Development of Multilayer Coatings for Hard X-ray Optics at NASA Marshall Space Flight Center

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Motivation

Broadband X-ray multilayer coatings are under development at NASA MSFC for use on future astronomical X-ray telescopes. Multilayer coatings deposited onto the reflecting surfaces of X-ray optics can provide a large bandpass enabling observations of higher energy astrophysical objects and phenomena.

STATUS - Calibration and optimization of the new multilayer coating system at MSFC has been completed. Initial periodic multilayers have been deposited with plans to begin regular depth-graded coating runs within the next month.

Deposition Chamber

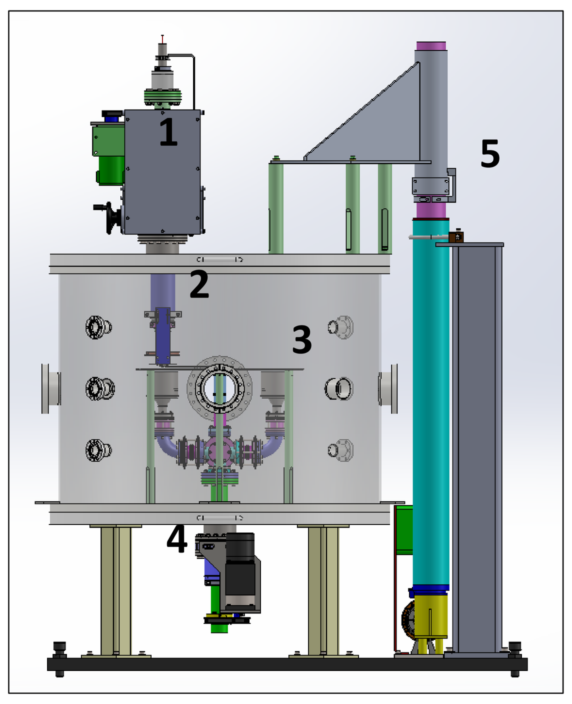

Fig. 1 CAD drawing of multilayer deposition chamber housed at MSFC.

1) Substrate holder motor
2) Rotating substrate holder
3) Cathodes
4) Cathode rotation motor
5) Chamber lid hoist.

- **DC magnetron sputtering system – planetary geometry**
- **Accommodates 1- 4 inch flat substrates**
- **2 cathodes provide single layer and multilayer coating capabilities (2 in diameter targets)**
- **Custom control software allows for precise and efficient deposition runs**

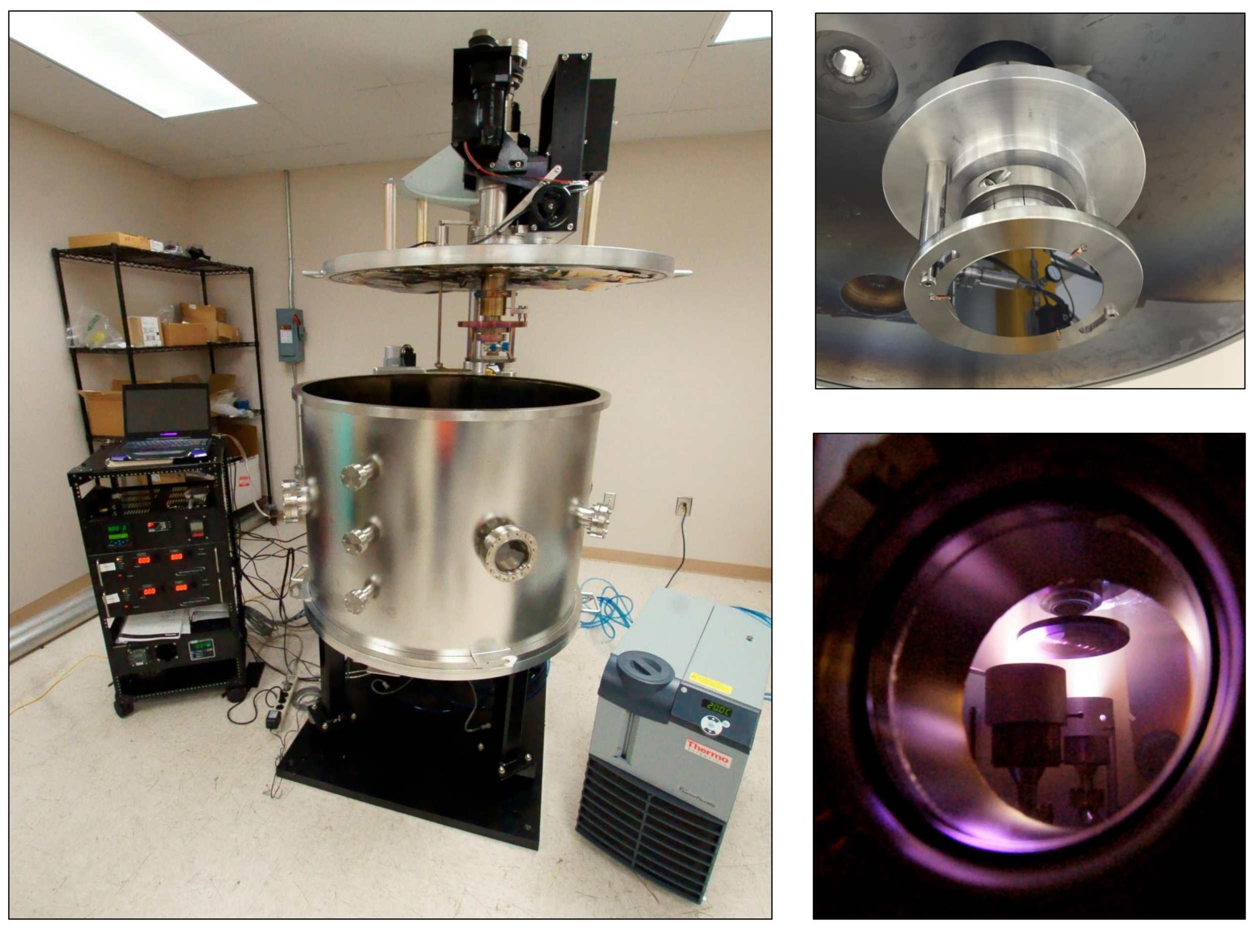

Fig. 2 Left: Multilayer Coating Chamber set-up. Top Right: Rotational substrate holder mounted on lid of chamber. Bottom Right: Lit W and Si cathodes during multilayer deposition run.

Typical Deposition Parameters	
W Cathode Power (W)	50
Si Cathode Power (W)	120
Gas Pressure (mTorr)	2.81
Gas Flow (sccm)	50

Coating Uniformity

Coating uniformity is sensitive to several geometry-dependent parameters:

- Relative vertical and radial position of cathode and substrate
- Distribution of ejected atoms from the target (plume distribution)

Two inch diameter cathodes were selected for this system due to the reduction of operating cost while expanding material research capabilities

Coating Uniformity as a Function of Radial Cathode Position

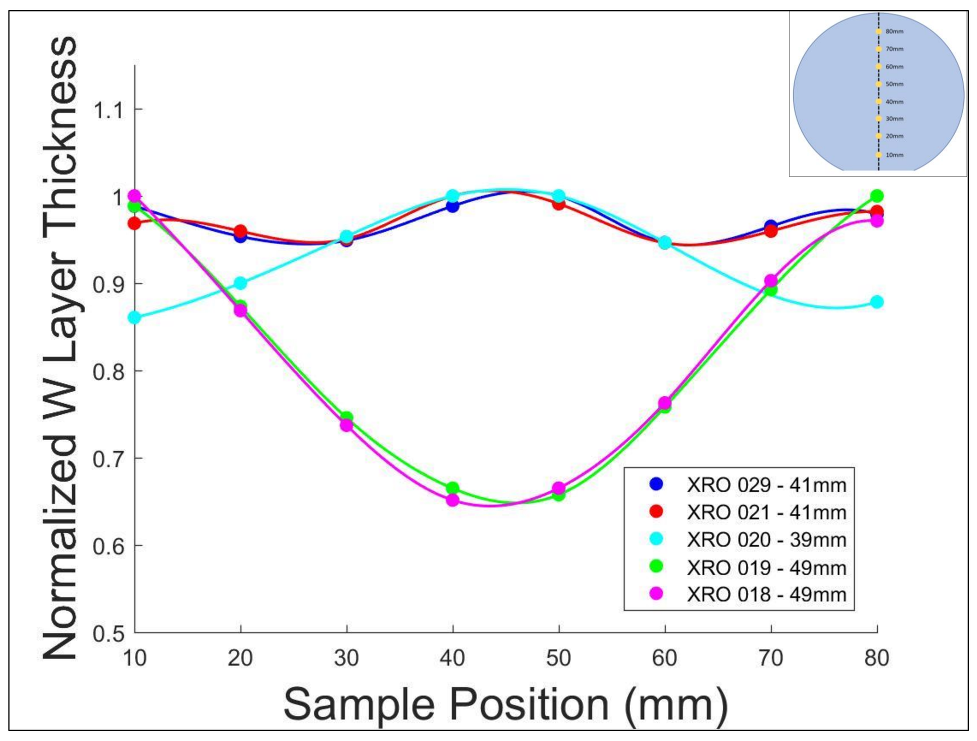

Fig. 3 Layer thickness profiles of single layer W on 4 inch glass substrates. The 50 mm position marks the center of the sample.
Subset: Diagram of 4 inch sample and XRR measurement positions.

- **Layer thickness profiles of single layer W on 4 inch diameter substrates demonstrate how the relative radial position of the cathode affects uniformity**
- **Additional use of a mask or velocity profiling can be implemented to further improve uniformity (less than +/- 1%)**

Target Material Plume Distributions

Used UniformityPro[1] software utility to model coating uniformity, calculate fitting parameter m

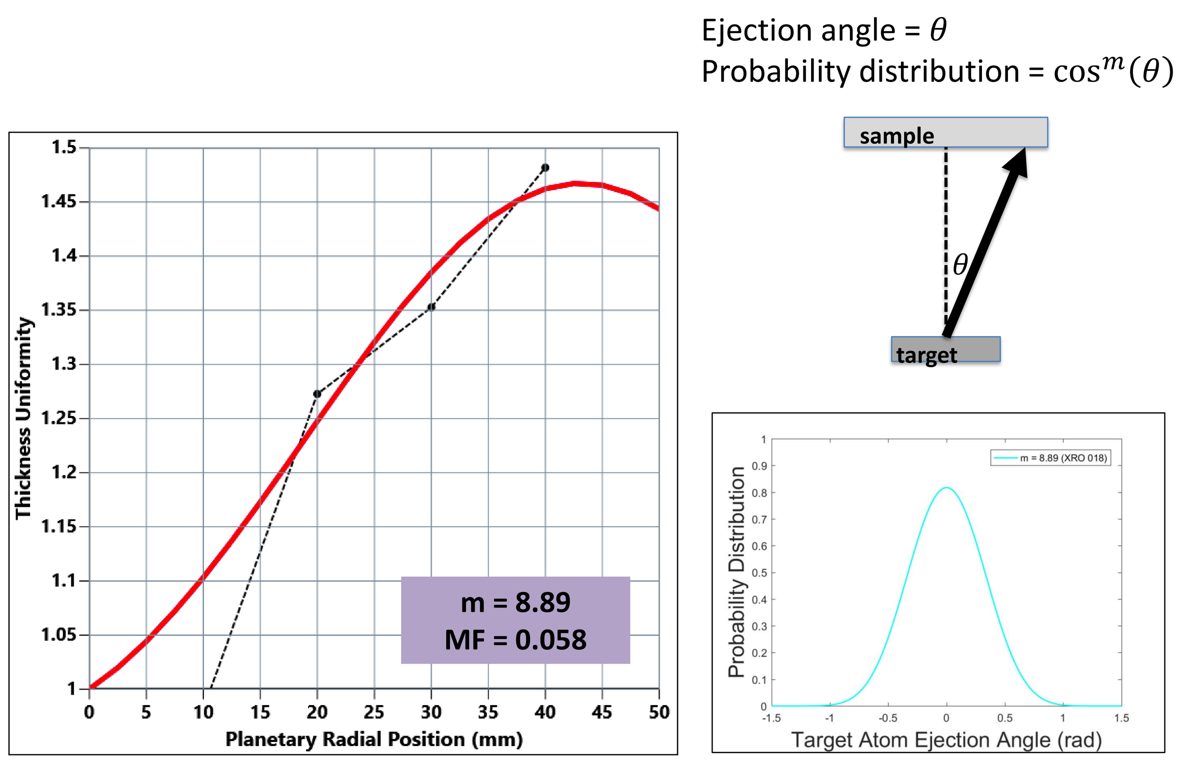

Fig. 4 Left: UniformityPro fit to thickness profile of XRO 018. The resulting fit for m is 0.18. Right top: diagram showing the target atom trajectory in 2D. Right bottom: Probability distribution of ejected atoms from W target. The layer thickness profile from XRO 018 was used in Uniformity Pro[1] to determine the plume distribution parameter, m. These values are then used to calculate the probability distribution.

Periodic W/Si Multilayers

Deposited three periodic W/Si multilayers with various d-spacings for system validation and deposition rate determination

D-spacings were selected within the d-spacing range of NuSTAR flight recipe 10 depth-graded W/Si multilayer[2]

NuSTAR Design + Periodic W/Si Coating Goal Parameters			
Coating ID	D-spacing (Å)	N	Γ
NuSTAR FR 10	75.4 – 25	291	0.38 (top)
XRO 032	45	10	0.38
XRO 034	74.5	20	0.38
XRO 035	25	50	0.38

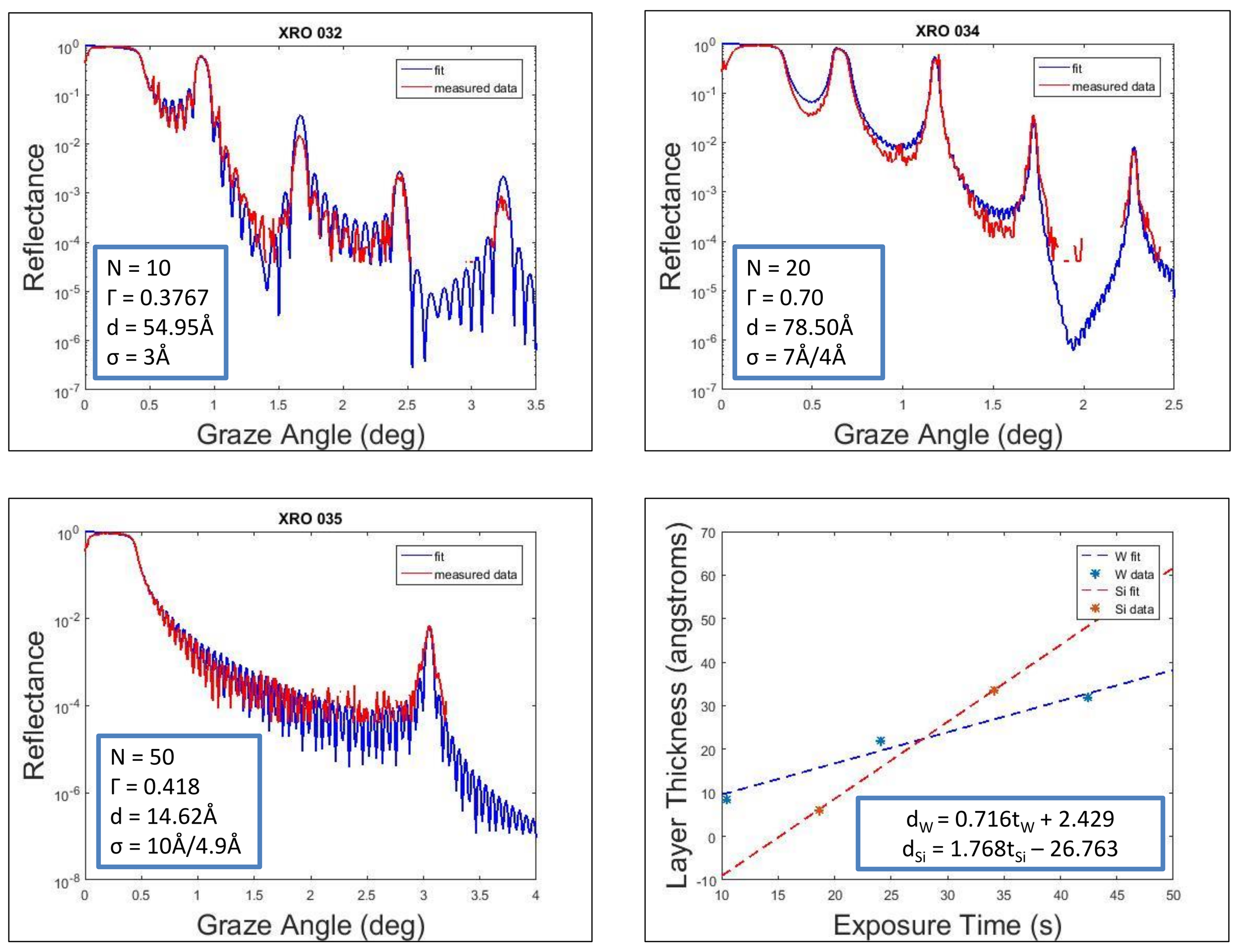

Fig. 5 X-ray reflectivity measurements of three periodic W/Si multilayers, XRO 032, 034, 035. Experimental data is shown in red with the theoretical model fit in blue. The plot on the bottom right shows the fitted d-spacing of each of the three periodic multilayers plotted as a function of the target exposure time over the sample. The slope of the linear fit to these data results in an experimentally accurate deposition rate (Å/s) for each of the two materials.

NuSTAR Flight Recipe 10 is the target design that will be used for validation of the system's depth-graded coating capabilities

Future Work

- **In situ coating stress measurements – configured for rotating substrate holder**
- **System geometry can be changed to accommodate linear cathodes**
- **Ion mill implementation**
- **Inverse solution of deposited depth-graded multilayer structures[3]**

References

1. UniformityPro software. http://www.tablemountainoptics.com /software. shtml
2. Finn E. Christensen, Anders C. Jakobsen, Nicolai F. Brejnholt, Kristin K. Madsen, Allan Hornstrup, et al. "Coatings for the NuSTAR mission", Proc. SPIE8147, Optics for EUV, X-ray, and Gamma-Ray Astronomy V, 8147OU (2011); doi:10.1117/12.894615
3. David M. Broadway, Yuriy Y. Platonov, Vladimir V. Martynov and Pao-Kuang Kuo. "Optimization and analysis of depth-graded multilayer structures", Proc. SPIE5537, X-ray Sources and Optics, 133 (2004); doi:10.1117/12.561446;

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