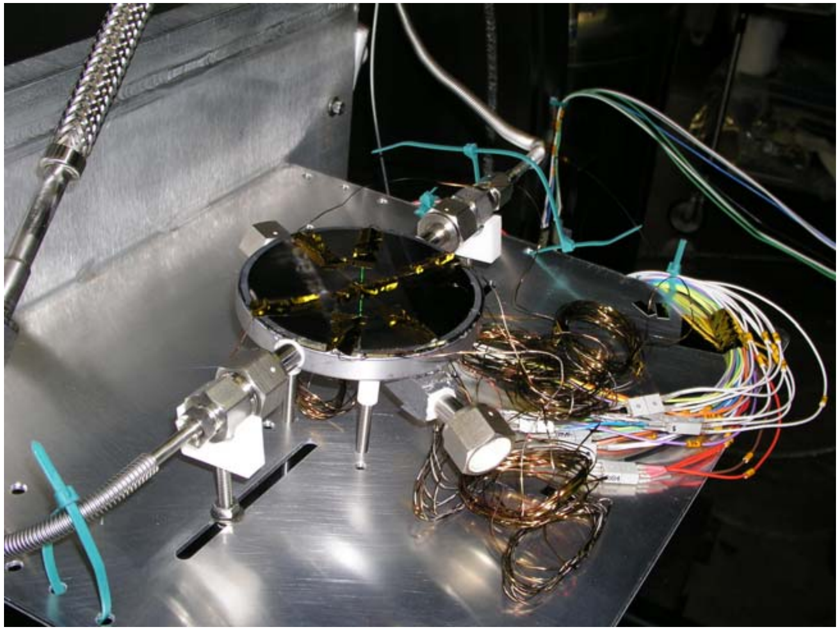
Actively Cooled Silicon Lightweight Mirrors for Far Infrared and Submillimeter Optical Systems
Phase II SBIR Contract No, NNM05AA16C
John West and Dr. Phil Stahl NASA MSFC



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Mirror Technology Days
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Briefing Outline

- Background
- Why SLMS™ for Cryogenic Optics
- Phase II Project

Background

- Achieving a telescope temperature of 4 Kelvin is one of the key technology development demonstrations that must occur in order to unravel the secrets of the early universe
- ~50% of the luminosity of the universe and 98% of the photons (excluding the cosmic microwave background) occur in the FIR
  - ⇒ That is where the young universe is redshifted
- Development of technology for 10-25 meter diameter optics for 20-800 μm bandwidth, with an areal density <5 kg/m^2, and a surface figure specification of λ/14 at 20 μm required for future FIR/SMM missions
  - ⇒ Premium for wavelengths >100 μm to achieve mirror temperatures lower than 10 K
  - ⇒ Some missions such as TPF-C require extreme figure and finish performance
- TRL 6 must be demonstrated for Cryogenic Optics and Telescopes
- SLMS™ technology development and demonstration effort is directly aligned with the vision of the FIR/SMM community

Why SLMS™ for Cryogenic Optics (1 of 2)

- Super-polishable, low distortion, dimensionally stable silicon skin:
  - ⇒ Avg CTE from 20-310K = 0.95 ± 0.01 ppm/K, 0.25 ppm/K instantaneous @ 20K
  - ⇒ High thermal conductivity: >5000 W/m-K at 25 K
- Silicon foam core is open-celled (up to 95% void space)
  - ⇒ Same CTE as skin, thermal conductivity ~50 W/m-K
  - ⇒ 1st fundamental frequency (120.35 ± 0.175 Hz) and damping (0.0055% ± 0.0043%) are temperature insensitive from 20-300K (20x2x0.5 inch bar measured by JPL – values are geometry dependent)
- *Static and Transient Distortion parameters are incredibly small!*
- SLMS™ engineered construct provides areal density and 1st fundamental frequency that match or exceeds lightweighted beryllium
- *High-stiffness reduces risk for phase matching segments*
- SLMS™ is super-polishable like glass or glass-ceramics
- *Exceptional figure and finish values have been demonstrated*

Why SLMS™ for Cryogenic Optics (2 of 2)

- *SLMS™ can be cooled either Internally or Externally*
- Phase I demonstrated Very Rapid and Uniform cooling for both Internal and External cooling modes with LN2
- Uniform external cooling of skin using Joule-Thompson cooler, or manifold, or cold plate, etc.
- *In situ* heat exchanger for Internal Cooling
  - ⇒ Uniform active cooling by flowing a coolant fluid (e.g. LHe) directly through foam core of mirror
  - ⇒ Foam structure has large surface area, and low flow resistance
  - ⇒ 1 ft^3 of foam has 1500-2000 ft^2 of heat transfer surface area
- Prior testing at NASA MSFC demonstrated minimal print-through (3.7 nm RMS) and figure change ($\lambda/100$ RMS HeNe) for 300 K to 24 K temperature change (radiative)

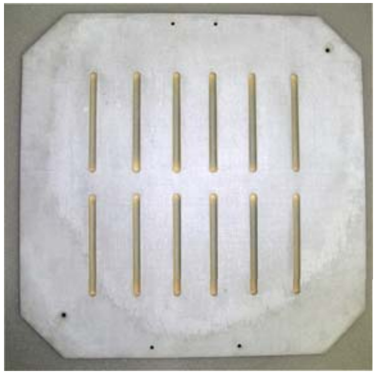
SLMS™ Transient Distortion Parameter is Orders of Magnitude Better Than Any Other Material

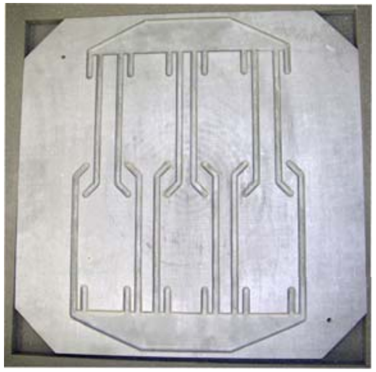
No Cryo-Nulling is Required, No Actuators for Figure Control

High Stiffness Should Minimize Phase Matching Issues

Phase II Project

- Matures Cryogenic Optic Technology to TRL6 at Component Level
  - ⇒ In Line With NASA Technology Development/Demonstration Goals
- Provides Useable Primary Mirror for Future NASA Mission
- Phase II Project Tests 55 cm Diameter SLMS™ Mirror at 4K using External Active Cooling
  - ⇒ Far Infrared Submillimeter Prototype (FISP) Mirror (Deliverable)
    - → FISP SLMS™ substrate being diamond turned by Corning NetOptix (CNO)
  - ⇒ Manifold/Mount for Cooling to 4 K (Deliverable)
    - → CeSic® manifold/mount has been manufactured



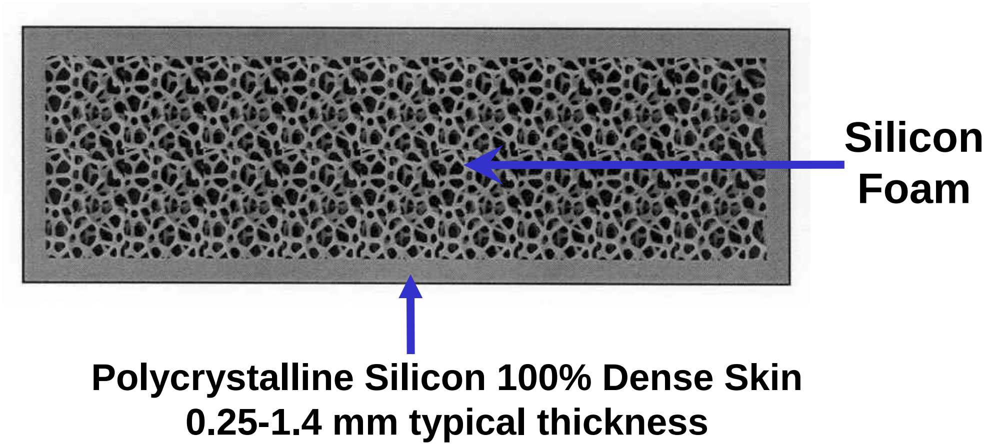


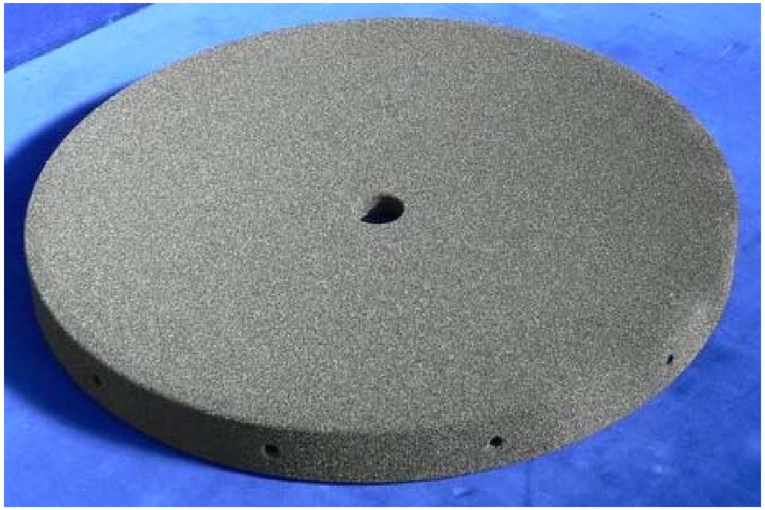
FISP SLMS™ PM Requirements

- Far Infrared Submillimeter Prototype (FISP) Mirror Suitable for Cryogenic Testing at NASA/MSFC
  - ⇒ Optical Surface
    - → CA: 50-cm; ROC: 1500 mm; Kappa: -1.0 (parabolic)
    - → Figure: 2 waves rms at 633 nm
    - → Roughness: 10 nm rms
    - → Scratch/Dig: 80/50
  - ⇒ Mechanical
    - → Overall Dia.: 55 cm
    - → Overall thick.: 4.1 cm
    - → Front annulus: 0.7 cm
    - → Flat Back Surface Flatness: 0.025 mm
  - ⇒ Material Properties
    - → 1.0 mm Silicon Skin Thickness
    - → 10-12% Silicon foam
  - ⇒ Predicted Mass Properties
    - → Mass = 2.77 kg
    - → Areal density = 11.7 kg/m^2

FISP SLMS™ PM Construction

- Foam Core Optics with a Continuous Shell



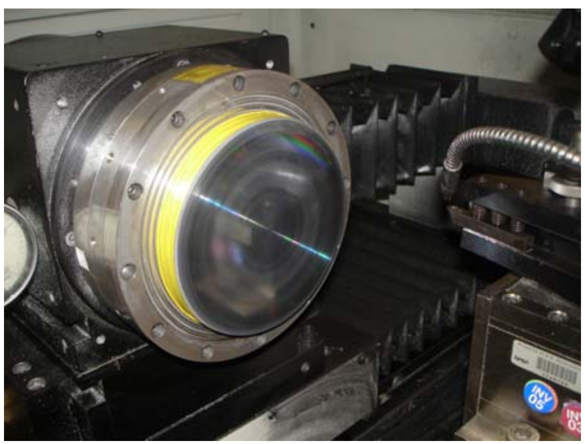


- Foam is Open-Cell, 90% Porosity
- Pore Size: 0.40 per mm (100 per in)
- 1500-2000 ft^2 surface area/ft^3
- CNC machined to parabolic shape to ± 50 µm (0.002 inch)

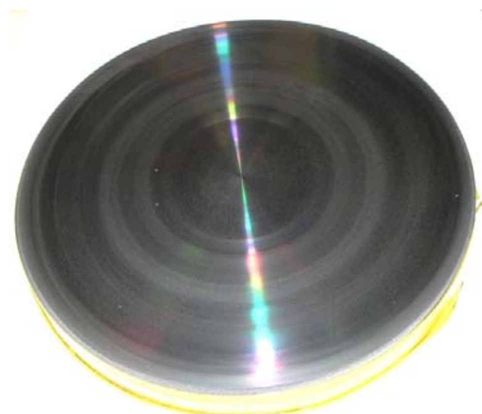
Parabolic Shape Machined Into Foam Core

NASA Diamond Turning Poly-silicon

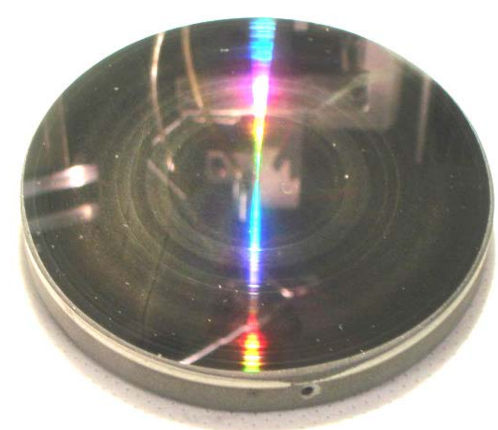
- Dr. David Lehner and Mr. Arthur Lapietra of NASA/MSFC developed a process for single point diamond turning (SPDT) of poly-silicon in 2006 under NASA IRAD
  - Previous attempts to SPDT poly-silicon by diamond turning vendors were based on SPDT of single crystal silicon (aqueous cutting fluids, expensive natural diamond tools, and a -30° rake angle) and resulted in poor finishes and damaged surfaces from rapid tool wear
  - NASA/MSFC key innovations were using a non-aqueous cutting fluid, a cheap polycrystalline diamond (PCD) tool for near-net shaping, light finish cuts using a natural diamond tool, and a 0° rake angle



Precitech Optimum 4200 SPDT Lathe



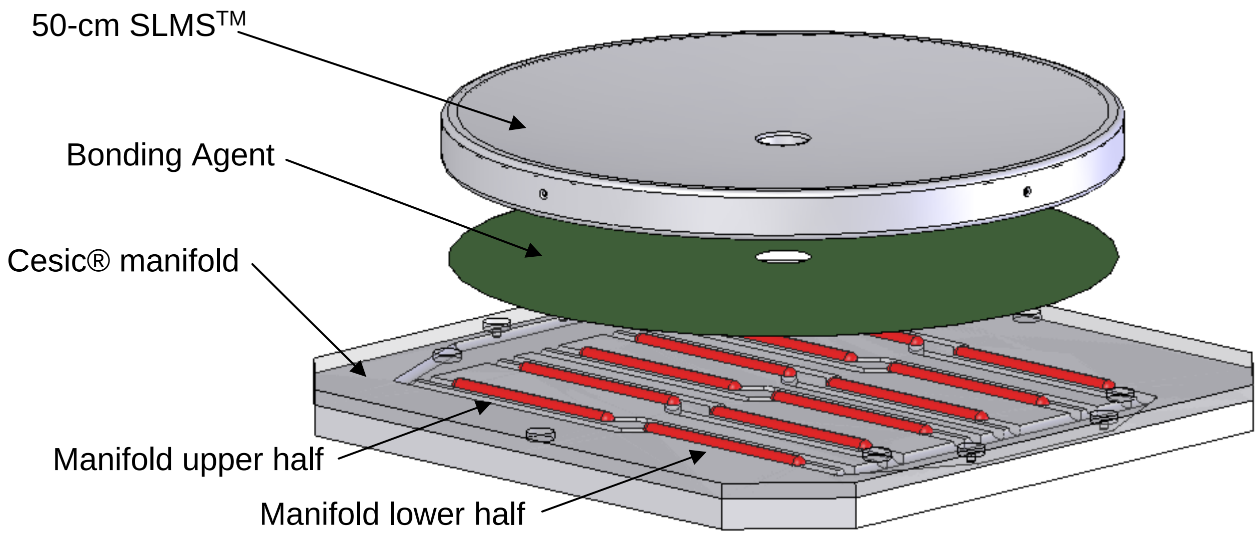
PCD Tool Roughing



Natural Diamond Tool Finish

CNO incorporating MSFC Innovations To Diamond Turn FISP SLMS™ PM

Assembly for Cryogenic Testing



- Bonding agent
  - ⇒Approximately .002-in thick bond line continuous over back surface of mirror
- Manifold
  - ⇒CeSic® upper and lower halves
    - →Upper half routes cooling agent near mirror
    - →Lower half routes cooling agent to and from test stand

Summary

- Cesic® manifold/mount has been manufactured
- Diamond turning of the first large parabolic SLMS™ substrate underway
- Successful transition of government sponsored research into industry use