Improving X-Ray Optics Through Differential Deposition

Brian Ramsey¹, Kiranmayee Kilaru², Carolyn Atkins³, Mikhail V. Gubarev¹, Jessica A. Gaskin¹, Steve O’Dell¹, Martin Weisskopf¹, William Zhang⁴, Suzanne Romaine⁵

¹NASA Marshall Space Flight Center
²NASA Postdoctoral Program Associate
³University of Alabama in Huntsville (Chandra Fellow)
⁴NASA Goddard Space Flight Center
⁵Smithsonian Astrophysical Observatory

X-raySAG / Aug 15, 2012
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

- X-ray testing
- Surface profile metrology
- Develop correction profile “Hitmap”
- Simulations - translation velocity of shell
- Differential deposition
- Surface profile metrology
- X-ray testing
Process sequence - differential deposition

- Before Correction
- After Correction with 5 mm Slit
- After Correction with 2 mm Slit
- After Correction with 1 mm Slit
Process sequence

Diagram showing a family of sputtered beam profiles and a desired coating profile along the axial position along the mirror in millimeters.
### Theoretical performance improvement

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

<table>
<thead>
<tr>
<th>Correction stage</th>
<th>Average deposition amplitude (nm)</th>
<th>Slit-size (mm)</th>
<th>Angular resolution (arc secs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>300</td>
<td>5</td>
<td>3.61</td>
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<tr>
<td>2</td>
<td>40</td>
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</tr>
<tr>
<td>3</td>
<td>4</td>
<td>1</td>
<td>0.22</td>
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<tr>
<td>4</td>
<td>1</td>
<td>0.25</td>
<td>0.14</td>
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</table>
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
- Metrology uncertainty
- Stress effects
Technique is used for synchrotron optics

Optic undergoing metrology

Figure errors after differential coating runs

Slope errors after differential coating runs

From:
A preferential coating technique for fabricating large, high quality optics
S.G. Alcock, S. Cockerton,
NIM A 616, 2010
Proof of concept on full-shell optics

Modify an old coating chamber

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

Demonstration showed that concept works for full shell optics but effectiveness severely limited by stylus profilometer necessary to measure inside the very small diameter medical imaging shells.
General metrology limitation

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

<table>
<thead>
<tr>
<th>Correction stage</th>
<th>Average deposition amplitude (nm)</th>
<th>Slit-size (mm)</th>
<th>Metrology uncertainty (nm)</th>
<th>Angular resolution (arc secs)</th>
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<td>± 0</td>
<td>3.6</td>
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<td>0.2</td>
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<td>± 2</td>
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• 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
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
New coating systems

Vertical chamber for segmented optics

Horizontal chamber for 0.25-m-scale full shell optics
Experimental Stress Measurements of Nickel Thin Films and Associated X-ray Optic Applications
Danielle N. Gurgew
Emory University, Atlanta, GA, 30322

Stress measurements on silicon wafers

Solarius laserscan profilometer

Deformed wafer

Calculated stress

Difference: Si Wafer 2 After - Si Wafer 2 Before
Current Status and Conclusion

• The differential deposition technique can in theory correct shell figures to ~ arcsecond value

• We have received APRA funding and are building two custom system to demonstrate the technique on full shell and segmented optics

• We hope to be able to demonstrate < 5 arcsec performance in < 2 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