NASA Astrophysics Research and Analysis (APRA)

Precision Optical Coatings for Large Space Telescope Mirrors

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R&D Objectives:

• Develop and demonstrate a broadband coating technology, which is scaleable to any size mirror (2-m diameter to 8-m diameter, limited only by the size of the vacuum chamber)

• Achieve as close to TRL-6 as possible within 3-years by making coatings and testing them in relevant environments such as simulated space radiation, ground-storage humidity, etc.
ZeCoat innovations for large FUV mirror coating:

- Motion-controlled evaporation process for applying precision dielectric coatings, adhesion layers, etc.
- Battery-powered hexagonal filament array for making the aluminum reflector
ZeCoat’s moving source technology to applies a very thin layer, quickly over a 1.1-m diameter area (process scalable to any size mirror)
NiCr layer thickness

### Average thickness (nm)

<table>
<thead>
<tr>
<th>Layers</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>5</th>
<th>6</th>
<th>8</th>
<th>8</th>
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</thead>
<tbody>
<tr>
<td>Radial</td>
<td>3</td>
<td>1.51</td>
<td>3.01</td>
<td>4.25</td>
<td>6.90</td>
<td>8.18</td>
<td>10.38</td>
<td>10.67</td>
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<tr>
<td>Position (cm)</td>
<td>16</td>
<td>1.80</td>
<td>3.17</td>
<td>4.83</td>
<td>7.43</td>
<td>8.85</td>
<td>11.41</td>
<td>11.56</td>
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<td>2.80</td>
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<td>6.50</td>
<td>7.88</td>
<td>10.16</td>
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</table>

### Average thickness per layer (nm)

<table>
<thead>
<tr>
<th>Layers</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>5</th>
<th>6</th>
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<th>8</th>
<th>8</th>
<th>Avg</th>
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</thead>
<tbody>
<tr>
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<td>1.51</td>
<td>1.51</td>
<td>1.42</td>
<td>1.38</td>
<td>1.36</td>
<td>1.30</td>
<td>1.33</td>
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<td>Position (cm)</td>
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<td>1.59</td>
<td>1.61</td>
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<td>1.48</td>
<td>1.43</td>
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<tr>
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<td>33</td>
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<td>1.46</td>
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<td>1.36</td>
<td>1.30</td>
<td>1.30</td>
<td>1.38</td>
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<tr>
<td>Avg</td>
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<td>1.46</td>
<td>1.47</td>
<td>1.38</td>
<td>1.38</td>
<td>1.32</td>
<td>1.34</td>
<td>1.42</td>
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</table>
ZeCoat’s Battery-powered Deposition (BPD)
Why use batteries to make aluminum?

- High evaporation rates possible (1,000+ A/sec)
- Small coating thickness variation possible
- (need many sources to coat large mirrors 2 to 8-meters)
- No excessive line-power facilities
- No large transformers
- No large conductors needed to carry high amps
- Less outgassing during process
- Placement in hexagonal pattern improves coating uniformity
Battery-powered deposition unit for aluminum coating
Polar Interpolation Thickness Distributions
Small plume results continued
Evaporation source placement map

(37) plumes over 2.4-meters, 5% PTV, 1.64-m flat diameter

(139) plumes over 2.4-meters, 2% PTV, 1.8-m flat diameter
Multi-ring thickness optimization

9-rings, 61-sources

2.4-m source diameter, 2.0-m flat area, +/- 2.85%,
Why do we need high evaporation rates to make FUV-quality aluminum?

<table>
<thead>
<tr>
<th>Al evap. rate (Å/sec)</th>
<th>Reflectance (%) @ 200nm</th>
<th>Reflectance (%) @ 400nm</th>
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<tbody>
<tr>
<td>40</td>
<td>82.7</td>
<td>91</td>
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<td>65</td>
<td>87.6</td>
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<tr>
<td>125</td>
<td>90.2</td>
<td>91.8</td>
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</table>

~$10^{-6}$ torr vacuum

Reference: Dr. Andrew Phillips, University of California Observatories, 2015.

Evaporation rate dependence of measured reflectance at 190nm unprotected aluminum coating

~$10^{-9}$ torr vacuum

Importance of quickly protected an aluminum film once its made in the vacuum chamber

Oxidation of aluminum film in 5x10^-7 torr vacuum

Fundamental limits of fluoride-protected aluminum coatings

The need for very thin protection schemes for telescopes operating below 105-nm

Future plans

• 6-meter vacuum chamber capable of uniformly coating up to 5-meter HabEx mirror
• Moving ZeCoat to St. Louis, Mo. in spring of 2019
• New facility located directly on the Mississippi river and includes the use of a $45M barge dock
• 8,000 square feet with a 30’ (~ 9-m) tall high-bay for housing the 6-meter chamber
QUESTIONS?