Reaction Bonded SiC Technology Developments

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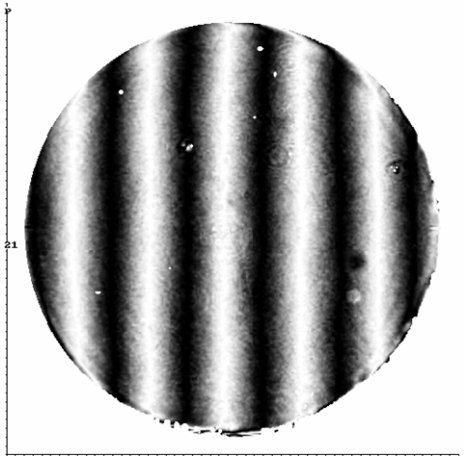
Outline

- SiC scan mirror for high energy laser applications (Phase II)
- Fiber reinforced, low-cost SiC material development (Phase II)
- Low cost SiC replication for LWIR applications (Phase I)
- Extension of RB SiC to large, segmented mirror demonstration

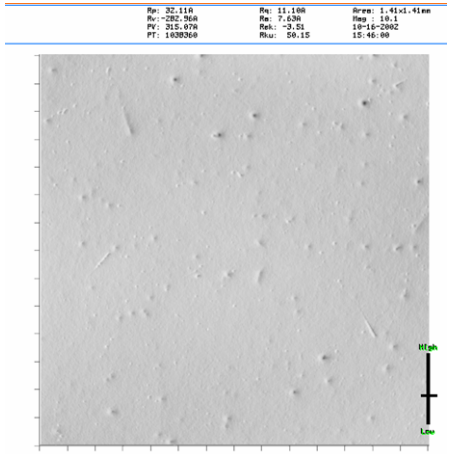
Typical Si Clad RB SiC Aspheric Mirror Results

Silicon Carbide GIFTS Primary Mirror

- 29.5 cm diameter
- RB SiC substrate slip cast with 3.2 mm facesheet and 2mm thick ribs (60 mm high)
  - Mass: 1.7 kgs
- Off-axis parabola
- CCOS polishing done in silicon cladding
  - CCOS processed by Tinsley



8 nm RMS surface error



8 Angstroms RMS surface roughness

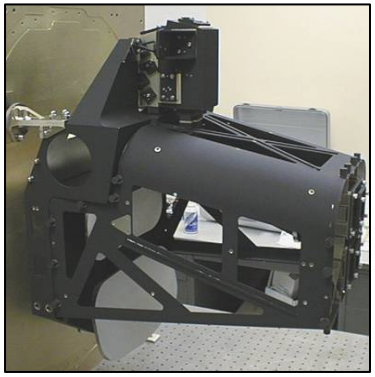
Slip Cast Rib Supports

SSG Precision Optronics, Inc.

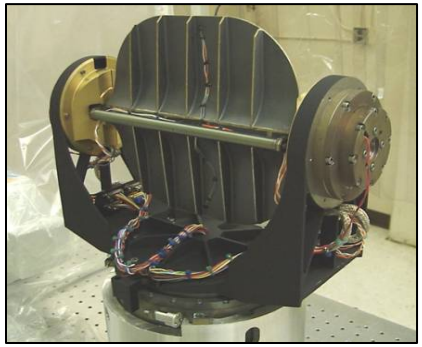
tinsley
a subsidiary of SSGPO

SSG SiC Technology Demos have led to Successful SiC Flight Hardware

MICAS
- All-SiC system for NASA DS-1
- 10 cm aperture
- Mass < 3 kg
- Demonstrated system level stability to visible quality to 130K



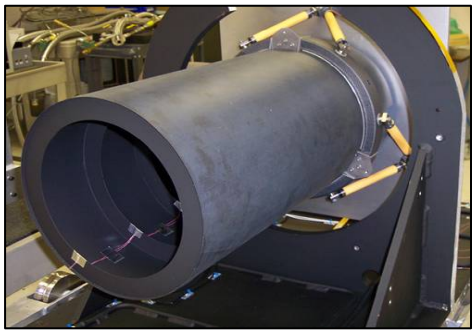
Advanced Land Imager
- WFOV (15 degree) all reflective design
- 12.5 cm aperture
- 0.6 waves (vis) p-v quality
- Stable over ± 50 C



HIRDLS
- 20 cm SiC scan flat
- Integrated to Beryllium telescope
- Launched on EOS-Chem platform

GIFTS PMA
- 45 x 30 cm SiC scan flat
- Integrated to Beryllium yoke
- 100 hz closed loop bandwidth achieved

GIFTS TMA
- All-SiC afocal system for GIFTS-IOMI
- 30 cm aperture
- Mass < 6 kg
- CCOS polished silicon clad RB SiC aspheres
- Athermal operation from 180K to 290K



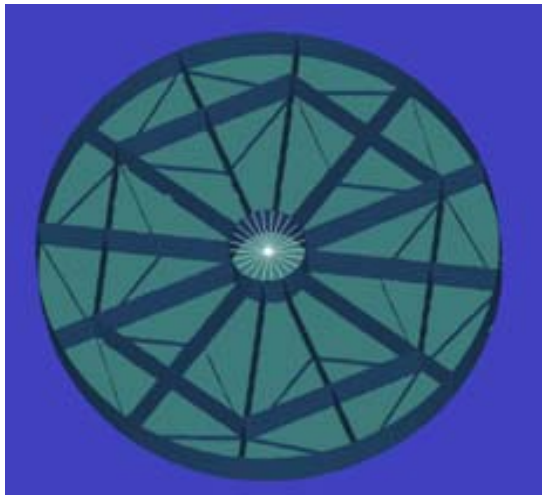
LORRI
- All-RB SiC imager for imaging of Pluto-Kuiper belt
- NASA New Horizons mission
- 21 cm aperture
- CCOS polished silicon clad RB SiC aspheres
- System thermal testing confirmed by NASA/GSFC

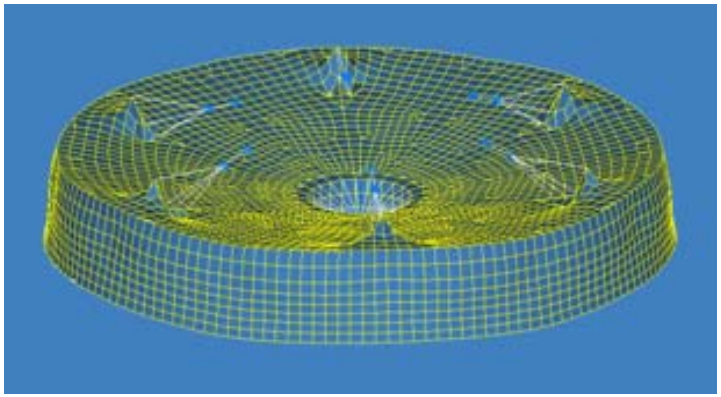
SiC Fast Steering Mirror for HEL

- Silicon Carbide Steering Mirrors for High Energy Laser Applications-Phase 2 SBIR
  - *Contract #: FA8650-04-C-5232*
  - *COTR: Dr. Lawrence Matson AFRL/MLLN*
- Objective: Preliminary design and analysis of a SiC Fast Steering Mirror (FSM) for the ABL application. Fabricate and test 30 cm SiC mirror for ABL Beam Control FSM LRU
- Results
  - *Closed back, open back, and partially closed back designs developed and analyzed*
  - *Material properties of SiC enable 5x reduction in mirror mass while meeting surface specifications*
  - *Combination of conventional and CCOS techniques being applied in Phase 2 demonstration mirror to meet surface specifications on a rib supported, lightweight SiC mirror configuration.*

Phase II Program: Create a SiC fast steering mirror which can be used as Line-Replaceable-Unit for existing Silicon mirror (5x reduction in mass while meeting all specifications)

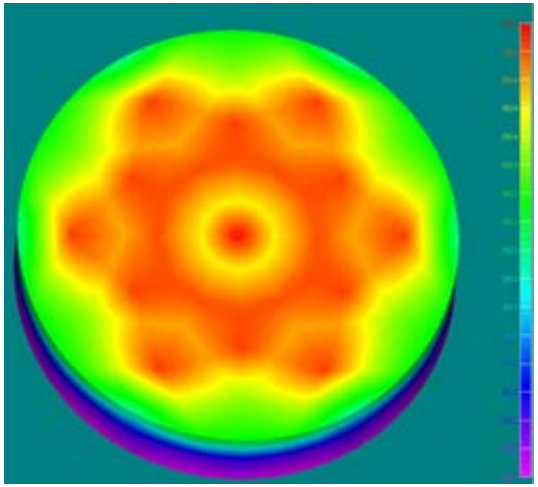
Structural/Thermal FEA used to Optimize SiC Mirror Design





First Dynamic Mode (constrained)
Frequency: 1811 Hz

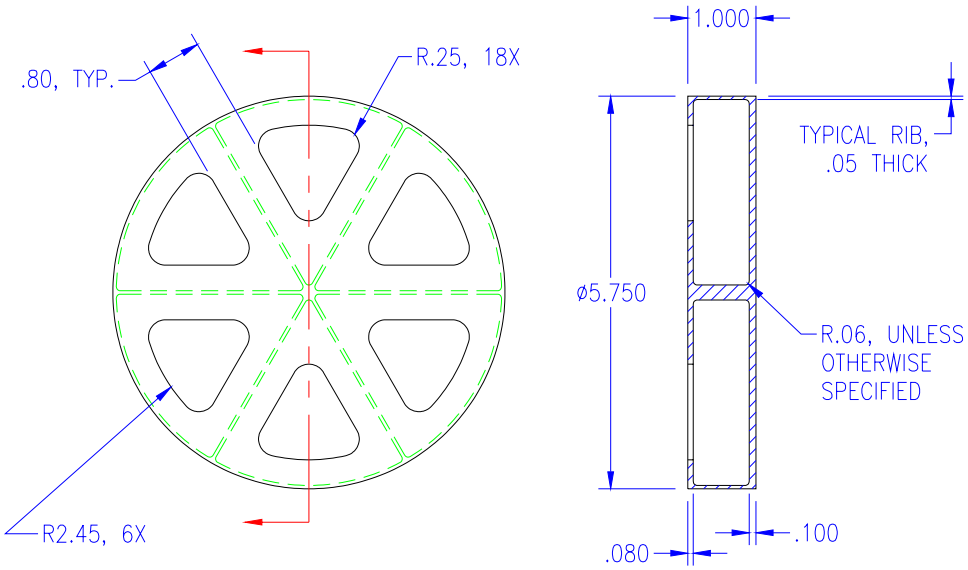
- **Partially closed back SiC design selected to address structural and thermal system requirements;**
- **Demonstration piece in process**



Thermal Load Applied to NASTRAN Model

Temperature Contour

Partially Closed Back Slip Casting Process



Partially closed back mirrors being produced to provide increased stiffness

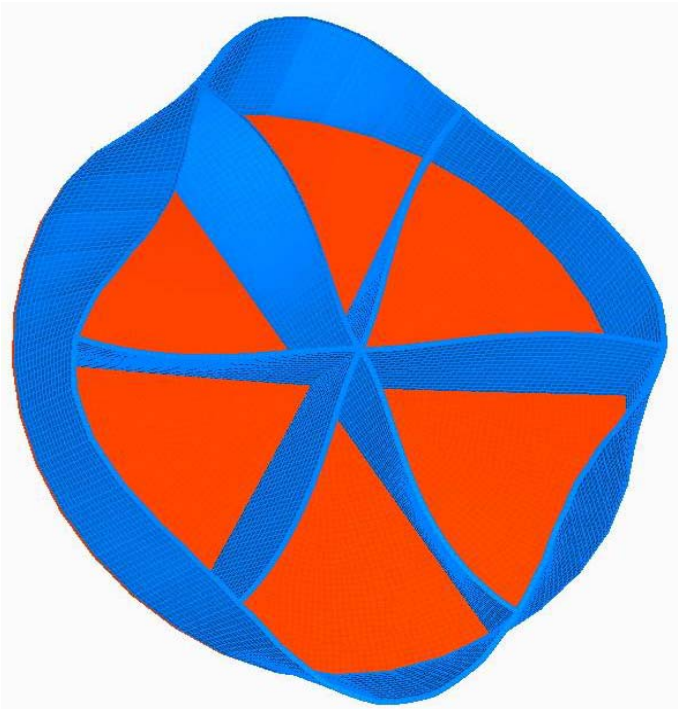
- Addresses applications with envelope constraints
- Process utilizes reusable tooling, consistent with more traditional open back mirror designs

Partially Closed Back –vs- Open Back Performance

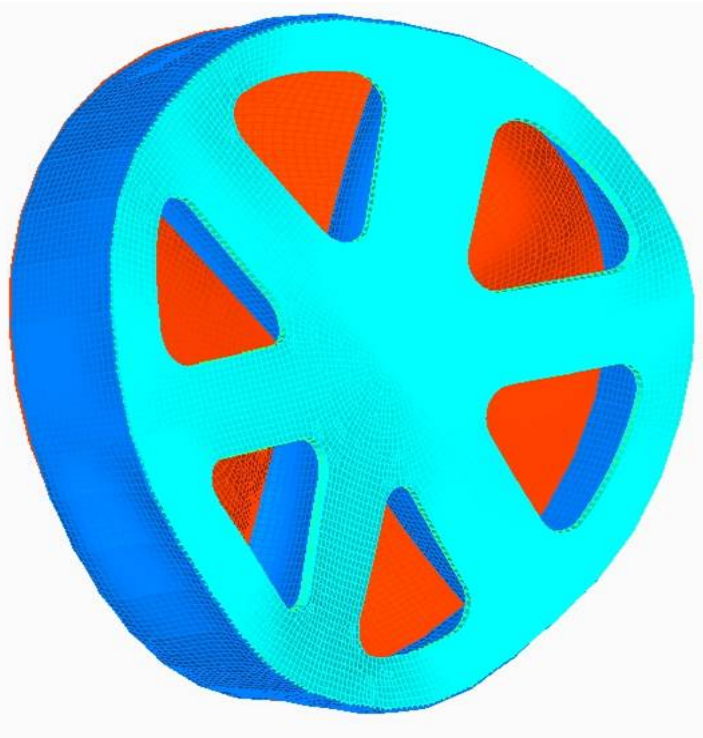
	Partially Closed Back	Open Back	*units*
Mirror Weight	0.6	0.6	*Lbs*
Frequency	9032	4276	*Hz*
Mirror Depth	1	1	*inch*
Face Sheet	0.1	0.1	*inch*
Ribs	0.05	0.09	*inch*
Back Sheet	0.08	-	*inch*

Partially closed back design improves stiffness by 2x compared to equivalent mass/thickness open back design

Partially Closed Back –vs- Open Back Mode Shape

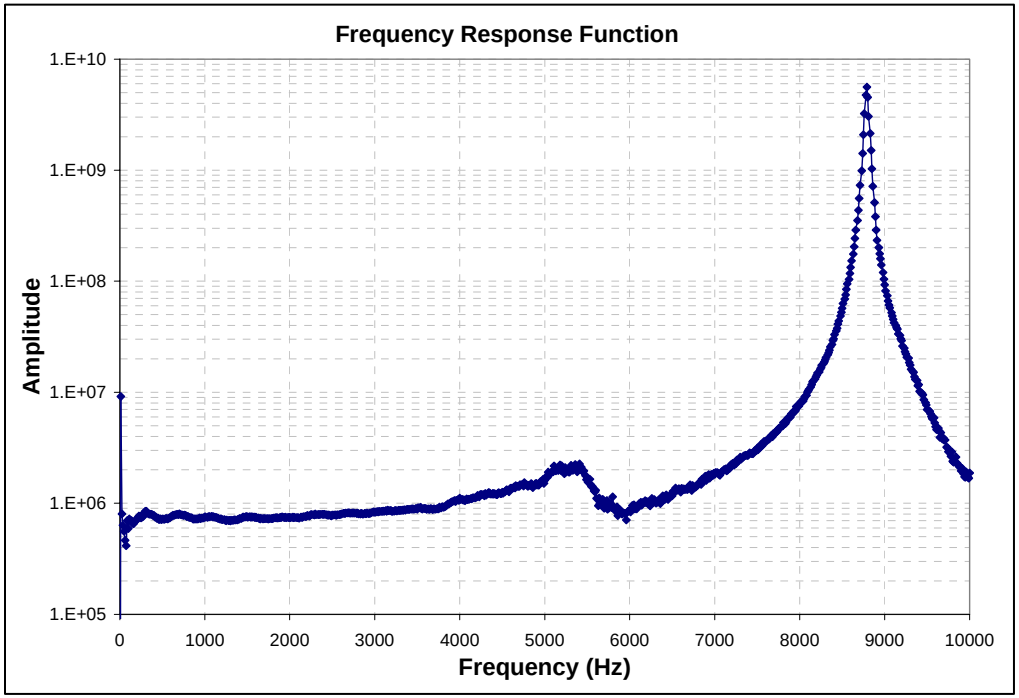


Open Back:
First Free-Free Mode
4276 Hz



Partial Closed Back:
First Free-Free Mode
9032 Hz

Partially Closed Back Stiffness Measurement



Tap testing confirms partially closed back mirror stiffness (8790 Hz)

Low, Cost, Fiber Reinforced SiC Material Development

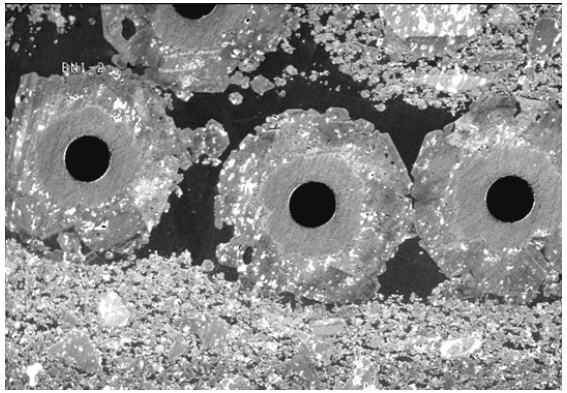
- **Low, Cost, Fiber Reinforced SiC Material Development-Phase 2 SBIR**
  - *Contract #: NAS5-02108*
  - *COTR: Dr. Peter Blake NASA/GSFC*
- **Objective: Develop a fiber reinforced, fracture tough SiC material which can be slip cast, allowing the production of low-cost durable SiC structural elements**
- **Results**
  - *SiC fibers have been successfully slip cast into traditional RB SiC slurry*
  - *2x Improvement in fracture toughness demonstrated with low fiber volume (< 5%)*
  - *Higher fiber volume samples currently in process (IRAD)*

Phase II Program: Maintaining Fiber Integrity through slip cast SiC furnacing process represents a major technical milestone

Fracture Tough SiC Material Development

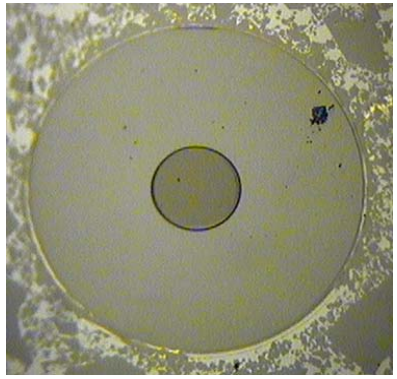
- Goal: Develop a fiber reinforced SiC material which can still be slip cast to near-net-shape
  - *Improve fracture toughness of RB SiC from 4 to >12 MPa $m^{1/2}$*
- Technical Challenge: Develop a process/fiber which will remain intact throughout processing
  - *SiC fibers tend to degrade or fuse with RB SiC matrix during high temperature furnacing*
- Chopped and continuous fibers being evaluated
- Results to date: Process which allows fibers to remain intact, and maintain fracture toughness has been demonstrated
  - *Small fiber volume (< 5%) demonstrated to improve fracture toughness by 2x*
  - *Higher fiber volume samples in process*

Initial Phase I Results



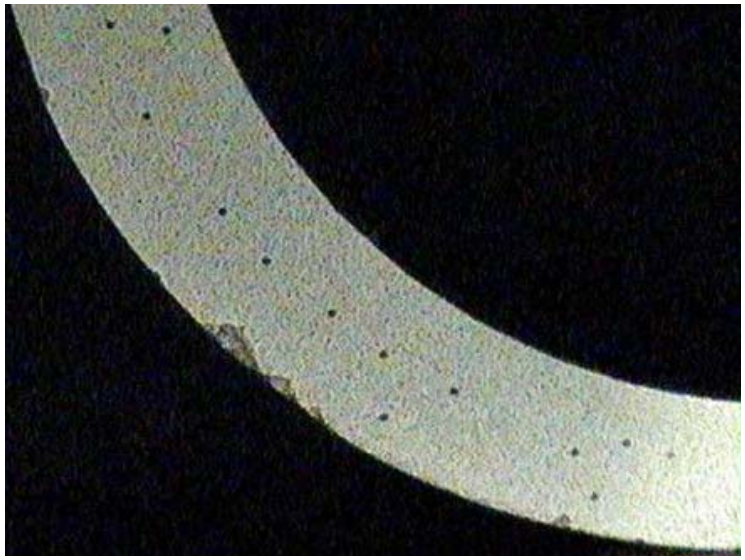
•Fibers degraded
•Open porosity

Successful Phase II Results



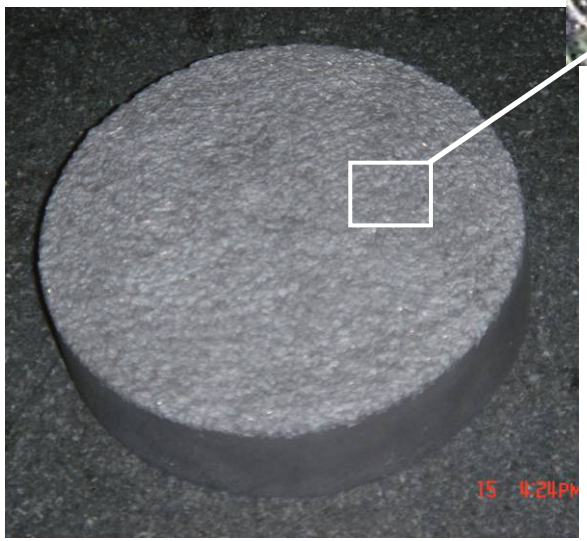
•Fibers intact
•Maintain fracture tough behavior

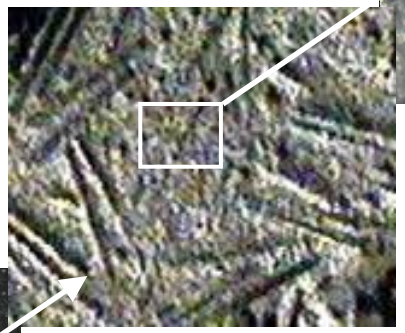
Fiber Reinforced, Slip Cast RB SiC Components



- Continuous fiber reinforced components demonstrated

Fiber Reinforced, Slip Cast, RB SiC Components





Micrograph shows random fiber distribution, in-plane and through thickness

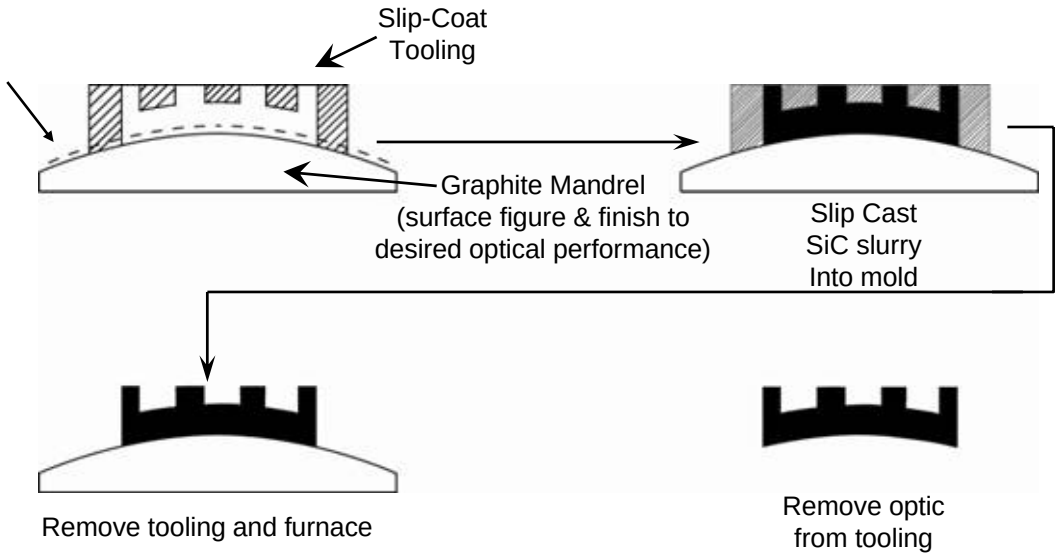
- Chopped fiber reinforced components demonstrated

LWIR SiC Replication Activity

- **SiC Replication of LWIR Optics: Phase 1 SBIR**
  - *Contract #: NNM05AA38C*
  - *COTR: Dr. Phil Stahl NASA/MSFC*
- **Objective: Develop "replication" process suitable for producing LWIR-quality optics using a process compatible with slip cast SiC materials**

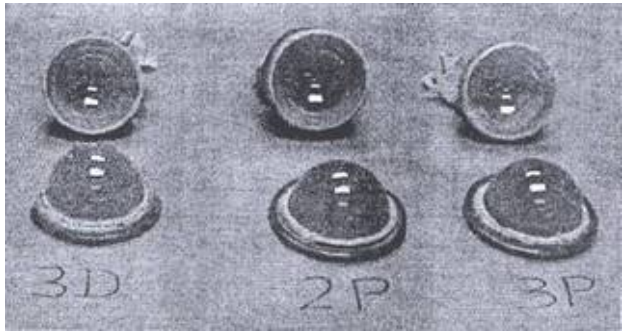
- **Results**
  - *Key technical issue is release of SiC material from mandrel*
  - *Numerous materials have been evaluated with no positive result to date*

SSG SiC Replication Approach



Proposed Slip-Cast Replication Process

- Methodology: Slip-Cast replication off of polished graphite tooling
  - *Process similar to what has been demonstrated by Rohm & Haas for IR domes*
- Issues: optimizing material formulation and mandrel/SiC release agent



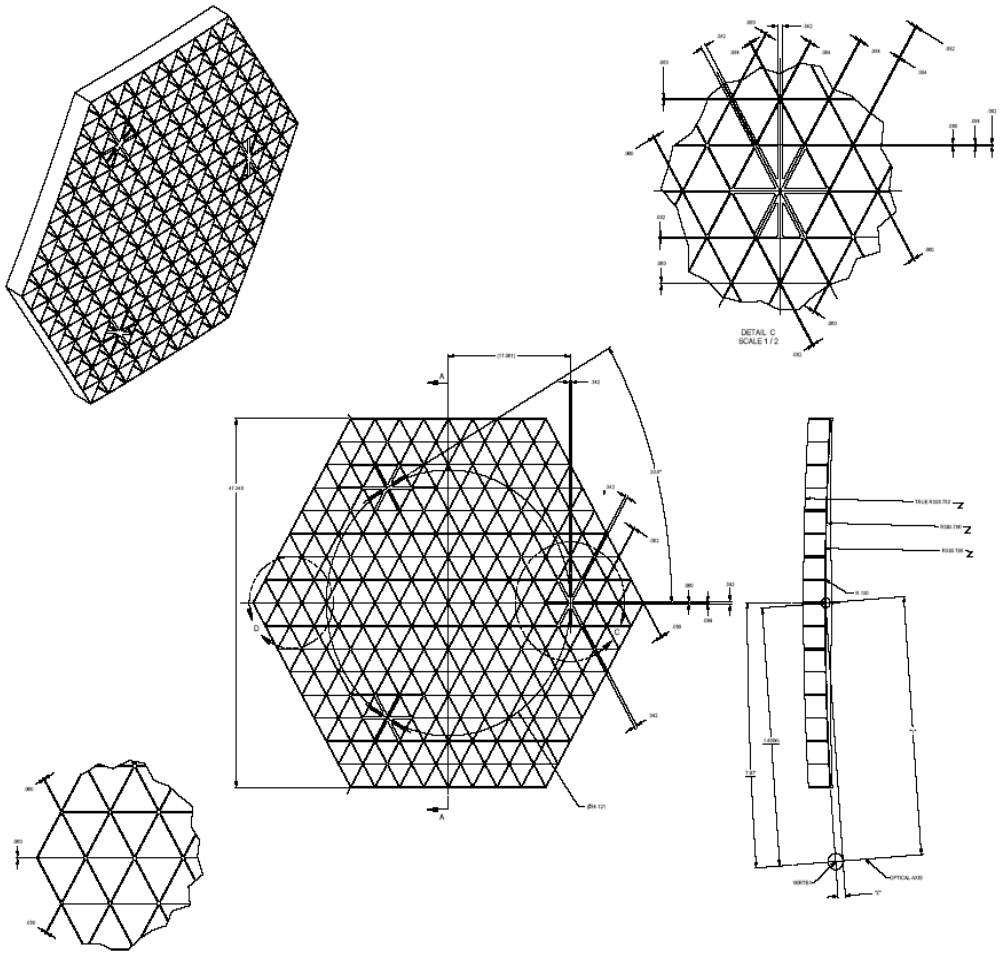
IR domes CVD-replicated from graphite mandrels (Rohm & Haas, 2001)

RB SiC Reflector Replicated from carbon tooling using SSG's slip casting process

LWIR Replication Activity

- Numerous mandrel substrate materials evaluated
- Release of SiC from mandrel has not been resolved

RB SiC Extension to Large Optics



- SiC Pathfinder mirror in process
- Off axis parabolic segment
  - *10 meter base radius of curvature*
  - *2 meters off axis*
- Open Back RB SiC Design
  - *1.2 m flat-flat*
  - *76 mm deep*
  - *2.5 mm facesheet thickness*
  - *1.5 mm rib thickness*
  - *Weight: 59 lb (26.8 kg)*
  - *Areal Density: 25 kg/m^2*
  - *Figure Requirement 20 nm RMS*

Large RB SiC Mirror Program Status

Tinsley Large Optic Facility (40,000 sq ft)

- Substrate through design
- Slip Cast tooling in process
- Furnacing facilitization almost complete (Fall 05 plan)
- Tinsley Large Optics Facility (JWST) on-line

Silicon Carbide Substrate Furnace In Process (1.8 m diameter)

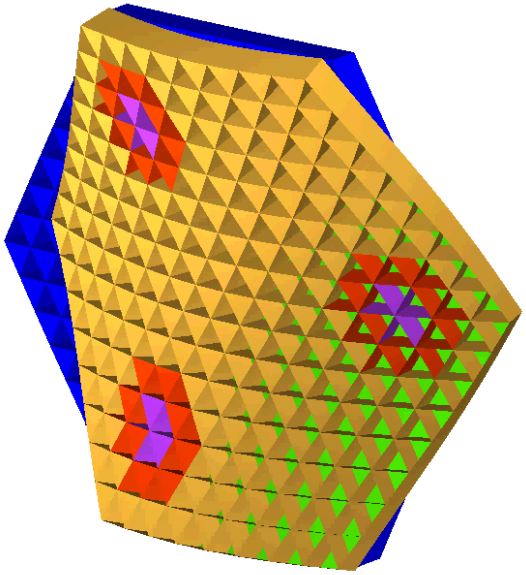
Large SiC Pathfinder Performance Predictions

Stiffness:

- 391 Hz 1st free-free mode (FEA)
- Approx. 2x stiffer than open back Beryllium AMSD mirror
- Horizontal gravity sag. 10x less than Beryllium AMSD mirror
  - *Be AMSD 2x lighter*

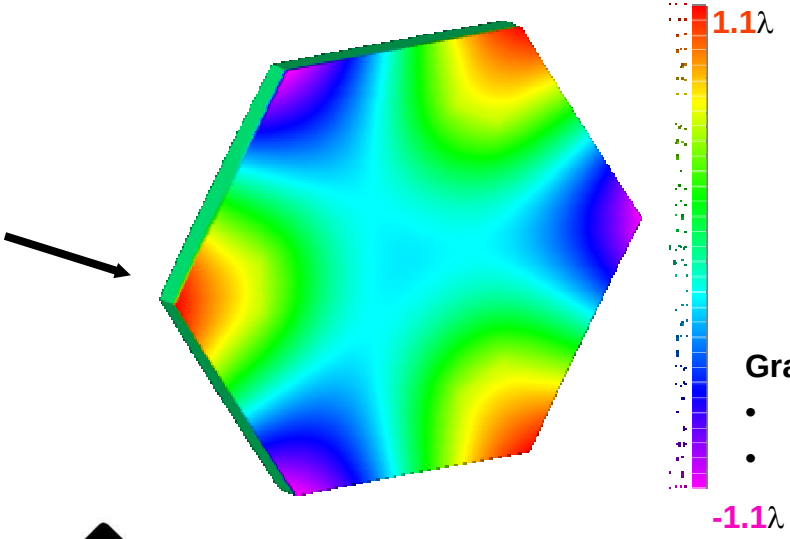
Thermal Stability:

- 4x better than equivalent mass Beryllium mirror



First Free-Free Mode: 391Hz

- **Second Mode: 661 Hz**
- **Third Mode: 811 Hz**



Gravity Sag Projections

- **296 nm (optical axis vertical)**
- **52 nm (optical axis horizontal)**

Summary

- Technology developments ongoing to improve performance, reduce cost, and extend to new application areas
  - *Fiber reinforced slip cast material developed for low-cost structural applications*
    - Small fiber volume (< 5%) demonstrated to improve fracture toughness by 2x
  - *Partially closed back mirrors produced to improve stiffness in tight volume constraints*
    - 2x improvement in stiffness obtained
  - *Extension of aspheric SiC optical fabrication to large AMSD-like optics is ongoing*
  - *LWIR replication activity has yet to yield a positive result*