE 8443-145, (2012).