NASA SBIR Subtopic S2.04
“Advanced Optical Components”

H. Philip Stahl, Ph.D.

Sub-Topic Manager

Guiding Philosophy

Define a customer or application

Define the problem based on clear criteria and metrics

Challenge the market place to develop a solution

Do Not Pre-Suppose or Pre-Select a Solution

Competition of Ideas

Deliver Demonstration Hardware not just a Paper Study

Customer / Application

Astrophysicists want bigger and better space telescopes:

- 4 to 8 m class monolithic primary mirrors for UV/optical or infrared
- 8 to 30 m class segmented primary mirrors for UV/optical or infrared
- 8 to 16 m class segmented x-ray telescope mirrors
- 8 to 10 m UV-transparent refractive Fresnel or diffractive lens

UV/optical telescopes require:

- 1 to 3 meter class mirrors with < 5 nm rms surface figures.

IR telescopes require:

- 2 to 3 meter class mirrors with cryo-deformations < 100 nm rms.

X-ray telescopes require:

- 1 to 2 meter long grazing incidence segments,
- angular resolution < 5 arc-sec to 0.1 arc-sec,
- and surface micro-roughness < 0.5 nm rms.

The Problem

Large Space Telescopes are Expensive.

And Budget and Constrained.

The Metric

For current launch vehicles, mass (areal density) is an important limitation, but this constraint is significantly relieved via the planned Ares V's 60,000 kg to L2 capacity.

Therefore, areal cost (cost per square meter of collecting aperture) rather than areal density is the single most important system characteristic of future advanced optical system.

Currently, both x-ray and normal incidence space mirrors cost \$3M to \$4M per square meter of optical surface area.

This research effort seeks a cost reduction for precision optical components by 20X to 100X to less than \$100K/m2.

The Challenge

The primary purpose of this subtopic is to develop and demonstrate technologies to manufacture ultra-low-cost precision optical systems for very large x-ray, UV/optical or infrared telescopes.

Potential solutions include but are not limited to direct precision machining, rapid optical fabrication, slumping or replication technologies to manufacture 1 to 2 meter (or larger) precision quality mirror or lens segments (either normal incidence for uv/optical/infrared or grazing incidence for x-ray).

An additional key enabling technology for UV/optical telescopes is a broadband (from 100 nm to 2500 nm) high-reflectivity mirror coating with extremely uniform amplitude and polarization properties which can be deposited on 1 to 3 meter class mirror.

Deliverables

Successful proposals will demonstrate prototype manufacturing of a precision mirror or lens system or precision replicating mandrel in the 0.25 to 0.5 meter class with a specific scale up roadmap to 1 to 2+ meter class space qualifiable flight optics systems. Material behavior, process control, optical performance, and mounting/deploying issues should be resolved and demonstrated. The potential for scale-up will need to be addressed from a processing and infrastructure point of view.

Phase I deliverable will be at least a 0.25 meter near UV, visible or x-ray precision mirror or lens or replicating mandrel, its optical performance assessment and all data on the processing and properties of its substrate materials. This effort will allow technology to advance to TRL 3-4.

Phase II deliverable will be at least a 0.50 meter near UV, visible or x-ray space-qualifiable precision mirror or lens system with supporting documentation, optical performance assessment, all data on materials and processing, and thermal and mechanical stability analysis. Effort will advance technology to TRL 4-5.

S2:04 Advanced Optical Component Systems.

The planned Ares V vehicle will enable the launch of extremely large and/or extremely massive space telescopes. Potential systems include 12 to 30 meter class segmented primary mirrors for UV/optical or infrared wavelengths and 8 to 16 meter class segmented x-ray telescope mirrors. UV/optical telescopes require 1 to 3 meter class mirrors with < 5 nm rms surface figures. IR telescopes require 2 to 3 meter class mirrors with cryo-deformations < 100 nm rms. X-ray telescopes require 1 to 2 meter long grazing incidence segments with angular resolution < 5 arc-sec down to 0.1 arc-sec and surface micro-roughness < 0.5 nm rms. Additionally, missions such as EUSO and OWL need 2 to 9 meter diameter UV-transparent refractive, double-sided Fresnel or diffractive lens.

In view of the very large total mirror or lens collecting aperture required, affordability or areal cost (cost per square meter of collecting aperture) rather than areal density is probably the single most important system characteristic of an advanced optical system. For example, both x-ray and normal incidence space mirrors currently cost $3M to $4M per square meter of optical surface area. This research effort seeks a cost reduction for precision optical components by 20X to 100X to less than $100K/m2.

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Phase II deliverable will be at least a 0.50 meter near UV, visible or x-ray space-qualifiable precision mirror or lens system with supporting documentation, optical performance assessment, all data on materials and processing, and thermal and mechanical stability analysis. Effort will advance technology to TRL 4-5.

Proposal must address technical need of a recognized future NASA space science mission, science measurement objective or science sensor for a Discovery, Explorer, Beyond Einstein, Origins, GOESS, New Millennium, Landmark-Discovery, or Vision mission. Missions of interest include: Constellation-X (http://constellation.gsfc.nasa.gov/); Generation-X (http://www.cfa.harvard.edu/hea/genx.html); Single Aperture Far-Infrared (http://safir.jpl.nasa.gov/technologies.shtml); Terrestrial Planet Finder (http://planetquest.jpl.nasa.gov/TPF/tpf_index.cfm); Orbiting Wide Angle Light Collector (http://owl.gsfc.nasa.gov/); Extreme Universe Space Observatory (http://hena.lbl.gov/EUSO/).

S2.04 & S2.05 Award Statistics Total

	Phase 1	Phase 2
2005	21% (8/38)	71% (5/7)
2006	28% (8/29)	63% (5/8)
2007	36% (4/11)	50% (2/4)
2008	59% (10/17)	
Total	32% (30/95)	63% (12/19)

S2.04 Award Statistics

	Phase 1	Phase 2
2005	22% (2/9)	100% (1/1)
2006	29% (6/21)	50% (3/6)
2007	33% (1/3)	100% (1/1)
2008	75% (3/4)	
Total	32% (12/37)	63% (5/8)

S2.05 Award Statistics

	Phase 1	Phase 2
2005	21% (6/29)	67% (4/6)
2006	25% (2/8)	100% (2/2)
2007	38% (3/8)	33% (1/3)
2008	54% (7/13)	
Total	31% (18/58)	64% (7/11)

2005 SBIR

Phase 1 9 Submitted 2 Selected (1 Funded)

S3.04-8120 Flextensional Microactuators for Large-Aperture Lightweight Cryogenic Deformable Mirrors, TRS Ceramics, Inc.

S3.04-9501 Scaling Actively Cooled SLMS Mirrors to the Meter-Class for Cryogenic Telescopes (SPIRIT, TPF-1, SPECS), Schafer Corp

Phase 2 1 Funded

S3.04-8120 Flextensional Microactuators for Large-Aperture Lightweight Cryogenic Deformable Mirrors, TRS Ceramics, Inc.

2006 SBIR

Phase 1 21 Submitted 6 Funded

- S3.04-8981 Nano-Enabled Low-Cost High-Performance UV Anti-Reflection Coatings AGILTRON Corporation
- S3.04-9129 Gadolinium EUV Multilayers for Solar Imaging Near 60 nm Reflective X-ray Optics, LLC
- S3.04-9254 Extremely Lightweight Segmented Membrane Optical Shell Fabrication Technology for Future IR to Optical Telescope Mevicon, Inc.
- S3.04-9363 Beam Combination for Sparse Aperture Telescopes Seabrook Engineering
- S3.04-9430 High Fidelity Multi-Mode Hyperspectral Multispectral Imager with Programmable Spectral Resolution Kent Optronics, Inc.
- S3.04-9665 Adaptive Lobster-Eye Hard X-Ray Telescope Physical Optics Corporation, EP Division

Phase II 3 Funded

- S3.04-8981 Nano-Enabled Low-Cost High-Performance UV Anti-Reflection Coatings AGILTRON Corporation
- S3.04-9129 Gadolinium EUV Multilayers for Solar Imaging Near 60 nm Reflective X-ray Optics, LLC
- S3.04-9363 Beam Combination for Sparse Aperture Telescopes Seabrook Engineering

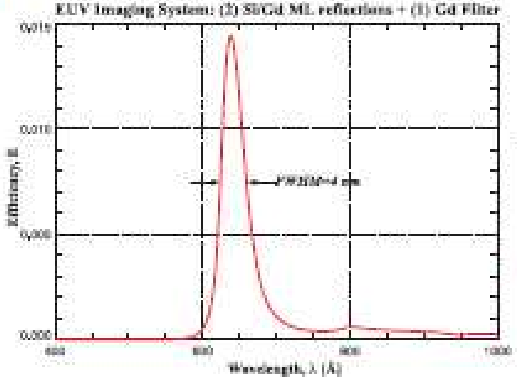
NASA SBIR/STTR Technologies

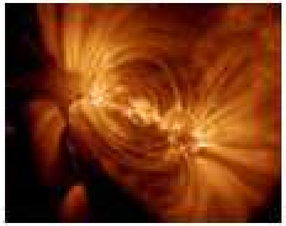
Gadolinium EUV Multilayers for Solar Imaging Near 60 nm

SBIR / STTR

PI: Dr. David L. Windt/Reflective X-ray Optics LLC, New York, NY

Proposal No: 06-1 S3.04-9129





Identification and Significance of Innovation

Develop and commercialize a new class of extreme ultraviolet (EUV) Si/Gd multilayers, designed as efficient narrow-band reflective mirror coatings operating near normal incidence in the 60-65 nm wavelength range. This will enable for the first time narrow-band EUV imaging of O V and Mg X formed at intermediate temperatures in the solar atmosphere.

Technical Objectives and Work Plan

Phase I Objective:

Experimentally determine the Si/Gd barrier-layer recipe that yields the best EUV performance and thermal stability.

Phase I Work Plan:

1. Deposit Si/Gd multilayers containing W, B4C and Si3N4 barrier layers in our 'production' coating system.
2. Use thermal annealing, XRR, and EUV reflectometry to identify the multilayer recipe having the best performance.

Technical Accomplishments:

The results of our Phase I activities have led to the selection of Si/Gd multilayers containing W barrier layers as the multilayer recipe that gives simultaneously the best EUV performance and the best thermal stability.

NASA and Non-NASA Applications

High-resolution, high-cadence solar imagers for unique observations of intermediate-temperature O V (63 nm) and Mg X (61 nm) emission lines, for NASA missions including Solar Probe, RAM, etc.

Applications to plasma physics, synchrotron research, EUV lasers, etc.

Firm Contacts

Reflective X-ray Optics

Dr. David L Windt
windt@rxollc.com
212-678-4932

NON-PROPRIETARY DATA

2007 SBIR

Phase 1: 3 Submitted 1 Funded

S2.04-9624 Radiation Hard Multi-Layer Optical Coatings, Nanohmics, Inc.

Phase 2: 1 Funded

S2.04-9624 Radiation Hard Multi-Layer Optical Coatings, Nanohmics, Inc.

NASA SBIR/STTR Technologies

Radiation hard multi-layer optical coatings

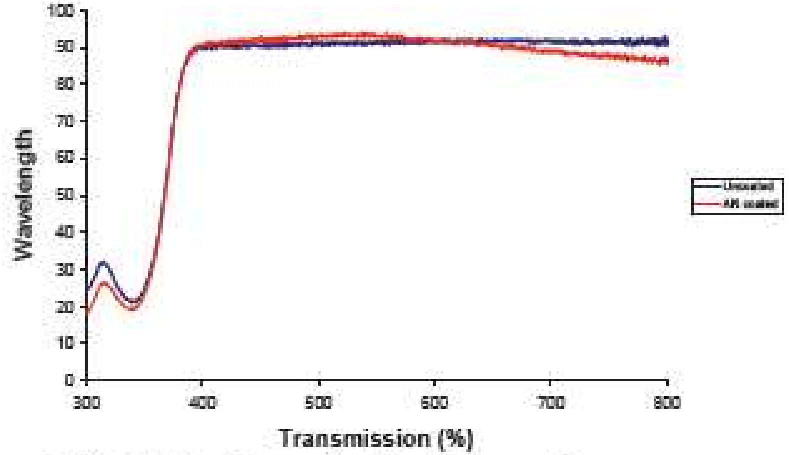
PI: Keith Jamison / Nanohmics, Inc, Austin, TX

Contract No: NNX08CC81P

Identification and Significance of Innovation

Next generation space telescopes require advanced optical coatings to provide low loss transmission of light in a variety of spectral ranges and protect optical components from damage in a space environment. In this SBIR program Nanohmics examined use of amorphous nitrides and oxides as a high quality, long lived coating for production of wide-acceptance angle IR anti-reflection and band-pass coatings on optical components. Amorphous nitrides are hard, flexible wide-bandgap semiconductor materials that can be used as an optical coating. Alternating layers of high index nitrides such as AlN combined with low index oxides such as SiO_2 can be used to make good wide acceptance angle anti-reflective coatings for a variety of optical components.

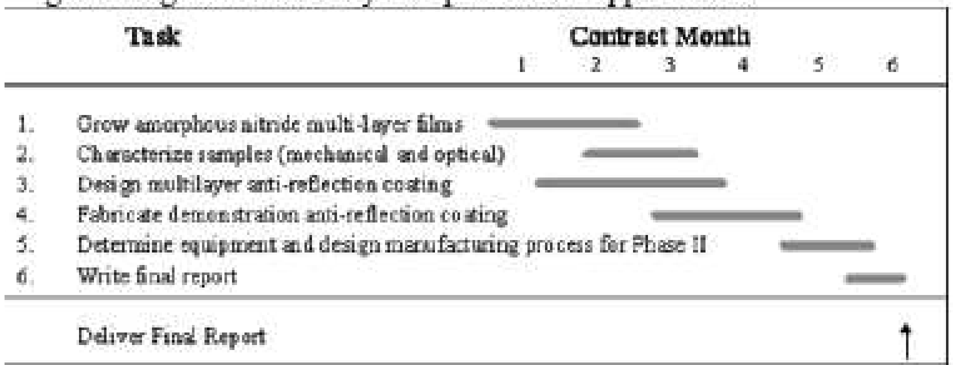
Expected TRL at end of Phase I contract: 4



Nitride / oxide antireflective coating

Technical Objectives and Work Plan

Objective: The technical objective of this Phase I SBIR project is to deposit multi-layer amorphous nitride and oxide thin films on various substrates and demonstrate that these films are ideal broadband polarization preserving anti-reflective coatings with good long term durability for space based applications.



NASA and Non-NASA Applications

- Flexible radiation hard anti-reflective or bandpass polarization preserving coating that can be deposited on many materials
- Improved lifetime optical coatings
- Scratch resistant optical coatings

Contacts

Keith Jamison
512-389-9990
Kjamison@nanohmics.com

NASA SBIR/STTR Technologies

Proposal No. S2.05-9745

Novel Materials for Mirror Substrate in Space Telescopes

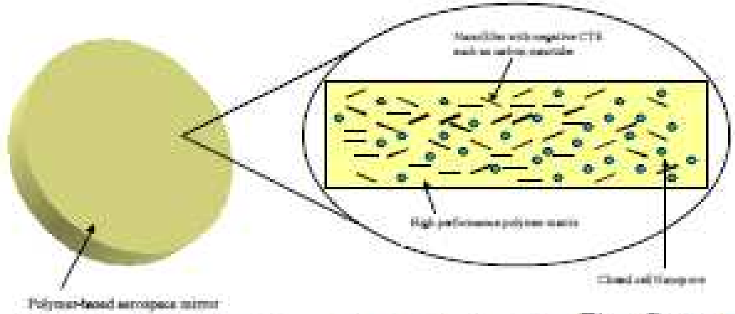
PI: Akbar G Fard

Advanced Materials Technology, Inc, 9324 Mandrake Ct, Tampa, FL 33647

Identification and Significance of Innovation

The proposed program is aimed at developing large, ultra-lightweight mirror substrate, including membrane optics for very large aperture space telescopes. Polymer-based membrane optics offer considerable weight and cost savings. In order to prevent significant figure error, polymers should have very low (ideally zero) coefficient of thermal expansion (CTE), low coefficient of moisture expansion (CME), low cure shrinkage, low internal stresses, low outgassing, and high thermal and environmental stability. To address this major challenge, we propose to develop a multicomponent polymeric system based on nanoporous polyimide nanocomposite (NPN) that will meet the desired requirements.

Expected TRL Range at the end of Contract: TRL 3-4



Conceptual illustration of our solution to develop thin mirror substrate materials

Firm Contact:
Dr. Akbar G Fard
Tel: 813-994-6360

Technical Objective

Development of novel nanoporous polymer nanocomposite (NPN) tailored for use in thin optical membrane with unique physical and mechanical properties, in particular low and tailorable CTE, low CME, and low outgassing, and demonstrate the feasibility of fabrication of these cost effective, lightweight thin mirror substrate materials

Work Plan

Task 1. Material selection and compounding
Task 2. Fabrication of nanoporous polyimide nanocomposite (NPN) films
Task 3. Evaluation of morphology and surface roughness of NPN films
Task 4. Characterization of physical and optical properties of novel mirror substrate materials
Task 5. Data analysis and down-selection

NASA Applications

-Enabling technology in space applications including space telescope, sunshield, antennas, concentrator, and solar sails
-Provide high strength, stiffness, dimensional stability, lightweight, resistance to space environmental effects, and ability to be coated
-Development of cost-effective, large, ultra-light weight, deployable, telescopes for astrophysics and Earth science
-Enabling optical technology that extend the state-of-the-art across wavelength bands from far-IR to Gamma-ray

Non-NASA Applications

-Commercial imaging and high data rate laser telecommunication
-Benefit aerospace, marine, aircraft, electronic, electrical, and automotive industries, as it offers unique combination of insulation and fire protection
-Enabling technology in IR imaging, used in sensors, weather monitoring and forecasting, and intelligent gathering
-Provide very low CTE for electronics packaging applications

NASA SBIR/STTR Technologies

Proposal: S2.05-8391 Reactive Atom Plasma Processing of Slumped Glass Wedges

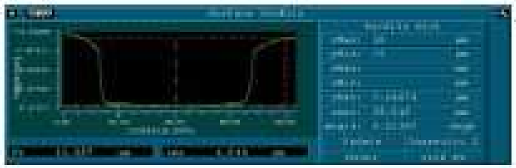
PI: Pradeep Subrahmanyan

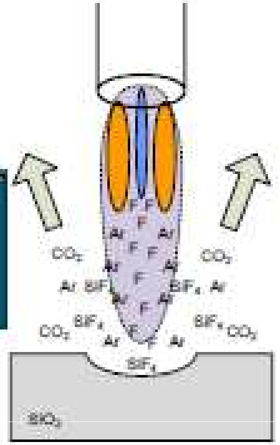
RAPT Industries, Inc. – Fremont, CA

Identification and Significance of Innovation

Future lightweight grazing incidence mirrors such as Constellation-X require thousands of lightweight mirror segments that require precision alignment and assembly. A "Fabricate and Assemble" technique developed at NASA requires the fabrication of precision wedges onto slumped glass forms. Conventional grinding of these thin wedges would lead to significant Twyman-like stresses from the subsurface damage and render the assembly technique impossible. The RAP process has been used to demonstrate the wedges required on glass substrates. Given the non-contact nature of the process, the wedge remains distortion free. The manufacturing process can be scaled in a cost-effective manner for volume manufacturing.

Expected TRL Range at the end of Contract (1-9): 1-3





Technical Objectives and Work Plan

The main technical objective is to demonstrate the fabrication of precision wedges on thin glass substrates similar to those planned for use in the Constellation-X program. The secondary objectives are to: 1) characterize the process on the glass substrates being used, 2) design and build a suitable heater for the glass substrates and 3) develop suitable metrology techniques to measure the profile of the wedge. In order to achieve these three objectives, RAPT Industries, Inc. divided the project into two major tasks:

Task 1: Process Characterization – Material removal rate studies using various temperatures, RF powers and gas flow rates. The RAP process is an Arrhenius rate reaction.

Task 2: Productization – Development of the appropriate tool path to etch in the wedge and the metrology to characterize the wedge profile.

NASA and Non-NASA Applications

Key NASA applications that could immediately use the technology are those involving high energy X-ray telescopes such as NuSTAR and Constellation-X. The technology developed is also applicable to other NASA programs that seek to minimize payload without sacrificing sensor performance.

Making precision surfaces with a high aspect ratio is a common problem across optics, semiconductors, compound semiconductors, photo-voltaics etc. The high aspect ratio results from a need to reduce mass (as in the case of lightweight mirrors), improve device performance/packaging (as in semiconductors), decrease costs (as in photo-voltaics). The methods developed in Phase 1 can be applied to the rapid manufacturing of such surfaces in these other areas. RAPT Industries, Inc. has already commercialized the edge cleaning of semi-conductor wafers through a licensing arrangement with Accretech, USA.

Firm Contacts

Pradeep Subrahmanyan, Ph.D., President/CEO TEL: 510-933-1001

2008 SBIR

Phase 1 4 Submitted 3 Funded

S2.04-9926 Low Cost Very Large Diamond Turned Metal Mirror, Dallas Optical Systems, Inc.

S2.04-9652 Silicon Carbide Lightweight Optics With Hybrid Skins for Large Cryo Telescopes, Optical Physics Company

S2.04-9748 A Low Cost Light Weight Polymer Derived Ceramic Telescope Mirror, United Materials and Systems

NASA 2008 Phase I SBIR S2.04-9652

Silicon Carbide Lightweight Optics with Hybrid Skins for Large Aperture Cryogenic Telescopes

PI: Marc Jacoby, Optical Physics Company, Inc. - Calabasas, CA
818-880-2907 x204; mjacoby@opci.com

Identification and Significance of Innovation

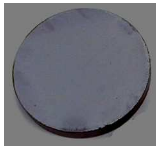
• Hybrid SiC fiber reinforced/SiC CVD facesheet coupled with SiC open-cell foam core to allow uniform cooling
• 500-750 μm thick SiC fiber reinforced layer ground finish with near net shape
• Post coat with a 125-250 μm thick, 100% dense CVD SiC polishing layer thus completing SiC foam core substrate
• Near net shape mirror reduces cost and schedule by 50%
• Scalable to meter class lightweight, athermal mirror

Expected TRL 4 at the end of Phase 1

SiC Foam Core

Hybrid SiC Skin

Near Net Shape Grind



SiC CVD Layer

Polish CVD

Technical Objectives

• 300mm dia. X 50mm thick f/2 spherical SiC foam core substrate with hybrid skin
•< 10 Å rms surface roughness
• < λ/10 rms surface figure
• Cryo mirror test at XRCF

Work Plan

• SiC fiber reinforced layer development
• Apply SiC fiber reinforced layer to 300 mm dia. SiC foam core
• Grind SiC foam core with hybrid skin to near net shape
• Coat with CVD SiC
• Polish 300mm dia. f/2 spherical SiC mirror

NASA Applications

• Lightweight cryogenic telescope mirrors: SAFIR, SPIRIT, SPECS, TPF-I

Non NASA Applications

• DOD requirements for IR/Vis imaging, surveillance and reconnaissance missions

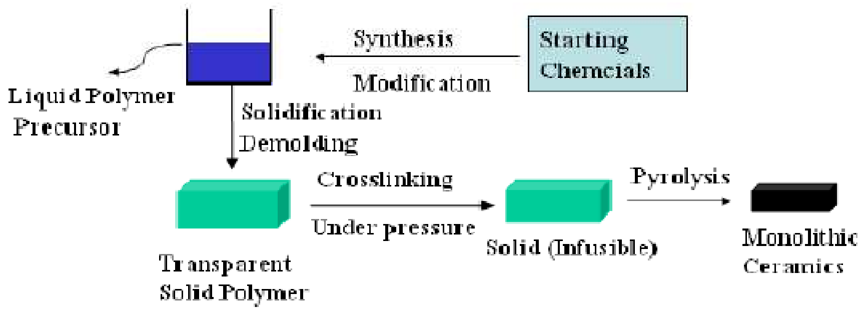
NASA 2008 Phase I SBIR S2.04-9748

A Low Cost, Light Weight, Polymer Derived Ceramic Telescope Mirror

PI: Fengxia Ma, United Materials & Systems, Inc. - Orlando, FL
Contact: Mark Tellam, 407-671-1156; mtellam@ceramicore.com

Identification and Significance of Innovation

• Develop SiCN, a polymer derived ceramics (PDC) for optical mirrors
• Starts with polymer precursors in a mold for near-net shape polymer, then cured by UV light
• Polymer cross-linked under pressure
• Pyrolysis at ~1000ºC to yield fully dense SiCN ceramic mirror substrate
• Material properties comparable or better than SiC
• Easier to machine than SiC
• Green technology – environmental friendly process



Processing steps for polymer-derived ceramics

Technical Objectives

• Deliver a 250mm dia. flat
• Cryo optical test at XRCF

Work Plan

• Collaborate with UCF for processes and material characterization
• Optimize green body manufacturing process
• Optimize mirror geometry and aspect ratio
• Characterize shrinkage, examine blank for inclusions and voids
• Coat mirrors, look for coating separation and characterize residual stress
• Determine process scalability

NASA Applications

• 0.25 to 0.5 meter class, with a specific scale up roadmap to 1 to 2+ meter class mirrors

Non NASA Applications

• Commercial telescope optics, telecomm and military optical systems.

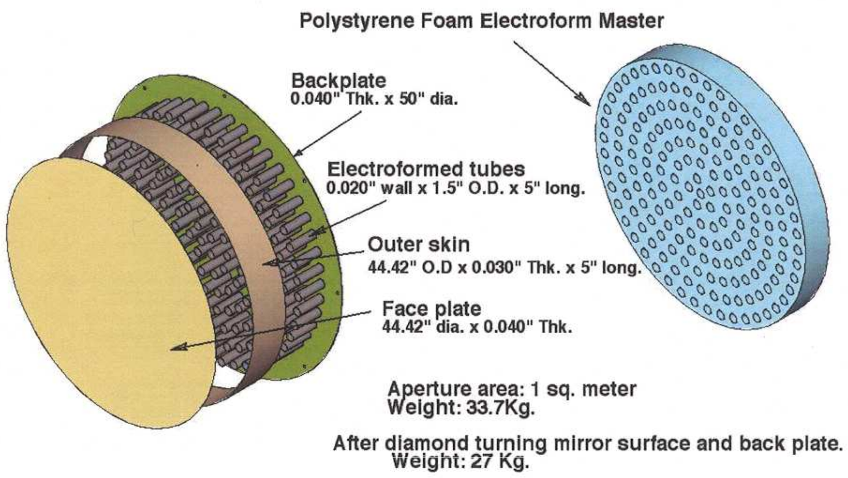
NASA 2008 Phase I SBIR S2.04-9926

Low Cost Very Large Diamond Turned Metal Mirror

PI: John Casstevens, Dallas Optical Systems, Inc. - Rockwell, TX
972-564-1156; c0029156@netportusa.com

Identification and Significance of Innovation

- Construction of low cost, light weight, large aperture mirror substrate by installing electroformed tubes onto a master machined from polystyrene foam
- Installed electroformed tubes allows the mirror faceplate and the back of the mirror to be plated
- Electrolytic plating of low stress, high phosphorus nickel (NiP) surface allows to be diamond turned for optical mirrors
- Excellent surface finishes on diamond turned NiP ~0.6nm rms can be obtained without any post polishing



Technical Objectives

- Material selection and process optimization
- Diamond turn a 150mm and a 300mm dia. flat
- Deliver a 300mm dia. flat
- Cryo optical test

Work Plan

- Process optimization for low areal density with high stiffness and dimensional stability
- NiP plating of mirror substrate
- Diamond turn mirrors

NASA Applications

- Lightweight cryogenic telescope mirrors: SAFIR, SPIRIT, SPECS, TPF-I
- X-ray telescopes missions: Con-X, Gen-X

Non NASA Applications

- DOD missions
- Weather satellite optical mirrors and astronomical telescope optics
- Commercial applications requiring lightweight optical components

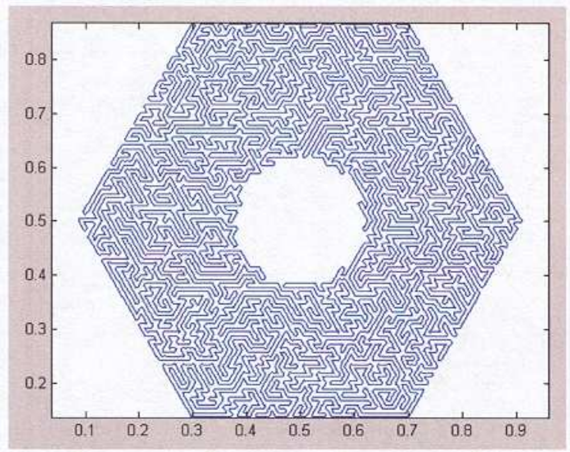
NASA 2008 Phase I SBIR S2.05-9001

Application of Zeeko's Novel Random Tool

PIs: John Kelchner and Dr. Christina Dunn, Zeeko Technologies, LLC. - West Lafayette, IN
765-775-1010; john.kelchner@zeekotechnologies.com

Identification and Significance of Innovation

• Deterministic CNC polishing with random unicursal tool path for optical flats, spheres, as well as aspheric and free-form surfaces
• Optimize dwell time according to influence function of the part



Random unicursal tool path

Technical Objectives

• Perform polishing trials to determine whether process can correct the part without inducing unwanted spatial frequencies error onto the part
• Incorporate non-uniform rational b-splines (NURBS) interpolation into the random tool paths
• Correct form error using random tool paths
• Process parameters optimization

Work Plan

• Perform experiments with Zeeko IRP200 CNC polisher on 50mm BK7 flats to <200nm RMS surface, and <3nm RMS roughness
• Incorporate NURBS into random tool paths
• Corrective polishing with random tool paths

NASA Applications

• Telescope mirrors: TPF-C, TPF-I, SAFIR, TMST

Non NASA Applications

• Medical imaging and defense optical systems
• High power laser systems
• Consumer products: camera lenses

Any Questions?