Comparative Mirror Cleaning Study

"A Study on Removing Particulate Contamination"

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Outline

- Introduction
  - Optical Devices
  - Contamination Effects of Optical Surfaces
- Experimental Design
  - Test Plan
  - Cleaning Procedures
  - Verification Instrument
- Design of Experiments (DOE) Software
  - Jump/Statistical Analytical Software (JMP/SAS)
- Results
- Conclusions
- Recommendations
- Future Work
Introduction

Optical Devices
- Mirrors and telescopes
- Microscope and lenses
- Lasers and interferometers
- Prisms and optical filters

Optical Industry
The cleanliness of optical surfaces is recognized as an industry wide-concern for performance of optical devices:
- No established standard for optical cleaning
- No standard definition of a “clean” optical element

Advantages of Experimental Study…
- It evaluates the effectiveness of commonly used optical cleaning techniques based on wafer configuration, contamination levels, and the number and size of removed particles
- The results can help ensure mission success to flight projects developed for the NASA Origins Program (JWST, SAFIR, etc.)
1. Molecular Contamination: Accumulation of submicron particles (i.e. Water, hydrocarbons, and silicones)
   - a. Absorptive Effects (Transmissive Surface)
   - b. Absorptive Effects (Reflective Surface)

2. Particulate Contamination: Conglomerate of visible sized particles (e.g. Dust)
   - a. Obscuration Effects
   - b. Scattering Effects
Experimental Objective:
To compare the effectiveness in removing particulate contamination from coated and uncoated silicon wafers with commonly used optical cleaning methods.

Technical Objectives:
- Determine the cleaning ability of each method based on the number and size of removed particles
- Assess the risk of surface damage for each cleaning procedure
- Evaluate each method as a function of its initial contamination level ("fairly clean", "dirty", "very dirty")

Experimental Process:
- Contaminate wafers
- Characterize surface (Measure and count number of particles)
- Clean wafers
- Characterize surface
Experimental Design

Cleaning Methods
- Detergent Bath
- Solvent Rinse
- CO$_2$ Snow Cleaning

Wafer Configuration
- (12) - Silicon (Si)
- (12) - Gold coated silicon wafer (Si+Au)
- (12) - Gold coated silicon wafer with a silicon oxide coating (Si+Au+SiOx)

Table 1: Wafer Specifications

<table>
<thead>
<tr>
<th>Wafer Properties</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness</td>
<td>500 µm</td>
</tr>
<tr>
<td>Diameter</td>
<td>4&quot;</td>
</tr>
<tr>
<td>Coating Thickness</td>
<td></td>
</tr>
<tr>
<td>Gold Coating</td>
<td>2000 Å</td>
</tr>
<tr>
<td>Silicon Oxide Coating</td>
<td>1000 Å</td>
</tr>
</tbody>
</table>

Exposure Times
- 1 day, 3 days, and 5 days (Building 7 Highbay)
Design of Experiments (DOE) Software

Sample Size (Total Sample Size = 36 wafers)
- Calculated by specifying a 95% Upper Confidence Level
  - 13 DOF: Number of values in final calculation that are free to vary

Randomization Table
- Randomly paired cleaning methods with wafer configurations and exposure time
- Divided into 9 blocks
  - Each block has 4 wafers

Table 2: Example of Block Format

<table>
<thead>
<tr>
<th>Cleaning Method</th>
<th>Wafer Configuration</th>
<th>Exposure Time</th>
<th>Y (Response)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rinse</td>
<td>Si+Au+SiOx</td>
<td>3</td>
<td>•</td>
</tr>
<tr>
<td>CO2</td>
<td>Si+Au</td>
<td>5</td>
<td>•</td>
</tr>
<tr>
<td>Bath</td>
<td>Si+Au+SiOx</td>
<td>1</td>
<td>•</td>
</tr>
<tr>
<td>Bath</td>
<td>Si</td>
<td>5</td>
<td>•</td>
</tr>
</tbody>
</table>

JMP/Statistical Analytical Software
- Simultaneously compares input variables
Mirror Cleaning Procedure (1)

Detergent Bath

Direct contact method that uses an aqueous based, nonionic detergent to remove contamination

Pre-Clean Preparation¹:
1. Alconox Solution
   a. 5 grams of Alconox detergent
   b. 4 cups of distilled water
2. Rinse Solution - 2 cups of distilled water at 120 °F

Cleaning Process:
1. Wafer submerged in Alconox Solution
2. Q-tip placed directly on wafer at a 20°; Surfaces cleaned using a multi-directional wiping technique for 1 minute
3. Wafer rinsed 10x’s in distilled water
4. Water vertically positioned (at a 10-15° angle) for drying (~15 min)

¹ NASA/GSFC Optical Component Cleaning (551-WI-8072.1.7B)
Mirror Cleaning Procedure (2)

Solvent Rinse

Direct contact method that uses an aqueous based, nonionic detergent and an acetone rinse to remove contamination

Pre-Clean Preparation¹:
1. Alconox Solution
   a. 5 g of Alconox detergent
   b. 4 cups of distilled water
2. Rinse Solution - 2 cups of distilled water at 120 °F

Cleaning Process:
1. Wafer submerged in Alconox Solution
2. Q-tip placed directly on wafer at a 20° angle; Surfaces cleaned using a multidirectional wiping technique for 1 minute
3. Wafer rinsed 10x’s in distilled water
4. Water vertically positioned (at a 10-15° angle) for drying
5. Wafer rinsed with 4fl. oz of IPA grade acetone in a top-bottom, left-right pattern

¹ NASA/GSFC Optical Component Cleaning (551-WI-8072.1.7B)

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CO₂ Snow Cleaning

Non-contact method that uses a high velocity stream of CO₂ gas and snow pellets to remove contamination

Pre-Clean Preparation:
1. Place vacuum chuck on hot plate; turn hotplate on “High” setting (120 °F). Let warm-up for 15-20 minutes

Cleaning Process:
1. Place wafer on vacuum chuck; power on motor
2. Open pressure valve on CO₂ cylinder tank
3. Position nozzle at the upper right hand corner (30° angle; 2” from surface)
4. Open CO₂ circuit using footswitch
5. Clean entire wafer surface using 7 vertical strokes; surface cleaned in a top-bottom, right-left pattern
Verification - Image Analysis

Image Analysis (IA) is a verification instrument that incorporates the use of a microscope, camera, and computer to measure the size, shape, and number of particles.

**IA Specifications:**
- Leica camera/CCD
- Olympus microscope (5X Obj; 50 Mag)
  - Detects 0.3\(\mu\)m particles at 95% certainty
- Robotic stage

**Facility Specifications:**
- Building 84 Cleanroom
- Class 10,000
- Avg. RH: 44%
- Average Temp: 69 °F
- Laminar Flow: 135-150 ft/min

\[
PAC = \frac{\text{Total Area of Particles}}{\text{Total Surface Area}} \times 100
\]

*Figure 1: IA Reading Area*
## Results – Detergent Bath

### Table 3: PAC Removal Percentage of Detergent Bath Samples

<table>
<thead>
<tr>
<th>Wafer Configuration</th>
<th>Exposure Time</th>
<th>PAC (Before Cleaning)</th>
<th>PAC (After Cleaning)</th>
<th>Efficiency Removal %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>5</td>
<td>0.23924</td>
<td>0.08072</td>
<td>66</td>
</tr>
<tr>
<td>Si+Au</td>
<td>3</td>
<td>0.09553</td>
<td>0.01502</td>
<td>84</td>
</tr>
<tr>
<td>Si+Au+SiOx</td>
<td>5</td>
<td>0.09312</td>
<td>0.01560</td>
<td>83</td>
</tr>
<tr>
<td>Si+Au+SiOx</td>
<td>1</td>
<td>0.08290</td>
<td>0.01974</td>
<td>76</td>
</tr>
<tr>
<td>Si</td>
<td>5</td>
<td>0.07863</td>
<td>0.03506</td>
<td>55</td>
</tr>
<tr>
<td>Si+Au</td>
<td>3</td>
<td>0.06028</td>
<td>0.02268</td>
<td>62</td>
</tr>
<tr>
<td>Si</td>
<td>3</td>
<td>0.04832</td>
<td>0.04448</td>
<td>8</td>
</tr>
<tr>
<td>Si+Au+SiOx</td>
<td>3</td>
<td>0.04033</td>
<td>0.05241</td>
<td>----</td>
</tr>
<tr>
<td>Si+Au+SiOx</td>
<td>1</td>
<td>0.02070</td>
<td>0.01017</td>
<td>51</td>
</tr>
<tr>
<td>Si</td>
<td>1</td>
<td>0.01020</td>
<td>0.01460</td>
<td>----</td>
</tr>
<tr>
<td>Si+Au</td>
<td>1</td>
<td>0.00454</td>
<td>0.01077</td>
<td>----</td>
</tr>
<tr>
<td><strong>Average Removal %</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>61</strong></td>
</tr>
</tbody>
</table>
Table 4: Particle Count for Sample B5_23_Si.Au_3D (67% PAC Reduction)

<table>
<thead>
<tr>
<th>Range of Particle Sizes (microns)</th>
<th>Total # of Particles (Before Cleaning)</th>
<th>Total # of Particles (After Cleaning)</th>
<th>Removal Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0 \leq x \leq 1$</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$1 \leq x \leq 5$</td>
<td>54</td>
<td>1770</td>
<td>-</td>
</tr>
<tr>
<td>$5 \leq x \leq 10$</td>
<td>482</td>
<td>782</td>
<td>-</td>
</tr>
<tr>
<td>$10 \leq x \leq 25$</td>
<td>656</td>
<td>326</td>
<td>50</td>
</tr>
<tr>
<td>$25 \leq x \leq 50$</td>
<td>542</td>
<td>231</td>
<td>57</td>
</tr>
<tr>
<td>$50 \leq x \leq 100$</td>
<td>420</td>
<td>29</td>
<td>93</td>
</tr>
<tr>
<td>$100 \leq x \leq 150$</td>
<td>211</td>
<td>2</td>
<td>99</td>
</tr>
<tr>
<td>$150 \leq x \leq 250$</td>
<td>235</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>$250 \leq x \leq 500$</td>
<td>245</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>$500 \leq x \leq 750$</td>
<td>125</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>$\geq 750$</td>
<td>146</td>
<td>1</td>
<td>99</td>
</tr>
<tr>
<td>Total No. of Particles</td>
<td>3116</td>
<td>3141</td>
<td>-</td>
</tr>
<tr>
<td>PAC (Cleanliness Lvl)</td>
<td>0.06 (375)</td>
<td>0.02 (300)</td>
<td>67</td>
</tr>
</tbody>
</table>
Figure 2: Average Particle Distribution for the Detergent Bath Samples
# Results – Solvent Rinse

Table 5: PAC Removal Percentage of Solvent Rinse Samples

<table>
<thead>
<tr>
<th>Wafer Configuration</th>
<th>Exposure Time</th>
<th>PAC (Before Cleaning)</th>
<th>PAC (After Cleaning)</th>
<th>Efficiency Removal %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si+Au</td>
<td>5</td>
<td>0.12063</td>
<td>0.00815</td>
<td>93</td>
</tr>
<tr>
<td>Si+Au+SiOx</td>
<td>3</td>
<td>0.08629</td>
<td>0.02234</td>
<td>74</td>
</tr>
<tr>
<td>Si+Au</td>
<td>5</td>
<td>0.07477</td>
<td>0.01800</td>
<td>76</td>
</tr>
<tr>
<td>Si</td>
<td>5</td>
<td>0.06177</td>
<td>0.00013</td>
<td>100</td>
</tr>
<tr>
<td>Si</td>
<td>3</td>
<td>0.06071</td>
<td>0.00718</td>
<td>88</td>
</tr>
<tr>
<td>Si+Au</td>
<td>3</td>
<td>0.04662</td>
<td>0.01021</td>
<td>78</td>
</tr>
<tr>
<td>Si+Au+SiOx</td>
<td>5</td>
<td>0.04414</td>
<td>0.01301</td>
<td>71</td>
</tr>
<tr>
<td>Si+Au+SiOx</td>
<td>5</td>
<td>0.04271</td>
<td>0.00171</td>
<td>96</td>
</tr>
<tr>
<td>Si</td>
<td>1</td>
<td>0.03862</td>
<td>0.03458</td>
<td>10</td>
</tr>
<tr>
<td>Si+Au</td>
<td>3</td>
<td>0.03226</td>
<td>0.00582</td>
<td>82</td>
</tr>
<tr>
<td>Si+Au+SiOx</td>
<td>1</td>
<td>0.02965</td>
<td>0.01254</td>
<td>58</td>
</tr>
<tr>
<td>Si+Au+SiOx</td>
<td>1</td>
<td>0.01209</td>
<td>0.00497</td>
<td>59</td>
</tr>
<tr>
<td><strong>Average Removal %</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>74</strong></td>
</tr>
</tbody>
</table>
Table 6: Particle Count for Sample B1_5_Si.Au.SiOx_3D (74% PAC Reduction)

<table>
<thead>
<tr>
<th>Range of Particle Sizes (microns)</th>
<th>Total # of Particles (Before Cleaning)</th>
<th>Total # of Particles (After Cleaning)</th>
<th>Removal Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 ≤ x ≤ 1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1 ≤ x &lt; 5</td>
<td>2026</td>
<td>2596</td>
<td>-</td>
</tr>
<tr>
<td>5 ≤ x ≤ 10</td>
<td>1409</td>
<td>660</td>
<td>53</td>
</tr>
<tr>
<td>10 ≤ x ≤ 25</td>
<td>995</td>
<td>278</td>
<td>72</td>
</tr>
<tr>
<td>25 ≤ x ≤ 50</td>
<td>418</td>
<td>58</td>
<td>86</td>
</tr>
<tr>
<td>50 ≤ x ≤ 100</td>
<td>119</td>
<td>33</td>
<td>72</td>
</tr>
<tr>
<td>100 ≤ x ≤ 150</td>
<td>13</td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td>150 ≤ x ≤ 250</td>
<td>12</td>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td>250 ≤ x ≤ 500</td>
<td>14</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>500 ≤ x ≤ 750</td>
<td>6</td>
<td>2</td>
<td>67</td>
</tr>
<tr>
<td>≥ 750</td>
<td>8</td>
<td>4</td>
<td>50</td>
</tr>
<tr>
<td>Total No. of Particles</td>
<td>5020</td>
<td>3665</td>
<td>-</td>
</tr>
<tr>
<td>PAC (Cleanliness Lvl)</td>
<td>0.086 (415)</td>
<td>0.022 (310)</td>
<td>74</td>
</tr>
</tbody>
</table>
Figure 3: Average Particle Distribution for the Solvent Rinse Samples
# Results – CO₂ Snow Cleaning

Table 7: PAC Removal Percentage of CO₂ Snow Cleaning Samples

<table>
<thead>
<tr>
<th>Wafer Configuration</th>
<th>Exposure Time</th>
<th>PAC (Before Cleaning)</th>
<th>PAC (After Cleaning)</th>
<th>Efficiency Removal %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si+Au</td>
<td>5</td>
<td>0.19466</td>
<td>0.00716</td>
<td>74</td>
</tr>
<tr>
<td>Si+Au+SiOx</td>
<td>5</td>
<td>0.07471</td>
<td>0.00555</td>
<td>93</td>
</tr>
<tr>
<td>Si</td>
<td>3</td>
<td>0.06550</td>
<td>0.00261</td>
<td>96</td>
</tr>
<tr>
<td>Si+Au</td>
<td>1</td>
<td>0.06086</td>
<td>0.00414</td>
<td>93</td>
</tr>
<tr>
<td>Si+Au+SiOx</td>
<td>1</td>
<td>0.03851</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Si+Au</td>
<td>5</td>
<td>0.03823</td>
<td>0.00554</td>
<td>86</td>
</tr>
<tr>
<td>Si+Au+SiOx</td>
<td>3</td>
<td>0.03606</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Si</td>
<td>5</td>
<td>0.03522</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Si+Au+SiOx</td>
<td>3</td>
<td>0.03380</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Si+Au</td>
<td>1</td>
<td>0.01034</td>
<td>0.00284</td>
<td>73</td>
</tr>
<tr>
<td>Si</td>
<td>3</td>
<td>0.01139</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Si</td>
<td>1</td>
<td>0.00317</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Average Removal %</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>86</strong></td>
</tr>
</tbody>
</table>
### Table 8: Particle Count for Sample B4_19_Si.Au_5D (86% PAC Reduction)

<table>
<thead>
<tr>
<th>Range of Particle Sizes (microns)</th>
<th>Total # of Particles (Before Cleaning)</th>
<th>Total # of Particles (After Cleaning)</th>
<th>Removal Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0 \leq x \leq 1$</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$1 \leq x \leq 5$</td>
<td>1184</td>
<td>1126</td>
<td>5</td>
</tr>
<tr>
<td>$5 \leq x \leq 10$</td>
<td>997</td>
<td>1028</td>
<td>-</td>
</tr>
<tr>
<td>$10 \leq x \leq 25$</td>
<td>739</td>
<td>942</td>
<td>-</td>
</tr>
<tr>
<td>$25 \leq x \leq 50$</td>
<td>277</td>
<td>901</td>
<td>-</td>
</tr>
<tr>
<td>$50 \leq x \leq 100$</td>
<td>46</td>
<td>7</td>
<td>85</td>
</tr>
<tr>
<td>$100 \leq x \leq 150$</td>
<td>10</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>$150 \leq x \leq 250$</td>
<td>10</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>$250 \leq x \leq 500$</td>
<td>5</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>$500 \leq x \leq 750$</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$\geq 750$</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total No. of Particles</strong></td>
<td><strong>3272</strong></td>
<td><strong>4004</strong></td>
<td>-</td>
</tr>
<tr>
<td><strong>PAC (Cleanliness Lvl)</strong></td>
<td><strong>0.038 (335)</strong></td>
<td><strong>0.006 (225)</strong></td>
<td><strong>84</strong></td>
</tr>
</tbody>
</table>
Figure 4: Average Particle Distribution for CO2 Snow Cleaning Samples
Control Wafers

Environmental Controls
Monitors particulate fallout from surrounding air during image analysis reading

Table 9: PAC Values for Environmental Controls

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>IA Reading Time (Hrs:Min)</th>
<th>PAC Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block 2</td>
<td>4:47</td>
<td>0.006615</td>
</tr>
<tr>
<td>Block 5</td>
<td>4:43</td>
<td>0.006966</td>
</tr>
<tr>
<td>Block 3</td>
<td>5:10</td>
<td>0.009732</td>
</tr>
<tr>
<td>Block 4</td>
<td>5:43</td>
<td>0.009523</td>
</tr>
</tbody>
</table>

Each Block includes 4 wafers

Cleaning Controls
Determines amount of introduced contamination from the cleaning materials

Table 10: PAC Values for Cleaning Controls

<table>
<thead>
<tr>
<th>Cleaning Process</th>
<th>$\text{PAC}_{\text{Before}}$</th>
<th>$\text{PAC}_{\text{After}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detergent Bath</td>
<td>0.000</td>
<td>0.011494</td>
</tr>
<tr>
<td>Solvent Rinse</td>
<td>0.000</td>
<td>0.009231</td>
</tr>
<tr>
<td>CO$_2$ Snow Cleaning</td>
<td>----</td>
<td>----</td>
</tr>
</tbody>
</table>

PAC = $\frac{\text{Total Area of Particles}}{\text{Total Surface Area}} \times 100$
Comparative Results

Figure 5: Regression Plot of Effective Removal Percentage

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Conclusions

- Cleaning method and exposure time plays a significant factor in obtaining a high removal percentage.
  - The detergent bath and solvent rinse method displayed an increase in effective removal percentage as the contamination exposure increased.
  - CO₂ snow cleaning showed a relatively consistent cleaning effectiveness.

- For optimal removal of particulate contamination, the following settings should be used:
  - CO₂ Snow Cleaning
  - Si+Au+SiOₓ
  - 1 Day Exposure Time
**Table 11: Advantages and Disadvantages of Optical Cleaning Methods**

<table>
<thead>
<tr>
<th>Cleaning Method</th>
<th>Description</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Detergent Bath          | Direct contact method that uses an aqueous based, nonionic detergent to loosen contaminants from the surface. | • “Free Rinsing” capability  
                          • Reduces “creep” contamination | • N/A to large/complex optics  
                          • Excessive handling  
                          • Direct contact increases risk of surface damage  
                          • Cleaning materials could introduce contamination |
| Solvent Rinse           | Direct contact method that uses an aqueous based, nonionic detergent and solvent rinse to loosen contaminants from the surface. | • “Free Rinsing” capability  
                          • Reduces “creep” contamination  
                          • Rapid/spot free drying  
                          • Removes some molecular contamination | • N/A to large or complex optics  
                          • Excessive handling  
                          • Direct contact increases risk of surface damage  
                          • Cleaning materials could introduce contamination  
                          • Excessive use of solvent could create water spots |
| CO₂ Snow Cleaning       | Non-contact method that uses a high velocity stream of CO₂ solid and gas; removing contamination through momentum transfer. | • Reduced risk of surface damage  
                          • Removes fingerprints  
                          • No waste  
                          • Quick cleaning process | • Requires controlled environ.  
                          • Electrostatic charge  
                          • Introduction of gas constituents |
Recommendations

Detergent Bath
- Select low or non-particulating cleaning materials
- Use a nitrogen purge gas during drying process

Solvent Rinse
- Select low or non-particulating cleaning materials
- Use a nitrogen purge gas during drying
- Use filtered solvents
- Use a certified clean storage method for solvent

CO\textsubscript{2} Snow Cleaning
- Perform cleaning in a dry box or with a nitrogen purge
- Develop a working instruction for the CO\textsubscript{2} cleaning procedures
Future Work

- SPIE Optics and Photonics Conference in San Diego, CA (August 2006)
- Perform a repetitive mirror cleaning study
- Develop a cleaning procedure for JWST’s Optical Telescope Element
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- George Harris, Coatings Engineer/Code 546

THANK YOU!
References


Back-Up Slides
James Webb Space Telescope
Secondary Mirror Support Structure (SMSS)
- Boron/M55J for thermal stability
- Simple four-bar linkage deployment

WFS&C Subsystem
- Simple steps
- Deterministic
- Four ISIM weak lenses and DHS

Secondary Mirror Assembly (SMA)
- Light-weighted, rigid Be mirror
- Hexapod actuator configuration
  - Six-DoF control for alignment
- Stray light baffle
- Rigid delta frame support w/simple interface to SMSS

Primary Mirror Segment Assemblies (PMSA)
- Light-weighted, semi-rigid segments
- 18 modular units make up PM
- Separable rigid body and RoC figure control
  - Hexapod rigid body actuation, one RoC actuator
- Simple, accessible interface to Backplane

Aft Optics Subsystem
- Fixed tertiary
- Fine steering mirror
- PM baffle
- ISIM bench radiator

OTE Clear Aperture: 25 m²

ISIM Enclosure
- ISIM Instrument Suite
  - NIRSpec
  - NIRCam
  - MIRI
  - FGS
- ISIM radiators

Deployment Tower Subsystem
- Simple, two-piece telescoping tube
- T300 for low conductivity
- Bi-stem deployed
  - Slenderness ratio <60

BackPlane
- Chord-fold deployment
  - Minimizes mechanisms
  - Maximizes thermal connectivity
- Boron/M55J hybrid material
  - CTE <0.1 ppm/K
  - High stiffness
    (near Be, 2X M55J)
Contamination Requirements

JWST Mission Requirements Document
JWST-RQMT-000634

- MRD-51 Observatory Sensitivity (particulate)
- MRD-121 Stray Light (particulate)
- MRD-211 Optical Transmission (molecular, water ice)

Derived End-of-Life (EOL) Requirements

- Particulate (1.0 PAC for PM, SM; 0.32 PAC TM, FSM)
- Molecular (400 angstroms)
- Water Ice (400 angstroms)

JWST Observatory Contamination Control Plan
(JWST-PLAN-002028)

Contamination Allowances
I&T Budget Observatory Elements and Subsystems

Implementation
Design, Facility, Personnel, MGSE & Operational Controls

Verification
Contamination Monitoring Plan, D40608
Predicted PAC (%) for Worst Case PM Segment
Assumes Cup Up I&T, No Cleaning, Facilities Currently Baselined,
Idealized (requested in DUA) and Conservative (more realistic) Launch Phase Particle Redistribution
Predicted PAC (%) for Worst Case PM Segment

Assumes Cup Up I&T, No Cleaning, Facilities Currently Baseline,
Idealized (requested in DUA) and Conservative (more realistic) Launch Phase Particle Redistribution

July 17, 2007
2007 Contamination and Coatings Workshop