SiC For Space Based and Ground-Based Astronomical Observing Applications

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NASA Mirror Technology Days
Rochester, NY
July 31 – August 2, 2012

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SiC Provides Material Properties Advantages

- Very light weight optics and systems due to high stiffness to weight ratio
- Excellent thermal stability under non-uniform thermal loading due to high conductivity and low coefficient of thermal expansion
- L-3 IOS SSG’s Reaction Bonded (RB) SiC provides low cost, near-net-shape fabrication
SiC Technology Demos have led to Successful L-3 IOS SSG SiC Space Flight Hardware

MICAS
NASA Deep Space-1

HIRDLS
NASA AURA

ALI NASA
Earth Observing-1

GIFTS-Afocal
NASA EO-3

GIFTS-PMA
NASA EO-3

ABI NASA/
NOAA GOES-R

LORRI
NASA New Horizons

JMAPS
U.S. Naval Research Lab

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L-3 IOS SSG RB SiC allows Low Cost Manufacturing

Slip-casting provides near-net-shape fabrication of complex features without the need for costly/time-consuming post machining

- 0.005” – 0.010” typical as-cast tolerances
- Shrinkage during processing < 0.5%
- End product is fully densified with silicon and SiC regions uniformly dispersed throughout the microstructure
- Components can be sinter-bonded together to form more complex structures
LORRI – Overview

- High resolution visible instrument within the New Horizons payload
- Launched 2006
- 3.2 billion km traveled
- 1000’s of images to date
- Science Objectives
  - Reconnaissance imaging of Pluto-Charon and Kuiper Belt
  - Measure shape/size of Pluto-Charon
  - Data on Pluto’s geology, surface morphology, collisional history, and atmosphere-surface interactions (50 m resolution)
  - Mapping of craters on Charon
  - Map orbits of objects in the Kuiper Belt
  - Provide Jupiter flyby imaging
Why SiC for LORRI?

**Thermal Performance**
- Challenging thermal environment requires a low CTE and high Thermal Conductivity
- Environment as hot as +40 C, CCD held to -70 C, viewing cold space
- Tight thermal gradients of 1.0 C (lateral) and 2.5 C (axial)

**Low Mass Requirements**
- 5.6 kg mass allocation for telescope with minimum resonant frequency of 60 Hz
- No mass allowance for a focus adjust mechanism drives passively athermalized opto-mechanical design configuration

**Long Term Dimensional Stability**
- Launch in 2006, primary imaging initiates in 2015

**Low-Outgassing**
- Internal cleanliness at beginning of life 250 A/2 and end of life 300 A (MIL STD 1246B)
LORRI Optical Design (Field Corrected Ritchey-Chretien)

<table>
<thead>
<tr>
<th>LORRI Optical Design Parameters</th>
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<tbody>
<tr>
<td>Aperture</td>
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<tr>
<td>EFL</td>
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<tr>
<td>F/Number</td>
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<td>FPA Format</td>
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<td>Power</td>
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<td>WFE</td>
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- Excellent thermal stability under non-uniform thermal loading due to high conductivity and low coefficient of thermal expansion
- L-3 IOS SSG’s Reaction Bonded (RB) SiC provides low cost, near-net-shape fabrication
LORRI Mechanical Design Overview

- Monolithic SSG SiC Structure
- Purge Fittings
- Silicon coated SSG SiC Mirrors
- Beryllium Radiator & Conduction BAR
- Magnesium Interior Baffles
- K13C2U Baffle Shell with M55 Baffle Blades
- External Isolators
LORRI SiC Telescope

- Silicon Carbide telescope structure material is identical to the mirrors
  - Allows for nearly ideal metering with low CTE, high conductivity material
  - Very high stiffness and low mass design
Monolithic Silicon Carbide Metering Structure

- L-3 IOS SSG RB Silicon Carbide fabrication process allows for very complex geometries
- Individual pieces are cast as simple parts, then sinter bonded together.
  - Joining material is the same as the parent material
  - Process can be repeated as many times as needed to build up monolithic structure
  - Joints are much stronger and more stable than epoxy joints
- Small Invar inserts are bonded at attachment points
LORRI SiC Aspheres Polished by L-3 IOS Tinsley

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Primary Mirror
11 nm rms surface error

Secondary Mirror
12 nm rms surface error
Laboratory Environmental Qualification Verified with On-Orbit Performance Characterization

Messier 7 Star Cluster reveals stars down to 12th Magnitude confirming LORRI Signal-to-Noise Ratio, Multiple measurements demonstrate no performance degradation over 6+ years. (courtesy APL/SWRI/NASA)
SiC Benefits for Ground Observatories: Advanced Technology Solar Telescope (ATST)

- Advanced Technology Solar Telescope (ATST) Summary:
  - 4 meter aperture solar telescope under construction on Haleakala, Maui, Hawaii
  - Explore 3-D structure of the solar magnetic field including corona at IR wavelengths and high resolution (30 milli-arc-sec) visible waveband imaging
L-3 IOS SSG RB SiC Used for M2 mirror within Top End Optical Assembly (TEOA)

- 2.5% of the solar flux incident on M1 passes through the heat stop to M2 = 300 Watts
- High heat load demands thermal gradients are minimized (High K) and thermal deformation is low (Low CTE)
- Active control of M2 mirror demands low mass and high stiffness to weight ratio (High E, low r)
ATST Top End Optical Assembly (TEOA) Overview

- L-3 IOS Brashear under contract for Top End Optical Assembly (TEOA)
  - M2 Assembly
    - Spider
    - Positioner System
    - Inner and Outer Plenums
    - M2 Bonded Mirror Assembly
  - Heat Stop / Shutter
  - Lyot Stop
  - Frame Assembly
  - Electronics Enclosure
ATST Top End Optical Assembly (TEOA) Overview

M2 Positioner

Thermal Control

Spider Mount

SiC M2 Mirror and Mount

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ATST SiC M2 Mirror Description

### ATST M2 Mirror Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Aperture</td>
<td>0.65 m</td>
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<tr>
<td>Radius of Curvature</td>
<td>2.08 m</td>
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<tr>
<td>Off Axis Distance</td>
<td>0.59 m</td>
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<tr>
<td>Conic Constant</td>
<td>-0.539 (ellipse)</td>
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<tr>
<td>Weight</td>
<td>25 lbs (11.3 kgs)</td>
</tr>
<tr>
<td>First Free-Free Mode</td>
<td>728 Hz</td>
</tr>
</tbody>
</table>

- L-3 IOS SSG Reaction Bonded SiC
- Aluminum Mounting plate
- Invar 36 epoxy mounted bipods
- Silicon Cladding for polishability
- FSS-99 Silver coating for reflectivity

- Typical Rib Thickness: 5 mm (0.2")
- Maximum Rib Depth: 86 mm (3.4")
### ATST SiC M2 Mirror Status

- **Analysis completed**
  - First free-free mode
  - Thermal soak surface error
  - Coating stress deformation
  - Gravity sag as a function of telescope zenith tilt angle
  - Surface error due to cooling jet impingement
  - Mount induced error

- **Detailed design in-process**

- **Manufacturing planned to begin Q3 2012**

**M2 Substrate – Free-Free Modes**
ATST SiC M2 Mirror Prototypes

- Prototypes, similar in scale to the ATST M2 mirror have been produced using L-3 IOS SSG RB SiC Slip Casting manufacturing process
- Near-net-shape fabrication produces lightweighting ribs with no post-machining
SiC Provides critical benefits for both ground and space-based optical systems

- Very lightweight optics and systems due to high stiffness to weight ratio
- Excellent thermal stability under non-uniform thermal loading due to high conductivity and low coefficient of thermal expansion
- No outgassing/moisture absorption
- L3-SSG’s Reaction Bonded (RB) SiC provides low cost, near-net-shape fabrication
- L-3 SSG has extensive experience in design, analysis, manufacturing and test of SiC optics/optical-systems including over 10+ years flight heritage