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This document is approved for public release

Low-weight, Low-cost, Low-cycle Time, Replicated Glass Mirrors

Engineered for life

Advanced Component Technology

0.5m f/1.95 Replicated Corrugated Borosilicate Mirrors

ITT Geospatial Systems
Rochester, NY

INNOVATION

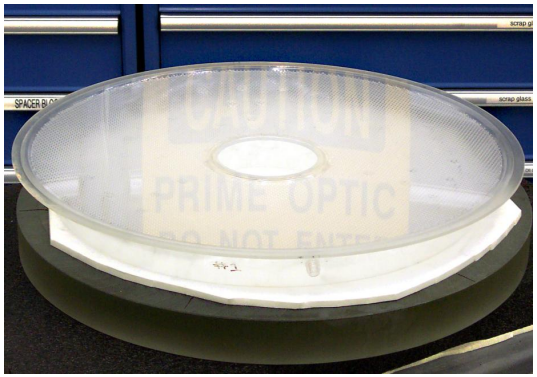
Development of technology to rapidly (< 1 month) fabricate large high quality , low mass, optics utilizing high temperature forming and replication processes

ACCOMPLISHMENTS

- Finished 0.5m mounted plano part to 52 nm-rms (ITT IR&D)
- Designed 0.5m borosilicate mirror blank and tooling for on-axis parabola
- Conceptual design for mirror mounts for mirrors
- Fabricated 7 0.5m f/1.95 corrugated mirror blanks matching ROC < 0.3%
- Polishing has been performed on two of blanks
- One part finished to ~365 nm-rms to within capture range of ITT's ion figuring processes (Part has been ion figured, but not optically tested as of this writing)

COMMERCIALIZATION

- ITT Corrugated Mirrors
- U.S. Patent #: 7,429,114 B2
- Commercial application opportunities are currently being explored
- Product is not yet available for purchase as a commercial item



0.5m ACT Corrugated Mirror Blank With Center-hole

GOVERNMENT/SCIENCE APPLICATIONS

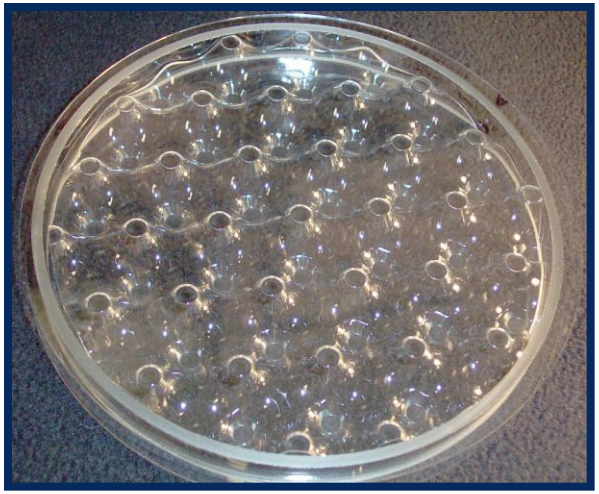
- Use in ground and space based optical systems
- Plano IR&D mirror needs additional testing to raise Technology Readiness Level (TRL) to 6 for flight applications
- Parabolic part TRL needs advancement to TRL 6 though incorporation of mount design and qualification testing
- For some earth science LIDAR applications, technology needs to be scaled to larger sizes and hexagonal geometry
- Future technology development opportunities include elimination of need for any conventional grinding processes and extending to other materials such as Corning ULE®

Agenda

- Introduction
- Corrugated Mirror Description
- Key Demonstrations of Corrugated Mirror Technology
  - Plano mirror prototype
  - Plano 0.5 m diameter mirror
  - Spherical 0.5 m diameter mirror
  - Parabolic 0.5 m diameter mirror with center-hole
- Technology development opportunities
- Summary

Introduction

- ITT is developing a family of mirror designs and processes to enable the fabrication of high quality lightweight mirrors which can be delivered for a fraction of the time and cost of more traditional mirrors
- One of the mirror types in this family is called a "Corrugated Mirror"
- Technology goals for this mirror type:
  - Size: up to 2 m
  - Areal density: 5-10 kg/m^2
  - Materials: borosilicate, ULE®, other glasses
  - Figure: 50 nm RMS
  - Fabrication time: 1 week blank fabrication
    3 weeks optical finish



Prototype Corrugated Mirror

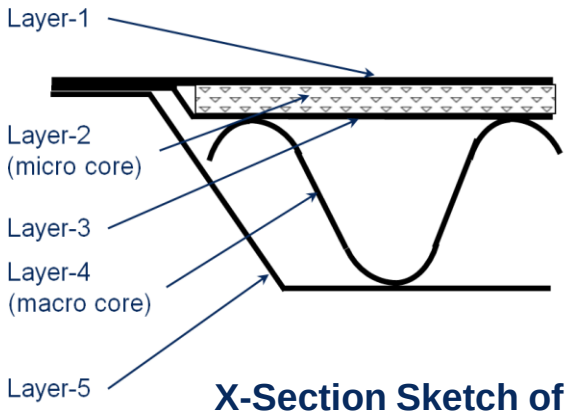
Introduction (continued)

- ITT has completed several key demonstrations of Corrugated Mirror technology and is actively working others
- Development has progressed through several key gates as demonstrated by:
  I. Plano mirror early prototypes (< 0.3 m)
  II. Plano mirror 0.5 m diameter (optically finished and mounted)
  III. Spherical mirror 0.5 m diameter mirror blanks (technology extended to curved surfaces)
  IV. Parabolic mirror 0.5 m with center-hole (currently in optical finishing)

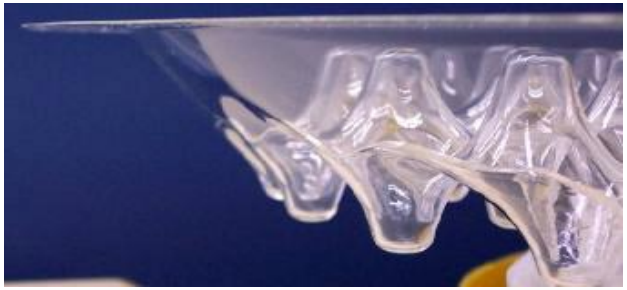
This presentation summarizes ITT's key demonstrations to date of Corrugated Mirror Technology

Corrugated Mirror Description

- Corrugated glass mirrors are closed-back lightweight optics
- Key features include:
  - Mirror components are molded from flat glass sheets and fused together at high temperature
  - The optical surface is formed over a precision mandrel
  - Mirror has depth resulting in excellent global stiffness-to-weight
  - Stiff lightweight optical facesheet
    - Facesheet itself has 3 layer ‘sandwich’ construction which results in 60%-70% mass reduction while maintaining local stiffness



X-Section Sketch of Corrugated Mirror

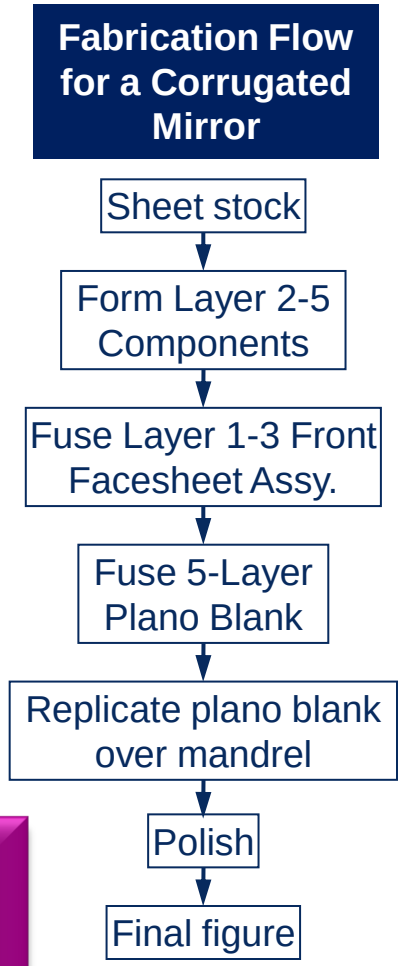


Central Core for a Corrugated Mirror (layer-4)

Corrugated Mirror Description (continued)

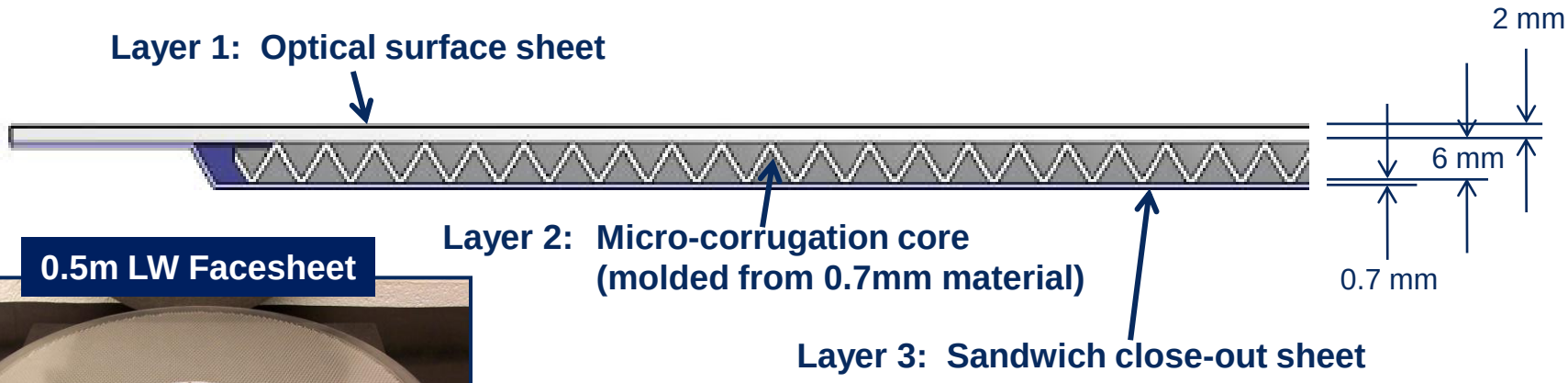
- A Corrugated mirror can be fabricated for a fraction of the time and cost of more traditional mirrors
  - All mirror components discussed in this briefing are currently fabricated from COTS material (Schott Borofloat® sheet material)
  - Borofloat® has low cost due to high volume from flat panel display market
  - Schott has demonstrated ability to fabricate sheets 0.7 mm thick in sizes up to 2.3m x 2.3m
  - Replication enables conventional mirror finishing processes to be minimized/eliminated

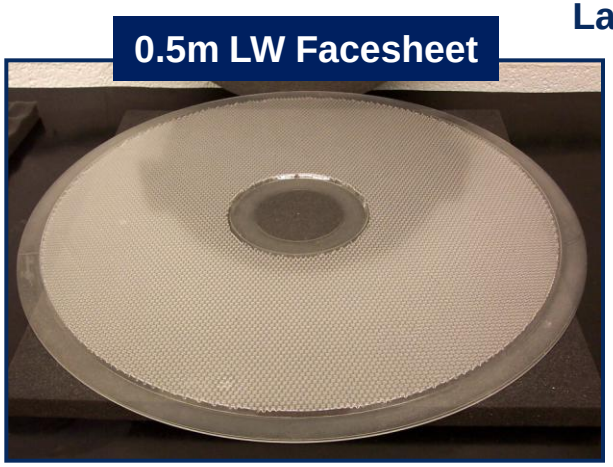
Corrugated borosilicate mirrors have rapid low-cost fabrication due molding and replication processes as well as the COTS glass sheet material



Lightweight Front Facesheet Fabrication

- The front facesheet consists of 3 layers fused together in a lightweight and stiff sandwich arrangement
  - Layers 2 & 3 are molded independently and then fused with layer-1
  - This facesheet reduces mass while maintaining local plate stiffness

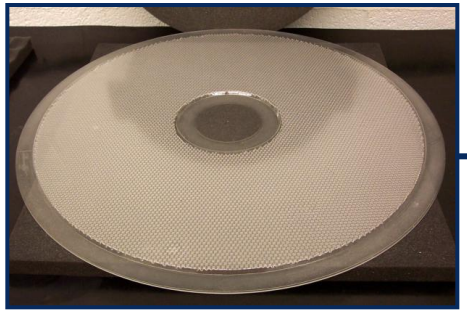




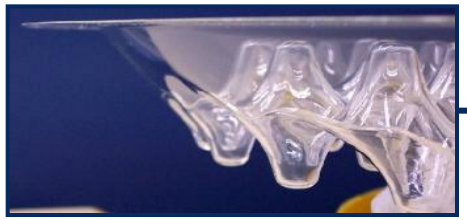
The lightweight facesheet is 60-70% lighter than a solid facesheet and has high stiffness to mass

Corrugated 0.5m Mirror Fabrication (5 layer)

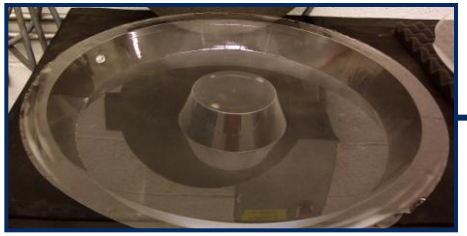
LW Front Facesheet
(layers 1-3)



Macro-Core
Molded from 0.7mm Sheet
(layer-4)



Back Facesheet
Molded from 0.7mm Sheet
(layer-5)



Kiln

Plano Mirror Blank

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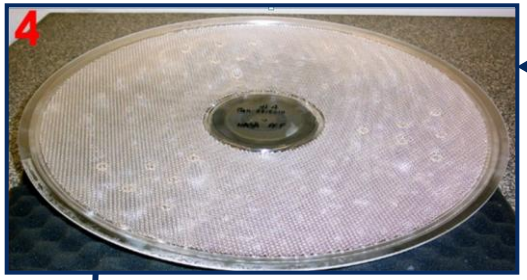


Replicated Parabola or Sphere

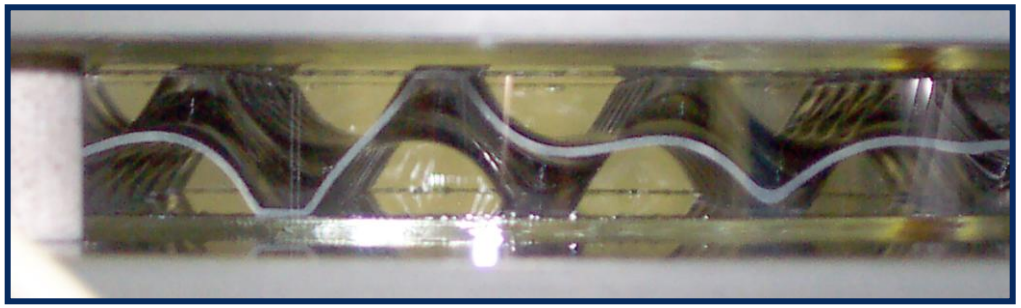
Polish

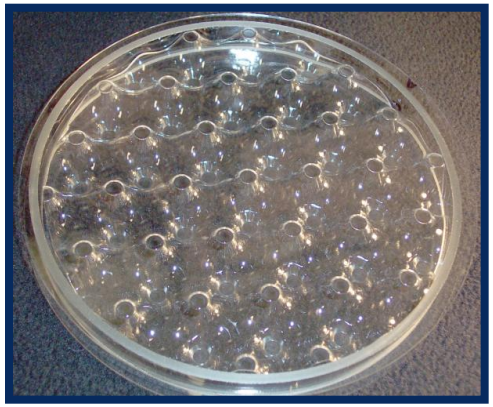
Final Ion Figuring

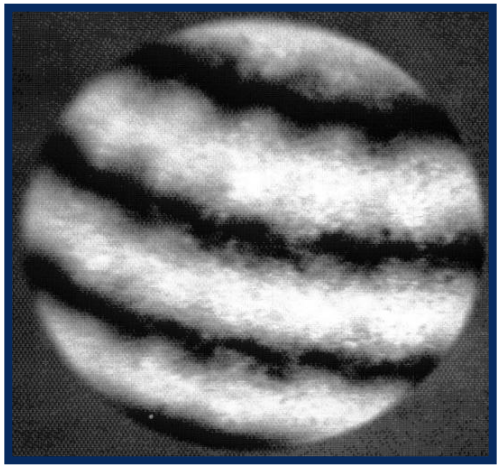
Corrugated mirror fabrication is rapid and readily scales to high volume manufacturing

I. Early Prototype Plano Mirrors

- Early prototype mirrors had a 3 layer design (i.e no lightweight facesheet)
  - Fabrication time: 5 days
  - Optical figure: 60 nm RMS surface
  - Areal density/size: 10 kg/m² / 150mm Ø
  - Accuracy of molded surface: ± 2 um







3-layer prototypes validated rapid fabrication approach for lightweight corrugated mirrors

II. Plano 0.5m Mirror, Finished & Mounted

ITT fabricated several 0.5m blanks

Areal Density: ~11 Kg/m^2

5-layer design provides significant global and local mirror stiffness compared to 3-layer design

Top 3 layers are a micro corrugation

6 mm tall micro core

Top 3-layers function as front facesheet

Top layer currently 2 mm to allow for fine grind prior to polish

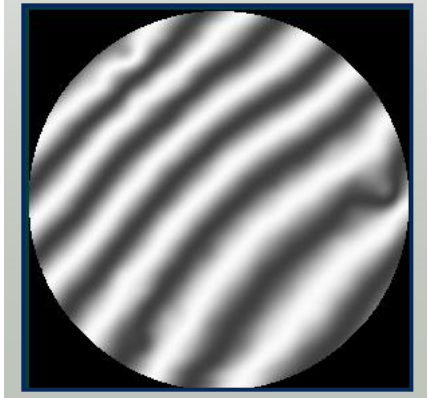
Environmental Testing

Testing performed by NASA GSFC under Innovative Partnerships Program funding

Survived 7-g RMS axial vibe (~32-g peak)

Mounted Plano Mirror Finishing

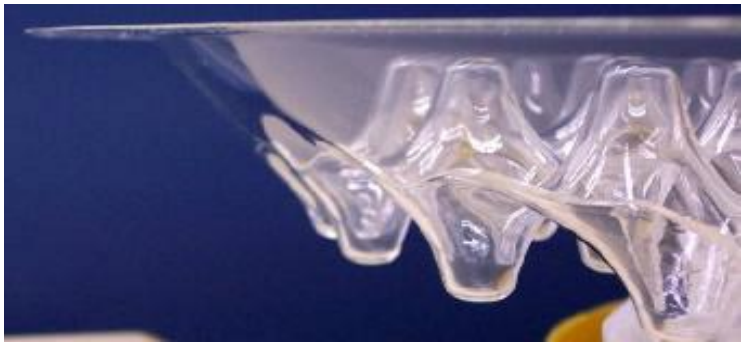
Part without center-hole mounted and finished to 52 nm RMS



Fabrication processes were successfully scaled up from 0.15m to 0.5m planos plus design was matured to include a stiffened facesheet and mounts

III. Spherical 0.5m Mirror Blanks

- ITT fabricated three f/2 spherical mirror blanks
- Blanks were fabricated to demonstrate extension of fabrication processes to spheres and aspheres



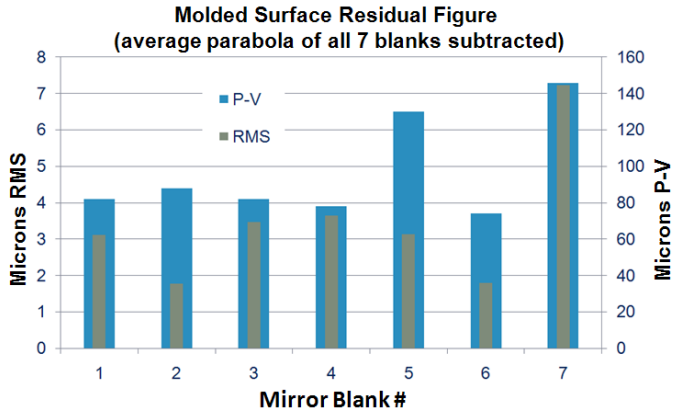
Macro Core

0.5m dia f/2 Spherical Mirror Blank

Fabrication processes were extended to produce spherical surfaces. This extension successfully paved the road for subsequent fabrication of aspheres.

IV. Parabolic 0.5m Mirror

- Activity funded by ESTO ACT grant
- Program goals
  - Design and fabricate a 0.5m f/1.95 parabola, <15 kg/m^2 mounted
  - Develop conceptual design of mounts for Taurus launch
  - Mirror to include a center-hole
  - Figure < 100nm RMS surface
- Status
  - Multiple mirror blanks successfully completed (7 blanks in < 9 weeks, furnace limited)
  - Blanks radius matched to 0.3%

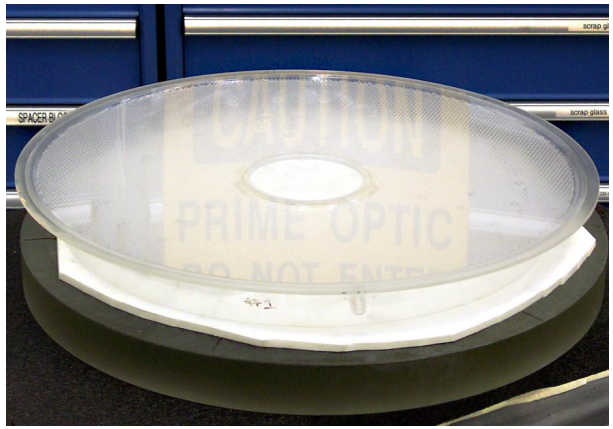


Rapid fabrication of multiple lightweight mirror blanks has been demonstrated

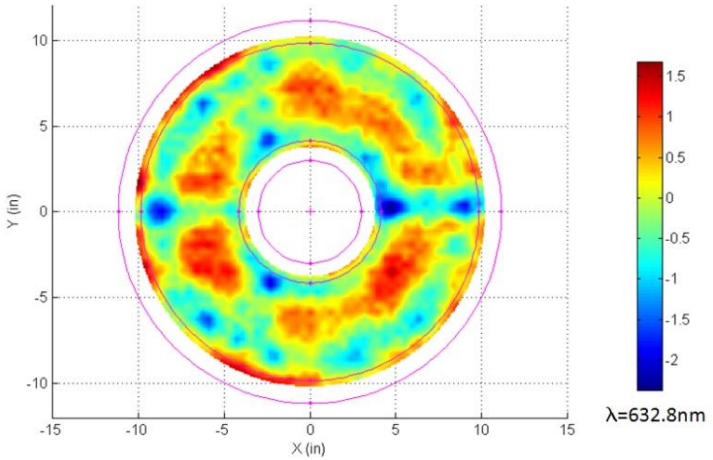
IV. Parabolic 0.5m Mirror (continued)

- Status (continued)
  - Two mirrors are in optical finishing
    - Mirror #1 current figure (pre-ion) 365 nm RMS (as of 6/1/10)
    - Mirror #2 being used to demonstrate computer controlled small tool polishing techniques
  - Finishing of mirror is progressing towards target figure as planned

Finishing of LW parabolic mirrors with center-holes is another significant milestone in the advancement of Corrugated Mirror Technology



f/1.95 Parabolic Corrugated Mirror



Surface Map of ACT Mirror # 1 prior to Ion (~365 nm RMS)

Technology Development Opportunities

- LW Mirror mounts for corrugated mirrors
- Qualification testing of mounted corrugated mirrors
- Scale to other sizes & shapes for different applications
- Replicate optical surface to tighter tolerance
  - Would reduce schedule & cost by eliminating current need for fine grind prior to polish
  - Would reduce areal density 2-3 kg/m^2 by allowing use of thinner material for the optical surface (layer-1)
- Extend corrugated mirror technology to other materials such as ULE® glass

Summary

ITT has developed and is successfully demonstrating designs and key processes which advance Corrugated Mirror Technology towards rapid fabrication of high quality lightweight optics at lower cost

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