Development of stacked core technology for the fabrication and processing of deep lightweight UV quality space mirrors

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Advanced UVOIR Mirror Technology Development (AMTD) Program

• Develop mirror blank technology applicable to building a cost effective, large (4m-8m class), passive, monolithic mirror capable of imaging in the UV spectrum
  ▪ 0.43m demonstration mirror fabricated
  ▪ 5.5nm RMS overall surface figure demonstrated

• Current limitations regarding a 4m class mirror
  ▪ Significant mirror depth required to achieve stiffness
  ▪ Core depth drives up cutting costs, schedule, risk, and areal density
  ▪ Stack sealing of boules to achieve overall depth is very expensive and time consuming

• AMTD program addresses these issues to reduce the cost and lead time for building a 4m class mirror blank and demonstrates the ability to polish and test the blank to UV quality
Large Lightweight ULE® Primary Mirrors at Exelis

High Temperature Fusion – 1970’s
(Hubble Primary Mirror)

Frit Technology with Flame Welded Core – 1980’s

Waterjet Cut Core – Low Temp Fusion Development – 1990’s

Primary Mirror – Low Temp Fusion – 2000’s
AMTD is Developing Technologies for Near Term Large Lightweight Primary Mirrors

Stacked core

> Core segments are fabricated from standard thickness boules, then stacked & fused during blank assembly to achieve a deep core
> Eliminates need for stack sealing of boules and deep Abrasive Water Jet (AWJ) cutting of cores
> Enables lighter weight cores and reduces cost & schedule for blank fab

Deep AWJ Cutting

> Extend AWJ cutting depth for LW cores from current 300mm (11.6 in) up to 480mm (19 in) depending on mirror stiffness
> More difficult to control exit surface parameters
4m Mirror Concept

4m Mirror Physical Attributes
- Pocket Milled Facesheet allows larger core cells while controlling quilting
- 12 Core Segments
- 3 Stacked Core Deep
- 10m RoC (F#1.25)

- Fabrication risk reduced by eliminating stack sealing and deep core cutting
- Reduced glass needs for tooling glass
Dynamic Considerations

4m Dynamic Performance
- 3 layer core
  - 35 kg/m²
  - 137 Hz First Free-Free Mode
- 4 layer core
  - 43 kg/m²
  - 150 Hz First Free-Free Mode

Mirror Dynamic Sensitivity
- First order first mode frequency generated for a variety of mirrors
- Provides some insight into sensitivity of thickness and first mode
- Some impact to areal density and limit to overall frequency

System Dynamic Control
- At large sizes, the mirror dynamics may not be the biggest problem
- A system approach is recommended
- Exelis active dynamic control is at TRL8

- Limited leverage at this scale to increase first mode frequency
- Active Dynamic Control measures likely needed at system level
AMTD 8m Mirror Design and Analysis

- Stacked core and Pocket milled facesheet design
- 24.2m RoC (f#1.5)
- The 8 meter mirror modeled to assess performance
  - Model includes light-weighted face plates joined to a light-weighted core.
  - 5% additional mass added to light-weighted sections to account for corner radii.
- Total mass was 3042 kg, 60 kg/m²
- First Free-Free mode at 33 Hz
0.4m Demonstration part fabricated

Mirror Blank is 3 cores high

Single Mirror Core
(Note large cell size)

- The individual core segment surfaces are polished and AWJ just like traditional LTF mirrors
- During Low Temperature Fusion (LTF), the faceplates and the core segments are fused together (Co-Fired)
Faceplate Pocket Milling

- Pocket milled facesheets have been used on other mirrors to provide additional stiffness between cell supports
- Allow for much larger core cell size to reduce overall areal density
- Extended to 24 pockets to enhance UV performance

Pocket Milled Facesheet
Core cells locations shown in red
(Core shown for reference)
Demonstration Blank Low Temperature Fusion

First-Ever Layered Core Demonstrator Successfully Fused

- LTF joint strengths in the core-to-core joints (2,500 psi) are consistent with faceplate-to-core strengths (1,940 psi)
- Highest stresses are at the faceplate-to-core interface so the core-to-core strengths are fully acceptable

Validates Reduced Cost Approach for Manufacturing Deep Mirror Cores
Low Temperature Slumping Incorporated into Development

• Low Temperature Slumping (LTS) demonstrated on AMSD/MMSD active mirror programs
• Incorporated into this development to reduce blank part processing costs
• Part successfully slumped to a very fast 100 inch (2.4m) Radius of Curvature (RoC)
  • Thermal testing at MSFC completed
• Minor but acceptable deformation of some of the core walls
Processing Quality

Processing completed to demonstrate that UV quality (5nm RMS) could be achieved.

Multiple orientation test minimized test errors and analytical backouts

> Some minimal trefoil did not cancel out during testing

Mirror was cryo tested at MSFC

> Reference 8837-11

Final Optical Test – 5.5nm RMS
First Light Test

117nm RMS – 524nm P-V Power Removed

Global polishing quilting over the large cells is observed after initial polishing
Post Ion Figuring #1

16nm RMS – 87nm P-V
Power Removed

- First ion cycle greatly reduced the global figure error by 86%.
- Some cell quilting still visible
Post Ion Figuring #2

4.9nm RMS – 37nm P-V
Power Removed

- Second ion cycle further reduced the global figure errors by an additional 68%
- Pocket milled quilting becomes visible
Post Ion Figuring #3

5.4nm RMS – 37nm P-V
Power Removed

- Final ion figuring run focused on pocket quilting errors
- Mount repeatability limits overall surface quality

- Rapid convergence to final surface quality
- Deterministic processes reduce schedule time
AMTD PSD Testing Summary

- Data collected using Zygo Verifire and White Light Interferometer
- Ion Figuring successfully removed most of the polishing quilting artifacts
- Results show no significant PSD change due to ion figuring in spatial periods smaller than 20mm.
Low order figure error has reached the current metrology reproducibility limit in the current configuration leading to no improvement in figure errors with spatial periods longer than 50mm.

Low order figure error present in the measurement after ion figuring is driven by mount reproducibility.

Metrology reproducibility and accuracy could be improved with an optimized mount design and additional part rotations.
The quilting period appears at ~20-30mm spatial periods before final ion figuring.

Ion figuring improved the rms in the 50-10mm spatial period band eliminating most of the quilting structure.
10mm FFT High Pass Filter (Final Ion Iteration)

The shorter spatial periods, <10mm, were negligibly affected by ion figuring.

Super polishing to improve the micro-roughness could be done if needed for the UV application.
Summary

To date, the stacked core approach shows great promise to reduce the cost and schedule for building large, 4m-8m, closed back, mirror blanks

- Lower cost using the ability to accomplish parallel work on multiple, lower cost waterjet robots
- Eliminates the high cost of stack sealing boules and traditional deep core cutting

Exelis has demonstrated the ability to fabricate and process a lightweight, stacked core mirror

- Mid/High Spatial Frequency Figure Errors were controlled
- Demonstrated the ability to ion figure processing quilting in a pocket milled facesheet to obtain a very high precision mirror
- Global surface figure limited by mount repeatability

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