ALI Optical Subsystem Technology

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Technology Description

- **Optical Design**
  - Wide field of view
  - Flat image plane
  - Low distortion
  - Excellent image quality

- **SiC Materials Technology**
  - Hot Pressed SiC Optics
  - Reaction Bonded SiC Optics
Optical Design Overview

• **Optical Design Form**
  – All reflective Cooke triplet
  – On-axis aperture
  – Off-axis field of view
  – Wide field of view: 1.26 deg x 15 deg set to accommodate FPA
  – Non-relayed (no intermediate image)
  – Aperture stop on secondary mirror
  – Constrained to be near telecentric (< 2.5 deg non-parallel chief rays) in order to maintain standard spectral filter requirements
  – Flat image plane
  – Low distortion (mappable to < 10 µm)
  – Excellent image quality (MTF > 0.6 @ 37.5 lp/mm)

• **Optical Components**
  – Primary Mirror: Concave general asphere
  – Secondary Mirror: Convex ellipsoid
  – Tertiary Mirror: Concave sphere
Optical Performance Summary (Image Quality)

- **System Level Wavefront Error**
  - WFE derived from MTF specification using Code V
  - Required system WFE (@ temp) < 0.15 \( \lambda \) RMS (@ 0.63 \( \mu m \))
  - 12 Field points tested, System WFE (@ temp) 0.089 - 0.148 \( \lambda \) RMS (@ 0.63 \( \mu m \))

- **System Level MTF**
  - MTF performance projected from wavefront maps input specification using Code V
  - System meets or exceeds spec at 18.75 and 37.5 lp/mm
Optical Performance Summary (Distortion)

- **Optical Distortion**
  - Distortion measured by mapping the angular locations of 40 points on a scribed target through the ALI optical system.
  - Uncorrected data shows maximum distortion vector length of 928 µm.
  - Cubic polynomial data correction (Dr. David Hearn, MIT/LL) brings residual distortion values down below 9 µm.

Distortion Map Prior to Correction

Distortion Map After Correction
Optical Performance Summary (Stray Light 1 of 2)

- **System Level Stray Light Performance**
  - Optical design optimized to provide excellent image quality, low distortion, and near telecentric chief rays over a wide FOV
  - Non-reimaged design form is not well suited to stray light suppression
  - As a result, system level stray light performance is dominated by mirror scatter
  - ALI flight optics do not meet system level stray light specifications

ALI Raytrace
Optical Performance Summary (Stray Light 2 of 2)

- **Component BRDF Performance**
  - Component level BRDF, consistent with all ALI stray light requirements has been demonstrated through a NASA funded technology program.
  - Silicon clad SiC aspheric optics and uncoated SiC flat optical surfaces demonstrated to have BRDF which will meet all ALI requirements.
    - Multiple optics demonstrated, including full scale, ALI primary mirror.
Optical Performance Summary

- ALI Optical design form optimized to meet a number of stressing requirements
  - Wide FOV, low distortion, flat field, near-telecenticity, excellent image quality
- ALI SiC optical system meets or exceeds most of the telescope requirements
  - Component level surface figure
  - Reflectivity
  - Field of view
  - Angular resolution
  - Point spread function
  - System throughput
  - Image quality over FOV
  - Distortion map over FOV
  - Focal length
  - Aperture uniformity
  - Mechanical stability
  - Thermal stability
  - Size
  - Weight

- The one exception noted is the system stray light performance of the system and component level BRDF of SiC optics
  - SSGPO has demonstrated that this is not a limitation associated SiC materials by producing a number of SiC optics (flats and aspheres) which meet all ALI stray light requirements
Silicon Carbide Material Overview

- **Combination of SiC and Invar materials used for ALI Optical Subsystem**
  - Specific Stiffness of SiC (HP, RB, CVD) 70% - 90% of Beryllium
  - Thermal Stability of SiC 3x - 1.5x better than ULE glass
  - Hot Pressed SiC suitable for simple “slab”-type geometries
  - Invar structure selected for its good CTE match to SiC and its good durability
Hot Pressed Silicon Carbide Optics

- **Hot Pressed SiC materials used for ALI flight optics**
  - HP SiC has flight heritage
    - SSGPO developed MICAS SiC flight system for NASA DS-1 mission from HP materials
  - HP SiC has excellent material properties
  - Optical grade HP can be figured and finished to produce good quality flat and spherical optics
  - Aspheric optical surfacing requires a silicon cladding
  - HP SiC materials produced in simple slab shapes
    - All lightweighting must be done by aggressive diamond machining
    - Costly and time consuming machining requirements
Reaction Bonded Silicon Carbide Optics

- Reaction Bonded SiC suitable for more aggressively lightweighted optical and structural requirements
  - RB SiC maintains excellent material properties while allowing complex structures to be produced with little to no post-machining
  - RB SiC can be figured and finished to produce good quality flat and spherical optics
  - Aspheric optical surfacing requires a silicon cladding
Silicon Carbide Optical Properties

- Spare ALI Primary Mirror Surface Figure
  - Silicon coated SiC Asphere
  - 0.035 λ RMS
  - 0.294 λ Pk-valley

- Hot pressed and reaction bonded SiC materials demonstrated to provide excellent surface figures and surface finishes
  - Bare flats and spheres and silicon coated aspheres demonstrated on numerous programs
  - Surface finish achievable does depend the optical surface being polished
    - RB or HP SiC polishes to 10-15 Angstroms RMS routinely
    - Silicon coated SiC polishes to 20-30 Angstroms RMS routinely
Silicon Carbide Material Summary

- SiC materials have been demonstrated to be suitable for LDCM and other future ALI-like missions
  - Surface figure and image quality demonstrated with ALI flight system
  - Surface scatter demonstrated with spare ALI flight optic
- Combination of SiC and Invar materials used for ALI Optical Subsystem
  - Other alternatives can be used to better benefit from the excellent lightweighting capabilities possible with SiC materials
    - Hot pressed SiC optics and structure applied to MICAS DS-1 optical subsystem with good success
    - Reaction bonded SiC optics and structures allow a higher degree of lightweighting
  - ALI optical design can be implemented with more traditional optical materials
    - SSGPO has extensive experience in producing off-axis aspheric optics in aluminum, beryllium and low-expansion glasses
Optical Subsystem Technology Summary

- ALI optical design well suited to address the unique demands associated with multi-spectral/hyper-spectral optical systems
  - Excellent image quality and MTF
  - Low distortion
  - Near telecentric
  - Wide field of view
- SiC materials demonstrated to meet all ALI optical requirements
  - Surface figure and image quality demonstrated with ALI flight system
  - Surface scatter demonstrated with spare ALI flight optic
- RB SiC materials can be applied to provide additional program benefits
  - Significant cost savings
  - Significant weight savings