
Chemical Vapor Composite Silicon Carbide for Space Telescopes (Postprint)

Clifford Tanaka
Kyle Webb

18 September 2006

Conference Proceedings

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AIR FORCE RESEARCH LABORATORY
Directed Energy Directorate
3550 Aberdeen Ave SE
AIR FORCE MATERIEL COMMAND
KIRTLAND AIR FORCE BASE, NM 87117-5776

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14. ABSTRACT The Purpose of this figure study was to demonstrate the optical figure and opto-mechanical performance capabilities for Trex's CVC SiC material. In the course of this activity a plano mirror was designed, fabricated, polished, and analyzed using interferometry tools and methods. The opto-mechanical and interferometric performance results are presented and analyzed in this report.					
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Chemical Vapor Composite Silicon Carbide for Space Telescopes

AFRL Phase 2 SBIR

Clifford T. Tanaka / Kyle Webb

Trex Enterprises Corporation



Chemical Vapor Composite Silicon Carbide for Space Telescopes

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 - General Optics for optical metrology.
 - 3D-Engineering Corp. for Finite Element Analysis.
 - ATA Engineering Corp. for modal testing.
 - Ormond, LLC for water jet milling.

Chemical Vapor Composite Silicon Carbide for Space Telescopes

Overview

- ◆ **Goal: Produce a 750mm aperture CVC SiC mirror for the Advanced Relay Mirror System (ARMS)**
- ◆ **Tasks:**
 - 150mm CVC SiC Plano Mirror Figure Study
 - Demonstrate fabrication of a stiff, high quality lightweighted mirror
 - Compare modeled FEA modal performance vs. experimental measurements
 - Evaluation of HEL coatings on CVC SiC coupons
 - 750 mm CVC SiC mirror design & fabrication
- ◆ **Status:**
 - 150 cm CVC SiC Mirror analysis completed.
 - HEL coating evaluation underway.
 - 750 mm CVC SiC mirror design completed. Fabrication in 2007.



Chemical Vapor Composite Silicon Carbide for Space Telescopes 150mm CVC SiC Plano Mirror Figure Study

- ◆ **The purpose of this figure study was to demonstrate the optical figure and opto-mechanical performance capabilities for Trex's CVC SiC material.**
- ◆ **In the course of this activity a plano mirror was designed, fabricated, polished, and analyzed using interferometry tools and methods.**
- ◆ **The opto-mechanical and interferometric performance results are presented and analyzed in this report.**



Chemical Vapor Composite Silicon Carbide for Space Telescopes 150mm CVC SiC Plano Mirror

- ◆ **The following specifications were established to benchmark the optical and opto-mechanical performance in this effort:**
 - Surface Figure:
 - Plano surface: 150mm outside diameter with a 95% clear aperture
 - Peak to Valley reflected wave front error: $< \lambda/10$ at 632.8 nm
 - Surface Roughness: $< 20 \text{ \AA}$ rms.
 - Areal Density: $\leq 10 \text{ kg/m}^2$
 - Modal Frequency Specification: $\geq 1500 \text{ Hz}$ in free-state
 - Ultra-Light-Weight, Open Back, Iso-Grid Mechanical Configuration: $\leq 200 \text{ grams}$
- ◆ **Design Approach:**
 - Finite Element Analysis (FEA) tools were used extensively to formulate an aggressive opto-mechanical design that would test the limits of the CVC SiC material as it is applied to challenging optical figure polishing processes.
 - Sensitivities associated with self-weight-sag and print-through or quilting were anticipated to be revealed and studied.

Chemical Vapor Composite Silicon Carbide for Space Telescopes

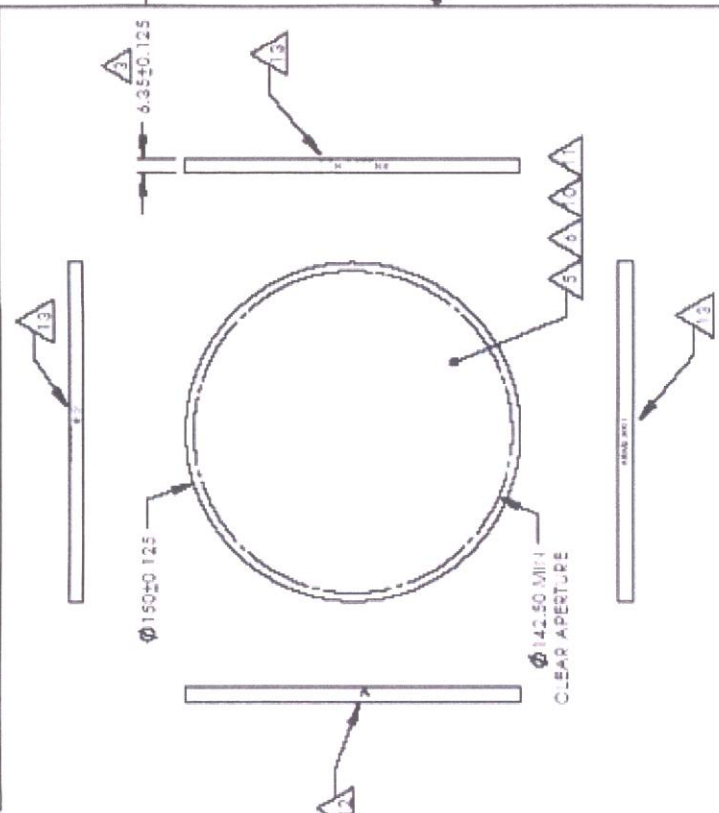
150mm CVC SiC Plano Mirror

150mm Mirror Detailed Design (sheet 1 of 2)

NOTES: UNLESS OTHERWISE SPECIFIED:

1. APPLICABLE STANDARDS/SPECIFICATIONS:
 A) ASME Y14.5M-1994 (DIMENSIONS AND TOLERANCES)
 B) ASME Y14.5M-1994 (LATEST REVISION) (DRAWING INTERPRETATION)
2. MATERIAL: TREX CVC SiC
3. WEDGE: < 1 ARC MINUTE
4. CHAMFER ALL EDGES TO 0.25(0.10 X 45° ±10°)
5. CLEAR APERTURE: MIN 95% OF OD
6. SCRATCH/DIG: 40-20 OR BETTER PER MIL-PRF-13830, OVER CLEAR APERTURE
7. EDGE CHIPS TO BE STORED AND NOT TO EXTEND INWARD BEYOND 1.0
8. SURFACES ARE TO BE FINE-GRAINED
9. ST. RADIUS: 99 (PLATING)
10. PEAK-TO-VALLEY REFLECTED WAVEFRONT ERROR < λ/10 AT 632.8 nm, SURFACE ROUGHNESS < 20 Å RMS OVER CLEAR APERTURE
11. COATING: T80 R-99.99% AT 1.054 MICROMETERS
12. IDENTIFY REFLECTIVE COATING SURFACE AS "V" APPROXIMATELY WHERE SHOWN USING NO PARTICLE GENERATING, INORGANIC MARKING MATERIAL
13. IDENTIFY WITH TREX PART NUMBER, RI NUMBER, AND ID NUMBER APPROXIMATELY WHERE SHOWN USING NO PARTICLE GENERATING INORGANIC MATERIAL. TEXT MUST BE CLEAR AND LEGIBLE WITHOUT MAGNIFICATION
 A) THE COATING RUN NUMBER (XXXXXX) WHERE X = CHAMBER ID (E.G. A=1, B=2, ETC.)
 B) THE URIGUS RUN ID AND H = HOLDER NUMBER
 C) MATERIAL LOT ID NUMBER
14. CLEAR PART AND PACKAGE USING CLEAR, NON-OUTGASSING, PARTICLE-FREE MATERIAL. INCLUDE DESIGNER'S DOUBLE-BAG PACKAGING OPTICS TO BE PACKAGED SUCH THAT NO MATERIAL, INCLUDING LEIS TISSUE, CONTACTS THE OPTIC WITHIN THE CLEAR APERTURE
15. PARTS TO BE PACKAGED INDIVIDUALLY AND LABELED ON THE OUTER SURFACE OF THE PACKAGE WITH TREX PART NUMBER AND CODE NUMBER THE SAME AS IN NOTE 12
16. THE FOLLOWING DOCUMENT MUST BE SUPPLIED FOR EACH SERIALIZED PART (ELECTRONIC DATA PREFERRED): REFLECTION SPECTRUM FOR EACH COATING RUN
17. MANUFACTURING METHODS, EQUIPMENT, AND MATERIALS THAT ARE USED TO FABRICATE THIS PART ARE NOT TO BE CHANGED AFTER TREX QUALIFICATION, WITHOUT WRITER APPROVAL
18. DIMENSIONS ARE IN MILLIMETERS

REV. NO.		DATE		APPROVED	
1		6/27/2005			
2		7/11/2005			



TYPE		P-WHITE		6/27/2005		TREX ENTERPRISES	
PROBING		P-WHITE		6/27/2005		10455 Enterprise Center, Suite 200, Honolulu, HI 96821-4331	
OTHER						ARMS 150 mm MIRROR	
PART		A		150		155 501	
REV		B		OZKJ6		ARMS 3001	
DRAWN BY		150		150		150	
CHECKED BY		150		150		150	
DATE		150		150		150	
SCALE		1:1		1:1		1:1	
SHEET NO.		1		1		1	
TOTAL SHEETS		1		1		1	



Chemical Vapor Composite Silicon Carbide for Space Telescopes 150mm CVC SiC Plano Mirror Interferometer Measurement Configurations

◆ Horizontal:

- Three Point Supported at Iso-Grid Nodes
- Supported on Tissue Paper
- Supported at center Iso-grid Node
- Three Point support at Mirror Edge

◆ Vertical:

- Edge mounted on a V block
- Edge mounted on a V block and rotated from original measured position.
- Edge mounted on a V block and rotated again from the last measured position.

Chemical Vapor Composite Silicon Carbide for Space Telescopes

150mm CVC SiC Plano Mirror

Horizontal, Mounted on Tissue Paper

◆ **Interferometer Performance:**

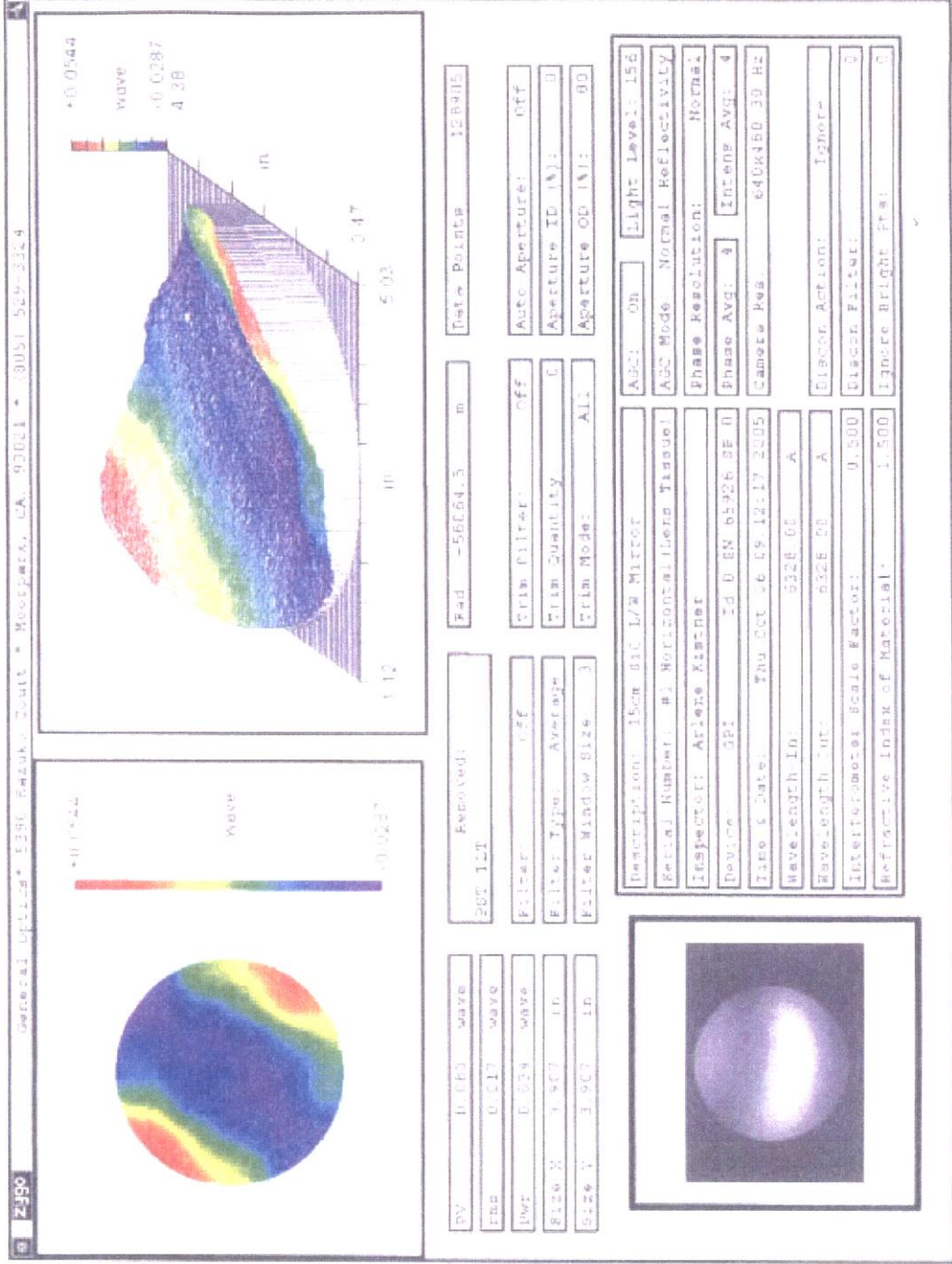
- pv 0.083 waves ($\lambda/12$)
- Rms 0.017 waves ($\lambda/59$)
- Pwr 0.034 waves

◆ **Measurement Orientation:**

- Horizontal (flat on optical table)
- Mirror supported with tissue paper only.
- Produces classic potato chip shape interferogram.



Tissue Paper Support



Chemical Vapor Composite Silicon Carbide for Space Telescopes 150mm CVC SiC Plano Mirror Horizontal Mount, Single Flat Contact Point at Center

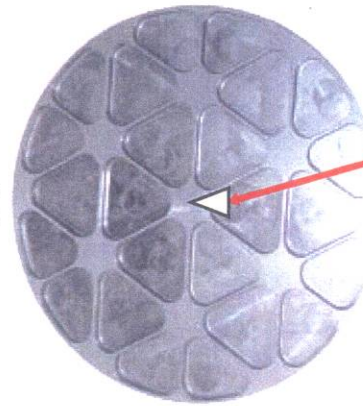
◆ Interferometer

Performance:

- pv 0.126 waves ($\lambda/8$)
- rms 0.029 waves ($\lambda/34$)
- Pwr -0.097 waves

◆ Measurement Orientation:

- Horizontal (flat on optical table)
- Mirror supported at the center iso-grid node flat on the back side only.
- Produces a convex shape as seen in the interferogram.



Single flat contact support at center Iso-grid node



PV	0.126 wave	Rms	0.029 wave	Date	2012.06	m	Data Point#	128785	
Wvr	-0.097 wave	Pwr	off	Filter	off	Trim Filters	off	ADD Aperture:	off
Plane X	0.007 in	Plane Y	0.007 in	Filter Type	Average	Trim Quantity	0	Aperture ID	All
Plane Z	0.007 in	Filter Width	0.007 in	Filter Mode	All	Trim Mode	All	Aperture OD	All

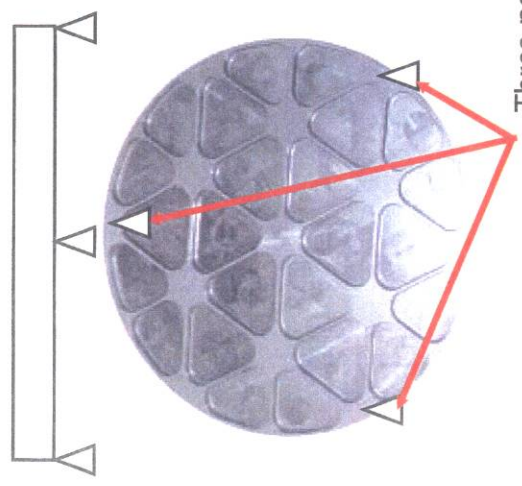
Description:	150mm SiC 1/8 Mirror	ADD:	On	Light Level:	15
Serial Number:	01 Horizontal	ADD Mode:	Normal	Reflectivity	
Inspector:	Arlene Fister	Phase Resolution:	Normal		
Probe:	Id D SN 65926 80 0	Phase Avg:	4	Interleaved	4
Probe Delay:	Thu Dec 06 09:31:05 2005	Camera Res:	640x480 30 Hz		
WaveLength In:	6328.00 A				
WaveLength Out:	6328.00 A	Discard Action:	Ignore		
Interferometer Scale Factor:	0.500	Discard Filter:	0		
Reflective Index of Material:	1.500	Ignore Bright Pts:	0		

Chemical Vapor Composite Silicon Carbide for Space Telescopes

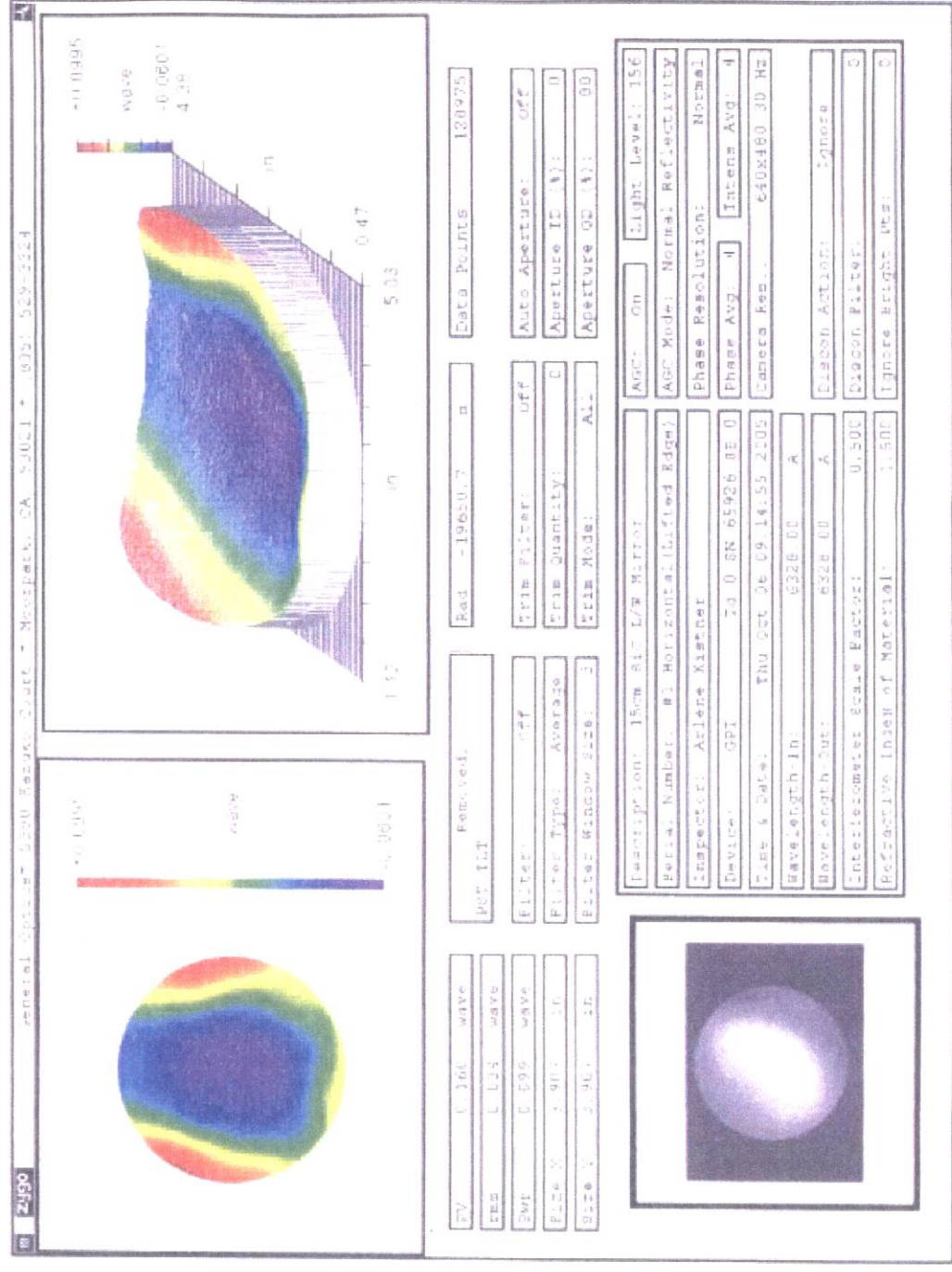
150mm CVC SiC Plano Mirror

Horizontal Mount, Three Point Support at Edge

- ◆ **Interferometer**
- Performance:**
 - pv 0.160 waves ($\lambda/6$)
 - rms 0.034 waves ($\lambda/29$)
 - Pwr 0.099 waves
- ◆ **Measurement Orientation:**
 - Horizontal (flat on optical table)
 - Mirror supported with 3 point contacts at perimeter edge
 - Produces lifted edge or concave profile on interferogram.



Three point edge support configuration



Chemical Vapor Composite Silicon Carbide for Space Telescopes

150mm CVC SiC Plano Mirror

Vertical Mount, V-Block

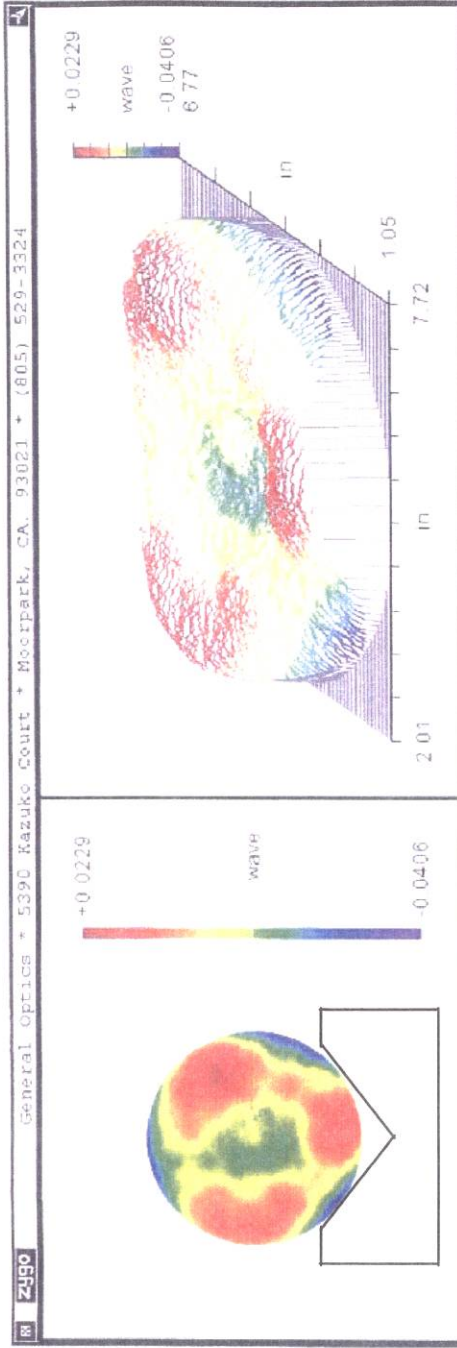
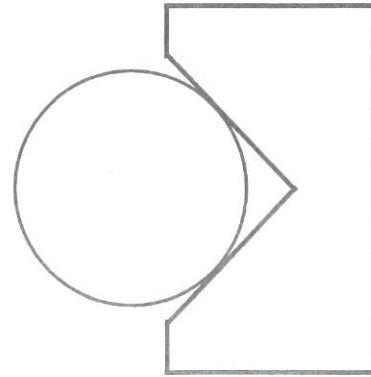


◆ **Interferometer Performance:**

- pv 0.064 waves ($\lambda/16$)
- rms 0.010 waves ($\lambda/100$)
- Pwr 0.003 waves

◆ **Measurement Orientation:**

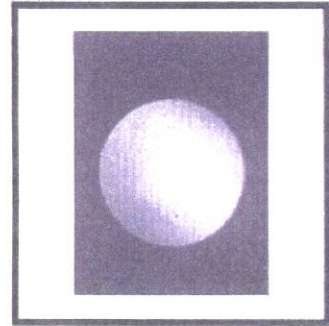
- Vertical (V-Block support)
- V-Block oriented in normal configuration as viewed in interferograms.
- Produces best results on interferogram for this mounting orientation.



PV	0.064	wave
Rms	0.010	wave
Pwr	0.003	wave
Size X	5.715	in
Size Y	5.715	in

Removed:	Rad	1427395.4	m
Filter:	Off		
Filter Type:	Average		
Filter Window Size:	3		

Data Points	94709
Auto Aperture:	Off
Aperture ID (#):	0
Aperture OD (%):	80



Description:	15cm SiC L/W Mirror	ASC:	On	Light Level:	151
Serial Number:	#1	AGC Mode:	Normal Reflectivity	Phase Resolution:	Normal
Inspector:	Arlene Kistner	Phase Avg:	4	Intens Avg:	4
Device:	Mark GPI Id U SN 3355 SB 0	Camera Res.:	640x460	Discon Action:	Ignore
Time & Date:	Thu Oct 06 08:19:34 2005	Discon Filter:	0	Ignore Bright Pts:	0
Wavelength-In:	6328.00 A				
Wavelength-Out:	6328.00 A				
Interferometer Scale Factor:	0.500				
Refractive Index of Material:	1.500				

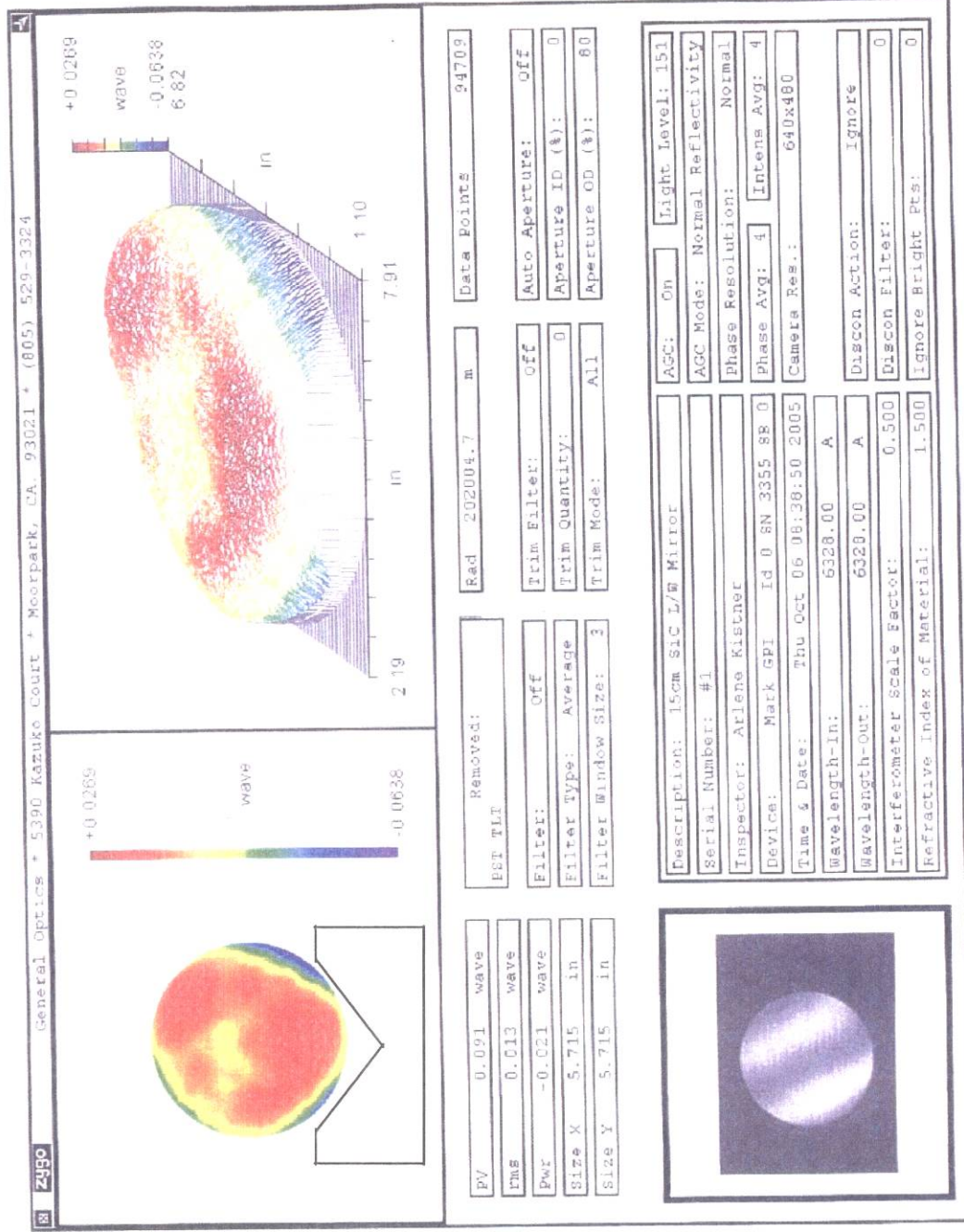
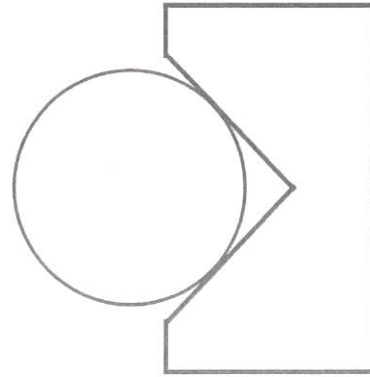
Chemical Vapor Composite Silicon Carbide for Space Telescopes

150mm CVC SiC Plano Mirror

Vertical Mount, V-Block (rotated)



- ◆ **Interferometer Performance:**
 - pv 0.091 waves ($\lambda/11$)
 - rms 0.013 waves ($\lambda/77$)
 - Pwr -0.021 waves
- ◆ **Measurement Orientation:**
 - Vertical (V-Block support)
 - V-Block oriented in normal configuration as viewed in interferograms.
 - Rotated from previous position.



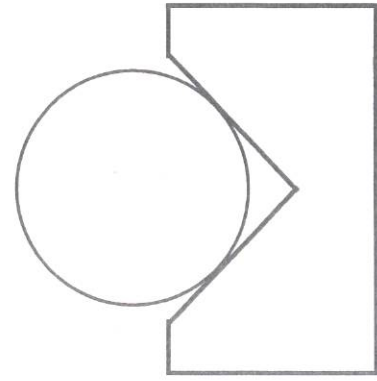
Chemical Vapor Composite Silicon Carbide for Space Telescopes

150mm CVC SiC Plano Mirror

Vertical Mount, V-Block (rotated again)



- ◆ **Interferometer Performance:**
 - pv 0.146 waves ($\lambda/7$)
 - rms 0.022 waves ($\lambda/45$)
 - Pwr waves -0.052
- ◆ **Measurement Orientation:**
 - Vertical (V-Block support),
 - V-Block oriented in normal configuration as viewed in interferograms.
 - Rotated again from previous position.



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Color scale: +0.0469 wave (red), -0.0990 wave (blue)

Color scale: +0.0469 wave (red), -0.0990 wave (blue)

pv	0.146	wave	Removed:	Rad	79777.6	m	Data Points	94709
rms	0.022	wave	Filter:	Trim Filter:	Off	Auto Aperture:	Off	
Pwr	-0.052	wave	Filter Type:	Trim Quantity:	0	Aperture ID (%):	0	
Size X	5.715	in	Filter Window Size:	Trim Mode:	All	Aperture OD (%):	80	
Size Y	5.715	in						

Description:	15cm SiC L/W Mirror	AGC:	On	Light Level:	151
Serial Number:	#1	AGC Mode:	Normal Reflectivity	Phase Resolution:	Normal
Inspector:	Arlene Kistner	Phase Avg:	4	Intens Avg:	4
Device:	Mark GPI Id 0 SN 3355 8B 0	Camera Res.:	640x480	Discon Action:	Ignore
Time & Date:	Thu Oct 06 08:43:31 2005	Wavelength-In:	6328.00	A	
Wavelength-Out:	6328.00	A		Discon Filter:	0
Interferometer Scale Factor:	0.500	Refractive Index of Material:	1.500	Ignore Bright Pts:	0

Chemical Vapor Composite Silicon Carbide for Space Telescopes

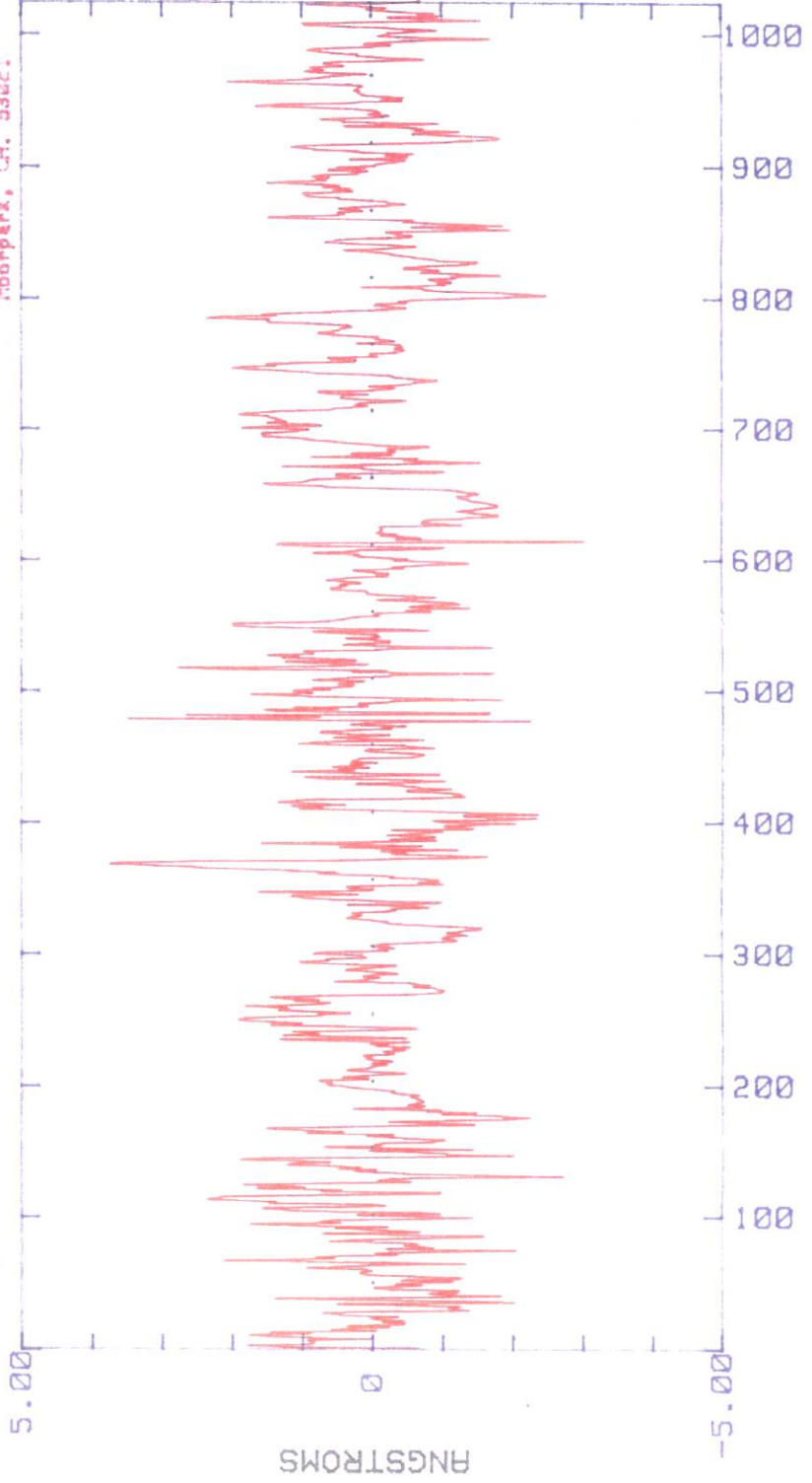
150mm CVC SiC Plano Mirror

Surface Roughness via Zygo



15cm SiC L/W Mirror #1

Processed 6 Oct 2005 09:31:36
RMS 0.93 angstroms
P-V 6.78
1024 points
General Optics
(825) 529-3324
535C Kazuko Ct.
Moorpark, CA. 93021



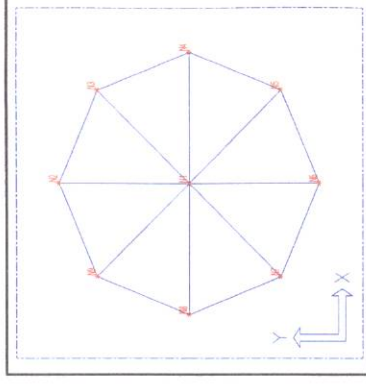
Chemical Vapor Composite Silicon Carbide for Space Telescopes

150mm CVC SiC Plano Mirror

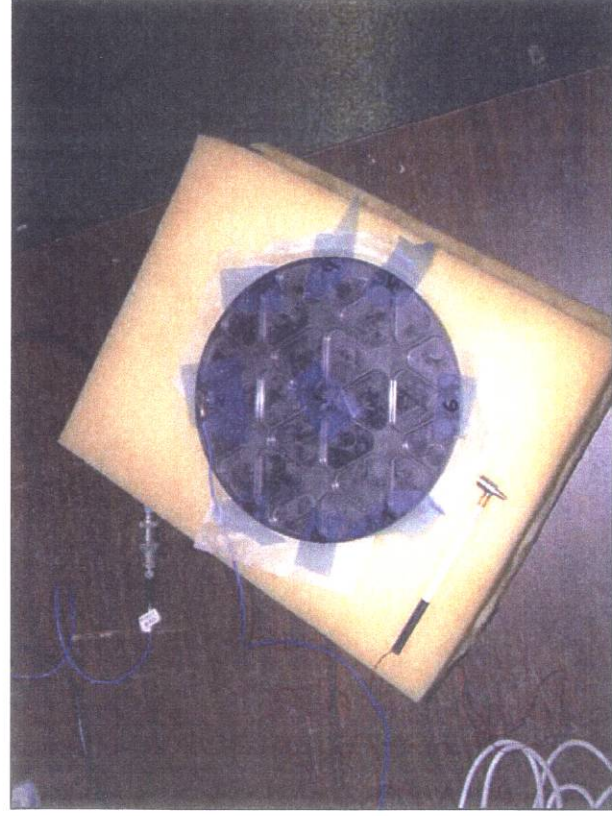
Modal Analysis

- ◆ **Test was performed via classical ping test protocol.**
 - Foam bed used to simulate free state mode.
 - Tiny hammer accelerometer & response accelerometer.
 - Ping responses were collected from nine (9) points depicted in schematic (in figure at right).
 - Software program transformed responses into wire plots of mode shapes as presented in earlier slides

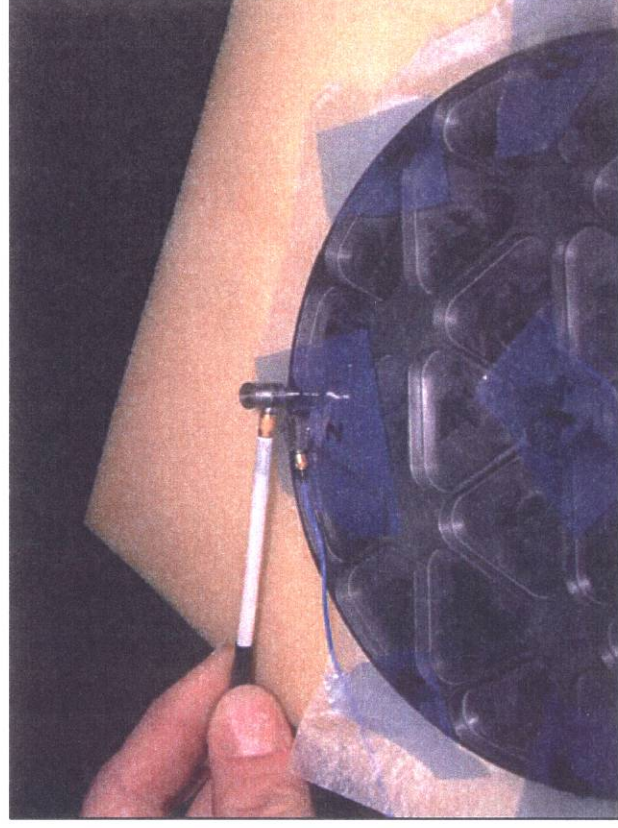
◆ Comparison made to Finite Element Analysis Results



Wire Frame Schematic of Ping Test Points on Mirror



Test Setup Showing Foam Bed & Tiny Hammer Accelerometer



Hammer Accelerometer Shown as Tested

Chemical Vapor Composite Silicon Carbide for Space Telescopes

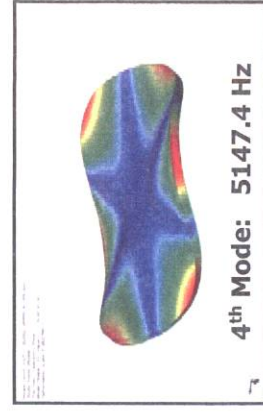
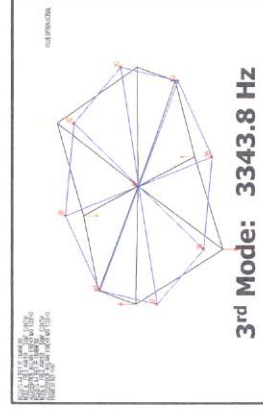
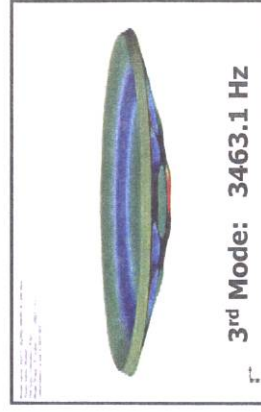
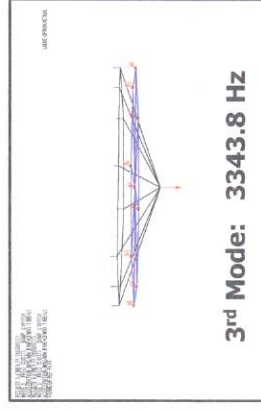
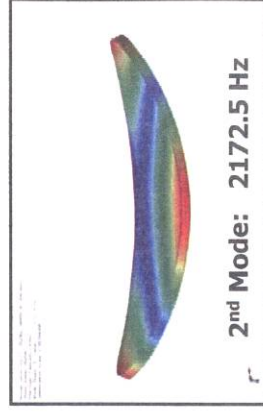
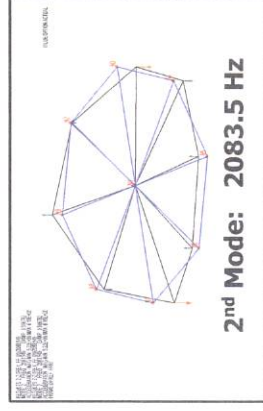
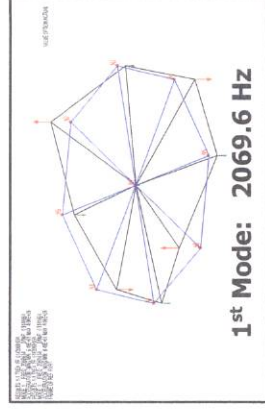
150mm CVC SiC Plano Mirror

Modal Analysis Results

- ◆ A close correlation is established between the predicted modal values and the actual measured modal values
- ◆ Variance in higher modes can be attributed to:
 - Difference between theory and reality.
 - Constraint conditions in FEA model can not exactly duplicate actual constraint system as tested (foam bed).

Measured

Predicted



Predicted		Measured	
Mode	Hz	Mode	Hz
1st	2172.3	1st	2069.6
2nd	2172.5	2nd	2083.5
3rd	3463.1	3rd	3343.8
4th	5464.1	4th	4646.9

Chemical Vapor Composite Silicon Carbide for Space Telescopes

150mm CVC SiC Plano Mirror

Water Jet Cutting of CVC SiC

◆ Development of water jet cutting and milling process have proven to be feasibility for fabrication:

- Demonstrated Water Jet Cutting and Piercing Processes:



Water Jet Cutting Through 1.3" of CVC SiC Material



Initial Water Jet Piercing Through .5" of CVC SiC Material



Water Jet Piercing Through 1.3" of CVC SiC Material

Chemical Vapor Composite Silicon Carbide for Space Telescopes

150mm CVC SiC Plano Mirror

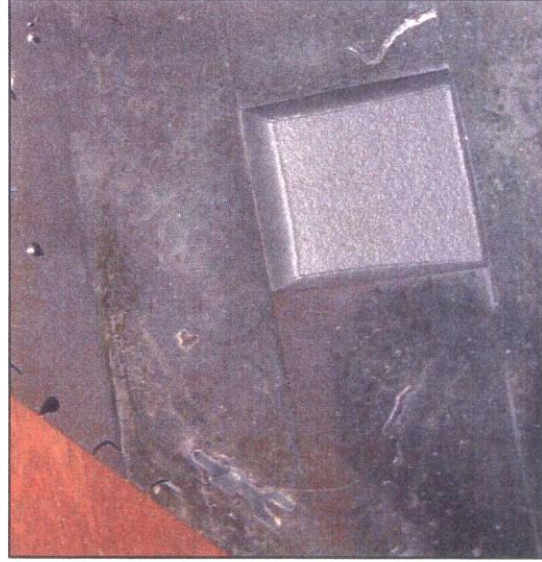
Water Jet Milling of CVC SiC

◆ 5 Axis water jet milling capability has been established:

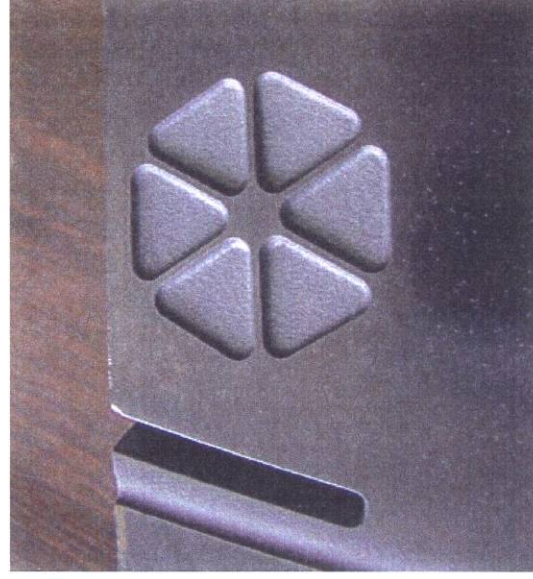
- Demonstrated water jet milling process:
- Current process produces punch through of 1.3" thick CVC SiC material in 40 seconds
- Cutting rates of over 1 linear inch per minute on 1.3" material have been demonstrated.
- Milling rates of .010" per pass have been demonstrated.



Water Jet Milling Simple Masking Setup



Water Milling of 25mm by 25mm Square by 4mm Deep Pocket in CVC SiC Material



Water Milling of Isogrid for lightweighting of CVC SiC



Chemical Vapor Composite Silicon Carbide for Space Telescopes Summary

- ◆ CVC Silicon Carbide is an ideal optical material, with high specific stiffness, superior thermal stability, polishability and low residual stress.
- ◆ 15cm plano CVC SiC mirror with excellent stiffness, surface figure and surface roughness has been demonstrated.
- ◆ Experimental and theoretical modal analysis show that CVC SiC components can be readily designed & modeled.
- ◆ Trex is proceeding with 750mm aperture mirror fabrication, to be completed in 2007.