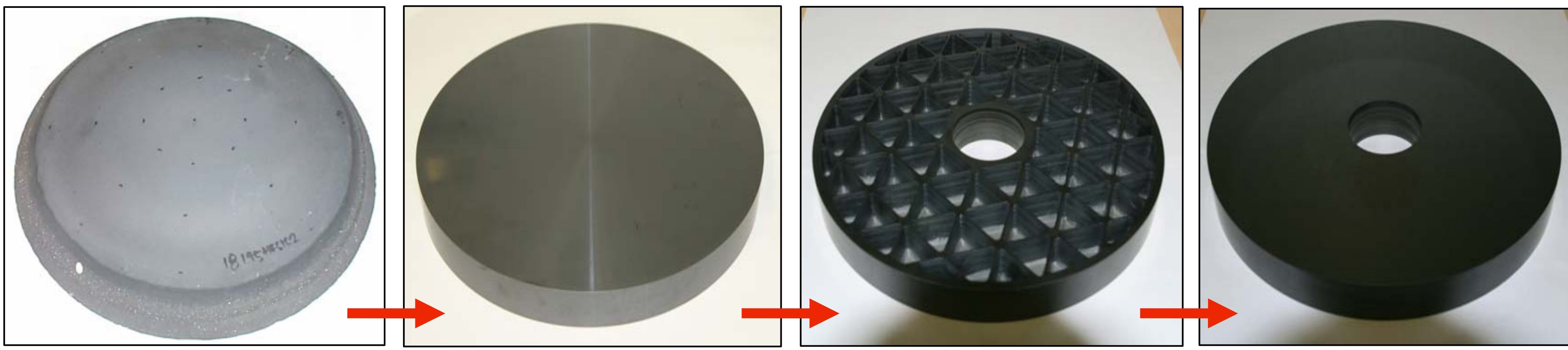
Advances in Fabrication Technologies for Light Weight CVC SiC Mirrors



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Presented by: Kyle Webb

Trex - Advanced Materials Group

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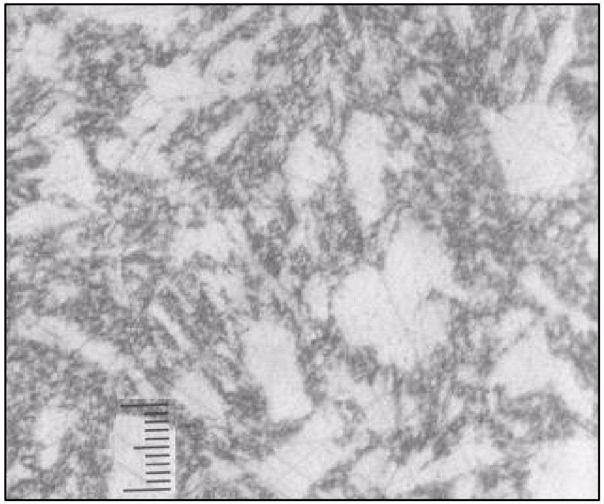
    - Dr. Ronald Jacobsen
  - Ormond, LLC, Auburn, WA
    - Tom Butler
  - Prema-Tech Advanced Ceramics, Worcester, MA

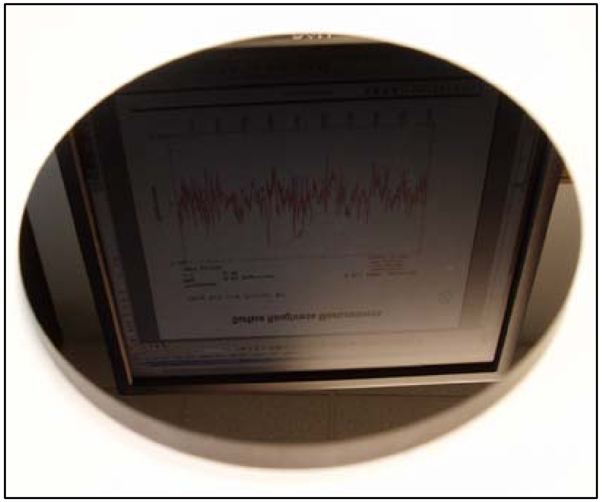
Trex CVC SiC Material Characteristics

- CVC SiC Material - Optical Grade - Ultra Pure
  - Grain Size, Structure: 5 micron, Uniform Isotropic
  - Hardness, (VH): 2850 (0.3) kg/mm^2
  - Young's Modulus, (E): 450 (GPa)
  - Density, (ρ): 3.2 (g/cm^3)
  - Specific Stiffness, (E/ρ): 143 ($GPa/g/cm^3$)
  - Coefficient of Expansion, (α): 2.3 ($\mu m/^oK$)
  - Thermal Conductivity, (K): 150 - 200 ($W/m\text{-}^oK$)
  - Heat Capacity: 680 ($J/kg\text{-}^oK$)
  - Total Impurities: < 5 ppm



Microscopic Picture of CVC SiC Isotropic Grain Structure

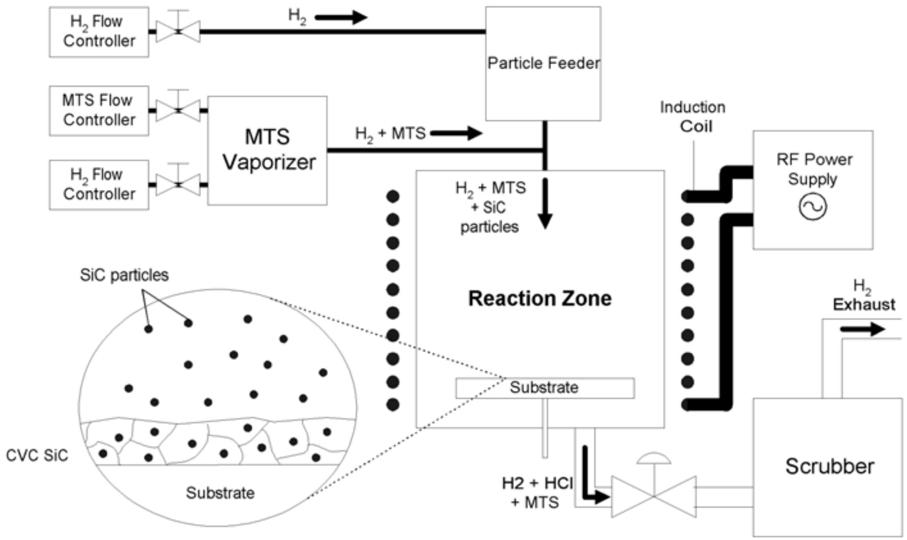
- Polishing Performance
  - Surface Roughness: < 4 Angstroms rms is routine
  - Figure: Limited by Polisher Processes
- High Temperature Performance
  - Demonstrates high flexural strength at 2004 C
  - No ablation at mach 3 and temperature of 1800 C
  - No erosion in hot gas at sustained temperature testing of 2500 C



CVC SiC Mandrel Deposition Process

- CVC SiC Blanks are Grown on Graphite Mandrels
  - Graphite material can handle the extreme temperature conditions of CVC reaction formation process.
  - Mandrel shapes can approximate near net shapes
    - Curves and slopes work well
    - Tight corners and sharp edges do not work well

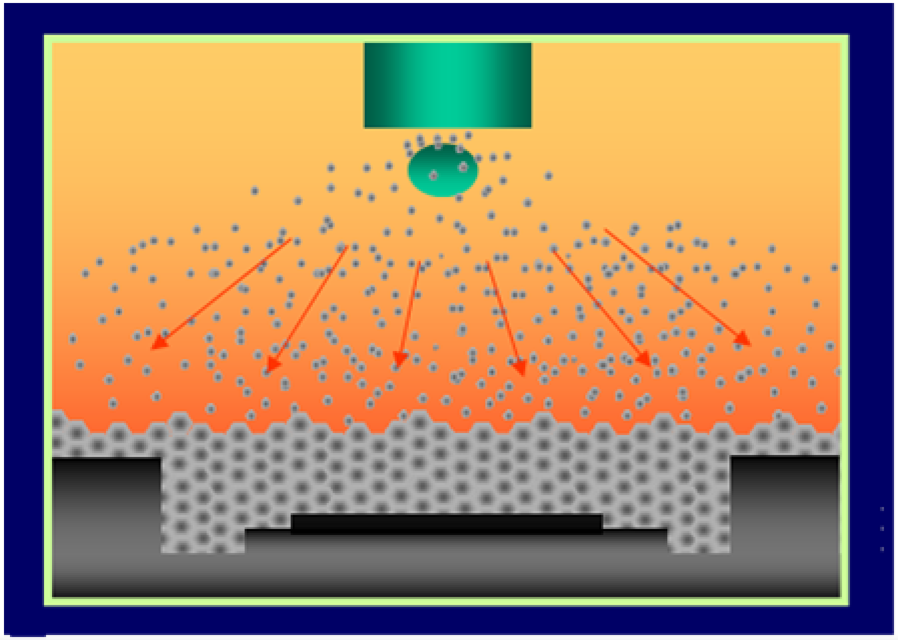
Mandrel for Large Diameter Concave Mirror



CVC SiC Reactor Deposition Process

MTS: Methyl-Trichloro-Silane

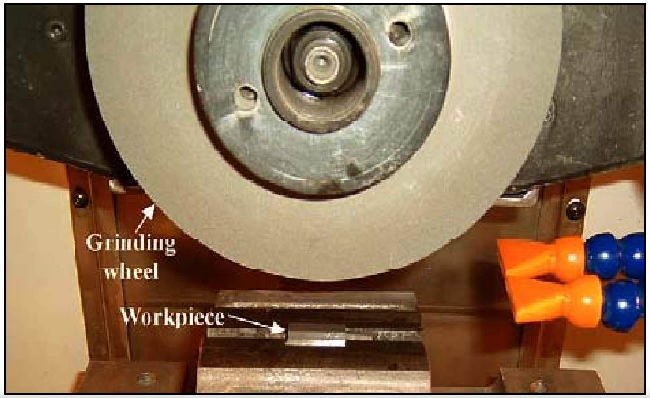
$$CH_3SiCl_{3(g)} \rightarrow SiC_{(s)} + 3HCl_{(g)}$$

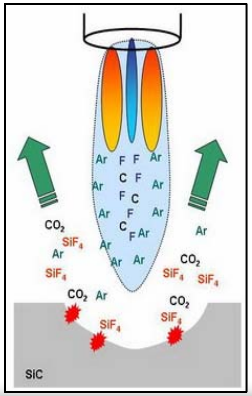


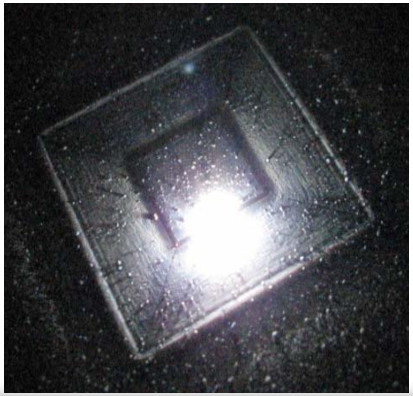
CVC SiC Fabrication Technologies

- CVC SiC fabrication process utilizes several different technologies:
  - Traditional Silicon Carbide Grinding
  - Reactive Atom Plasma Etching
  - Laser Milling & Micro-Machining
  - Water Jet Milling & Cutting

- Each technology provides a unique solution to different challenges presented in the fabrication process of CVC SiC. Careful utilization of these technologies provides economical solutions for fabrication of light weighted large aperture mirrors from CVC SiC material.

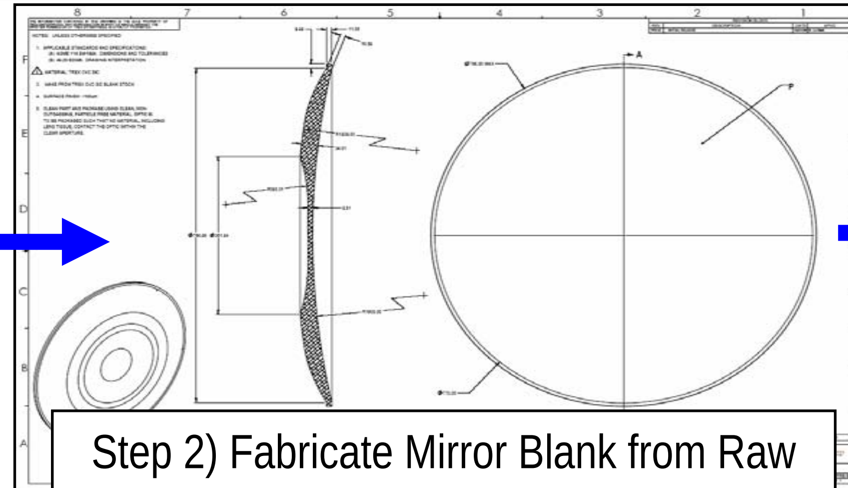




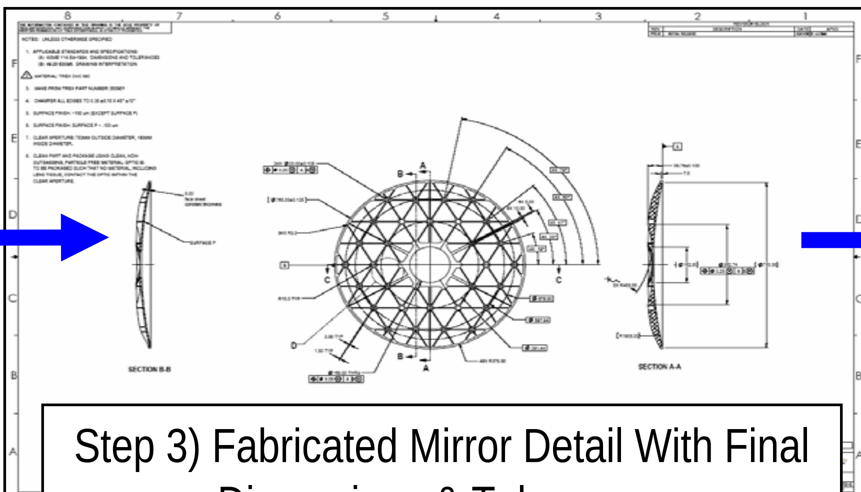


CVC SiC Mirror Fabrication Process Steps

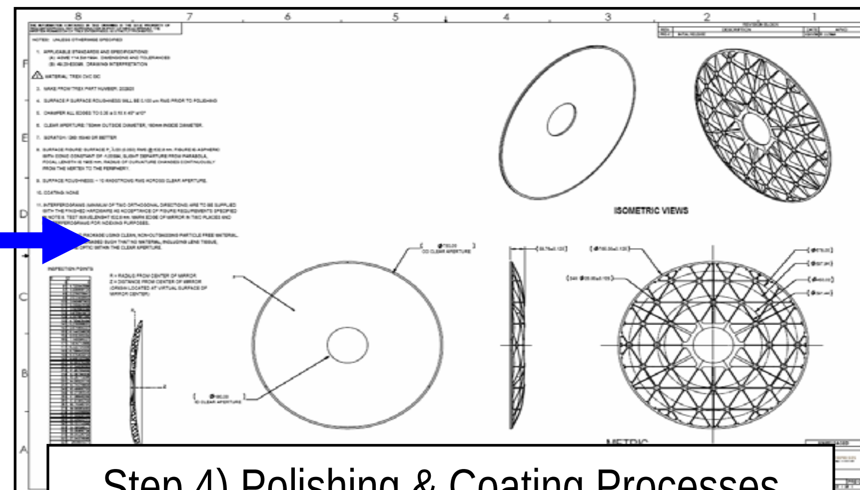
Step 1) Deposition of Raw Blank on Mandrel



Step 2) Fabricate Mirror Blank from Raw as Deposited Blank



Step 3) Fabricated Mirror Detail With Final Dimensions & Tolerances

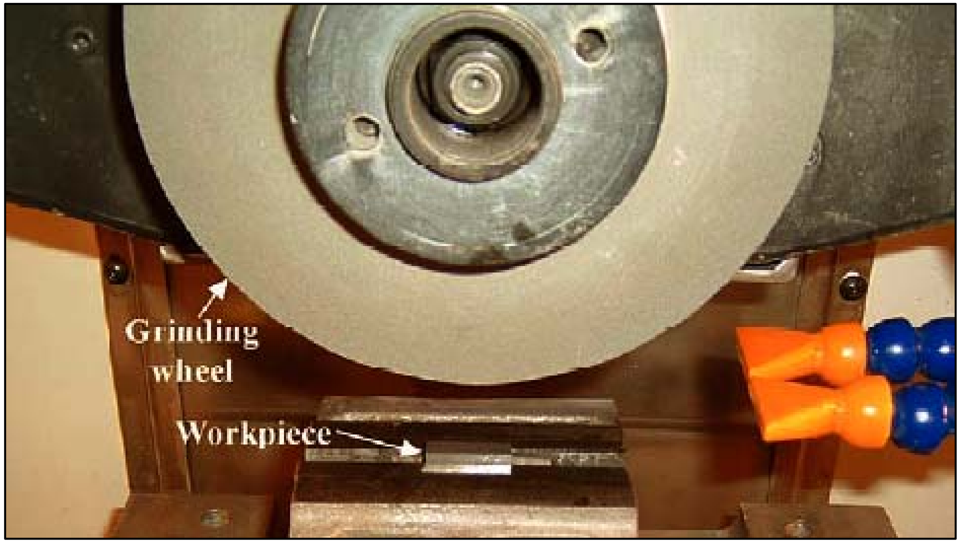


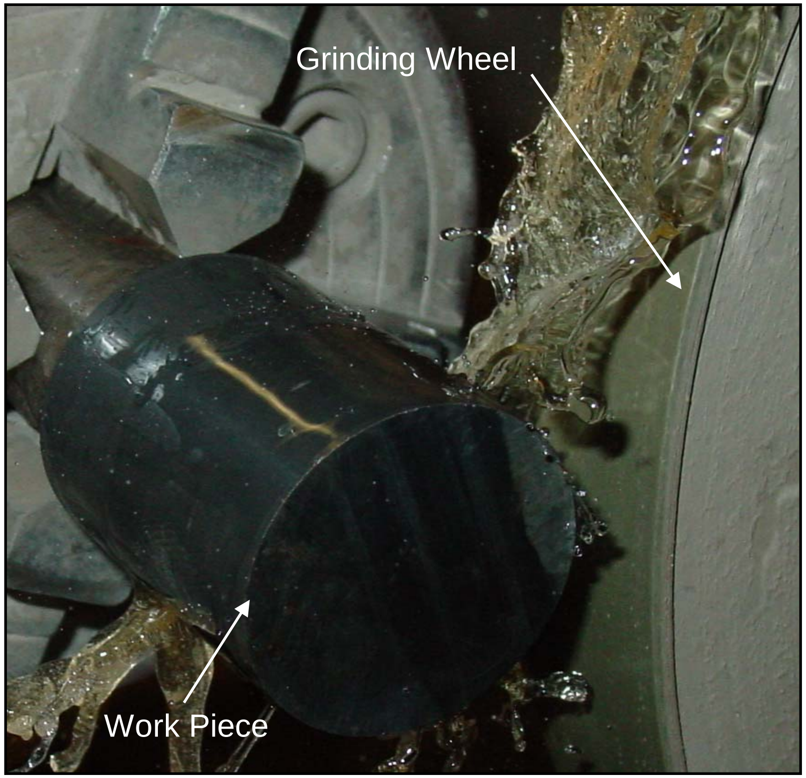
Step 4) Polishing & Coating Processes

Traditional Diamond Grinding

Traditional Silicon Carbide Grinding Processes

- Extremely good dimensional, tolerance, and surface finish performance.
- Good material removal rates on features that can be accessible.
- Feature that are hard to access such as Iso-grid pockets with high volumetric removal requirements become uneconomical very quickly.
- Material Removal Rates for CVC SiC:
  - Bulk Rough Grinding: .492 cm^3/min
  - Finish Grinding: .098 cm^3/min

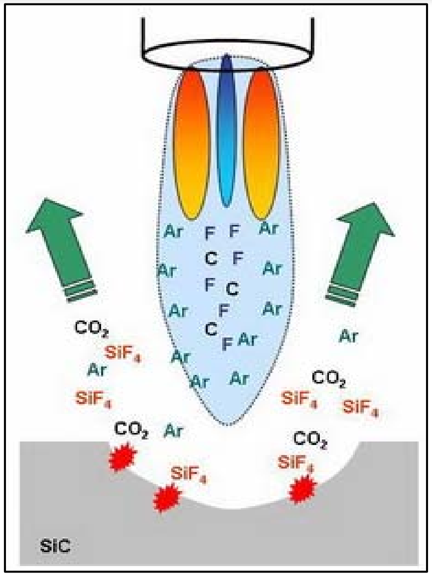


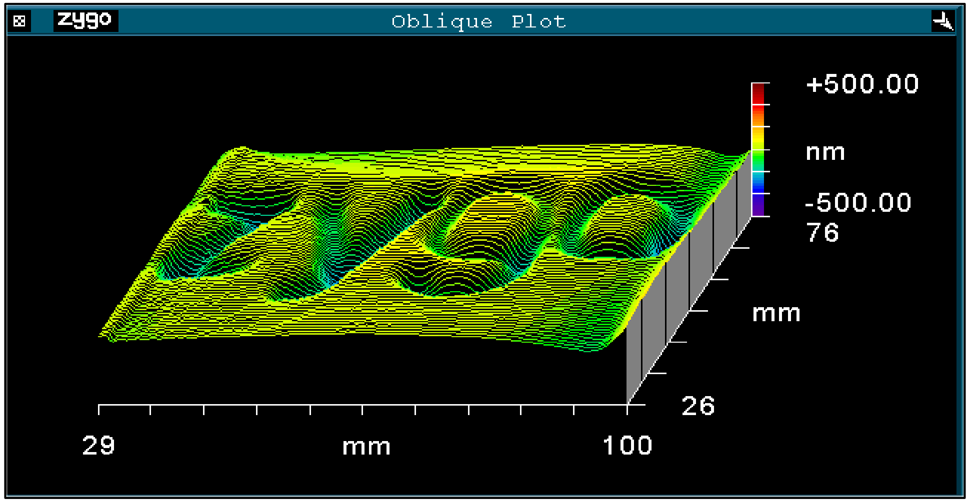


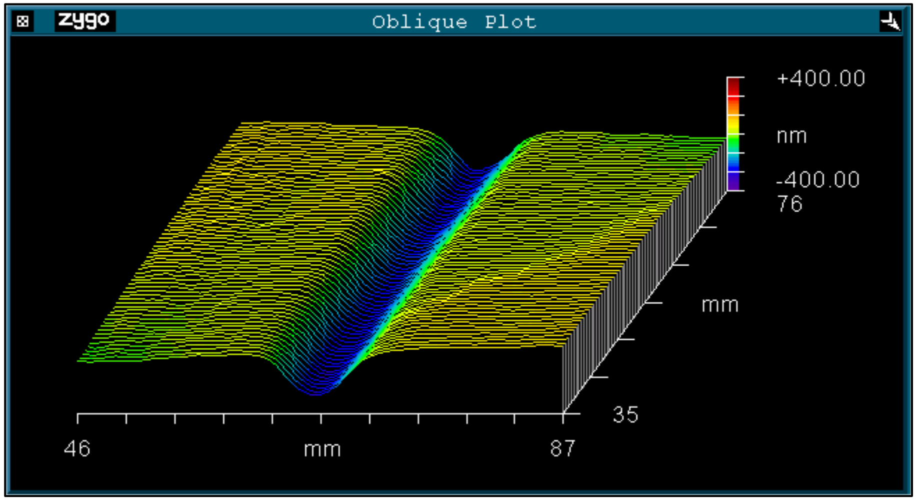
Pictures Courtesy of PremaTech Advanced Ceramics, Inc.

Reactive Atom Plasma

- Reactive Atom Plasma Process
  - Touch-less chemical etching process with sub-surface damage removal characteristics.
  - Dimensions, tolerances, and surface finishes are very good.
  - Material removal rates are temperature dependent..
  - Process is extremely useful for milling aspheric departures from spherical shapes in the range of +/- 25 μm or less.
    - Material Removal Rates for CVC SiC: 0.033 cm^3/min





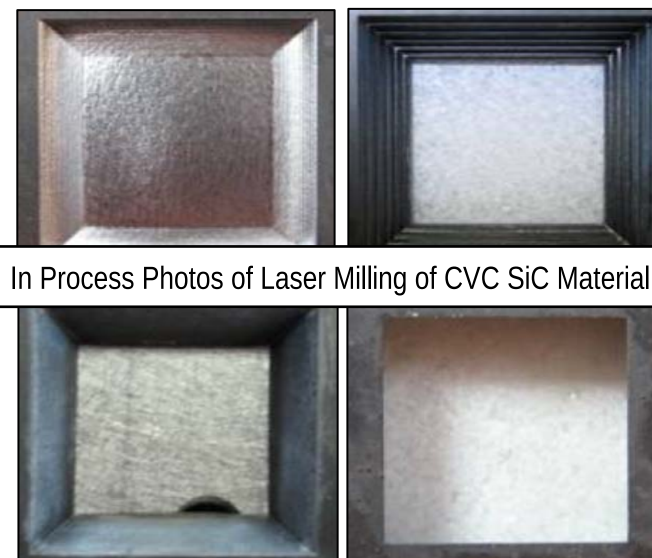


Pictures Courtesy of RAPT Industries

Laser Milling and Micro-Machining

Laser Milling Processes

- Scanning laser ablation technology. Touch-less process implements high speed, high precision, scanning mirrors that direct a focused pulse of pico or fempto second solid state laser energy to a given surface for ablation.
- This process provides fabrication solutions for features that other methods can't provide such as knife edges, apertures, blind holes, and micron size features.
- Dimensions, tolerances, and surface finishes are good in quality.
- Material removal rates are low and therefore not applicable for bulk material removal for large aperture light weight mirrors.
  - Material Removal Rates for CVC SiC: 0.008 cm^3/min

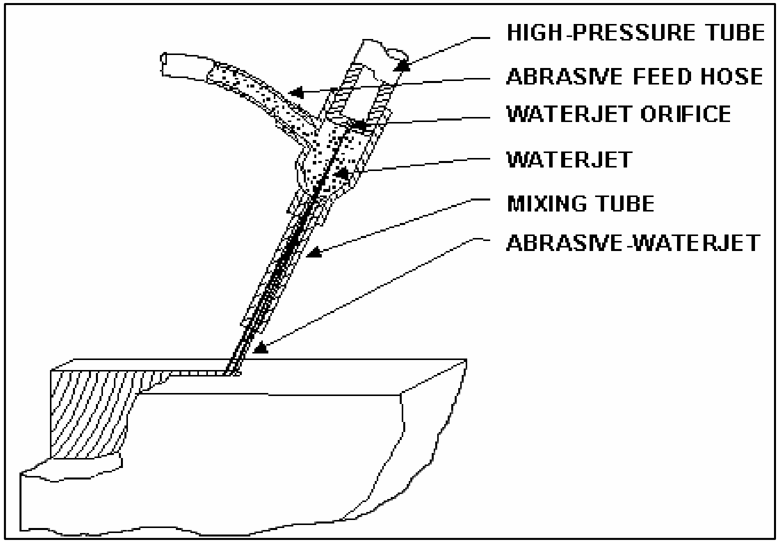


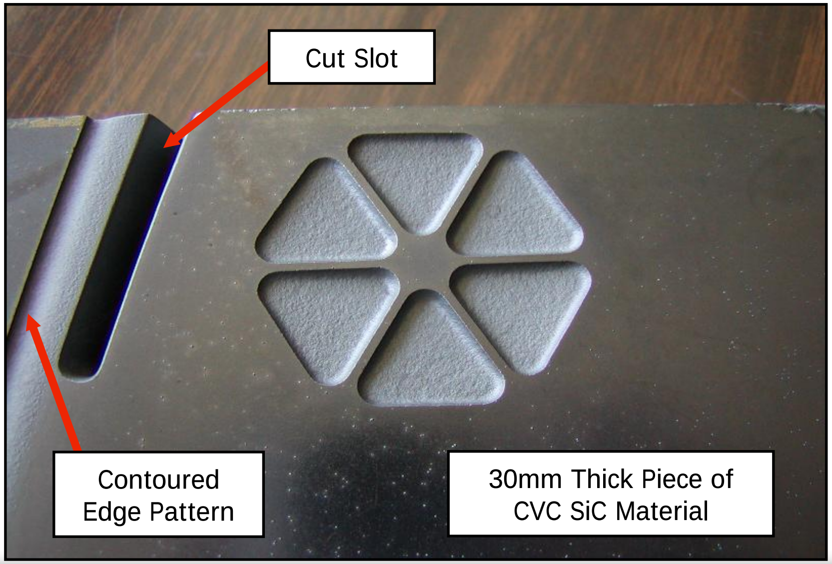
In Process Photos of Laser Milling of CVC SiC Material

Pictures Courtesy of MLPC, Inc.

Water Jet Milling & Cutting

- Water Jet Milling
  - Water Jet milling process is performs by using a very high pressure water jet with abrasive aggregate particles added into the jet stream.
  - 5 axis system allows for complex shaping.
  - On going development activities include improved surface finish performance and even higher material removal rates.





Water Jet Milling & Cutting

- Water jet Milling & Cutting Processes
  - Dimensions, tolerances, and surface finish performance is good but not quite up to par with conventional grinding processes. More development efforts are currently being focused toward improvements is this area.
  - Extremely fast material removal rates.
    - Material Removal Rates for CVC SiC: 6.06 cm^3/min

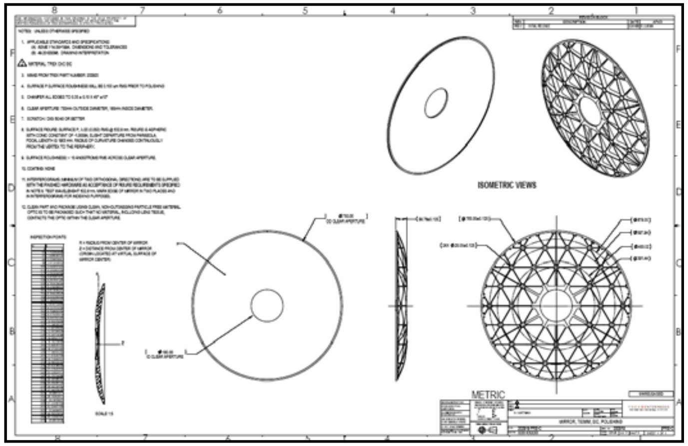
CVC SiC Fabrication Technologies Summarized

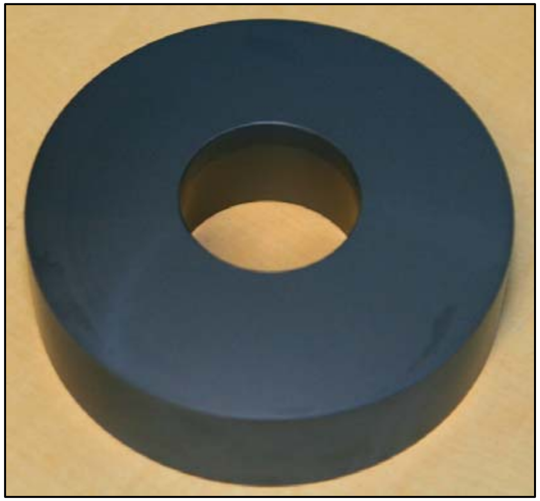
- Different Fabrication Technologies Provide Differing Solutions for Fabrication of Large Aperture CVC SiC Light Weight Aerospace Mirrors:

	CVC SiC Fabrication Technology Characteristics					
CVC SiC Fabrication Technology	Material Removal Rates	Feature & Dimensional Control	Surface Roughness Control	Bulk Material Removal	Fabricate Aspheric Departures	Sub-Surface Damage Removal
Traditional Diamond Grinding	0.492 cm^3/min	Excellent	Excellent	Good	Poor	n/a
Reactive Atom Plasma	0.033 cm^3/min	Excellent	Excellent	Fair*	Excellent	Excellent
Scanning Laser Ablation	0.008 cm^3/min	Excellent	Very Good	n/a	Good	n/a
Water Jet Milling & Cutting	6.060 cm^3/min	Fair	Fair	Excellent	n/a	n/a
			*Temperature Dependant			

Aspheric Mirror Fabrication

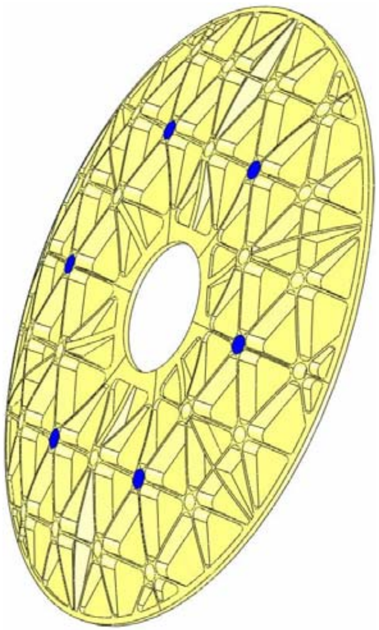
- CVC SiC Fabrication Process for Aspheric Mirrors
  - On axis aspheric mirror fabrication process:
    - Mirror blanks are fabricated with best fit spherical shape via Trex 4 step process.
    - Aspheric departures are then machined into the mirror using RAP processes prior to polishing.
      - Final pre-polish surface preparations of all Trex CVC SiC optics includes RAP process for sub-surface damage removal.
  - Off axis aspheric mirror fabrication process is assessed for fabrication on an individual requirement basses. Fabrication requirements for these applications are typically much more complicated.





CVC SiC Material Compared to Beryllium:

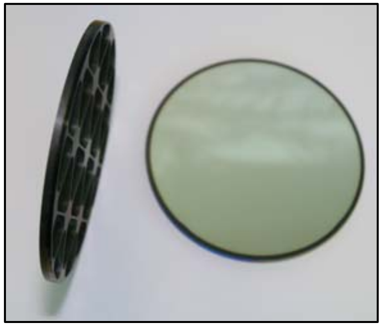
Material Property	*Trex CVC SiC*	*Beryllium*
Young's Modulus: E (GPa)	E = 456	E = 303
Density: ρ (g/cm^3)	ρ = 3.20	ρ = 1.86
Specific Stiffness: E/ρ ($GPa/g/cm^3$)	E/ρ = 143	E/ρ = 163
Coefficient of Expansion: α ($\mu m/^oK$)	α = 2.3	α = 11.5
Thermal Conductivity: K (W/m^oK)	K = 150 to 200	K = 210



Areal Density Performance:

- Light Weight Mirror Configurations Optimized for Self Weight Sag

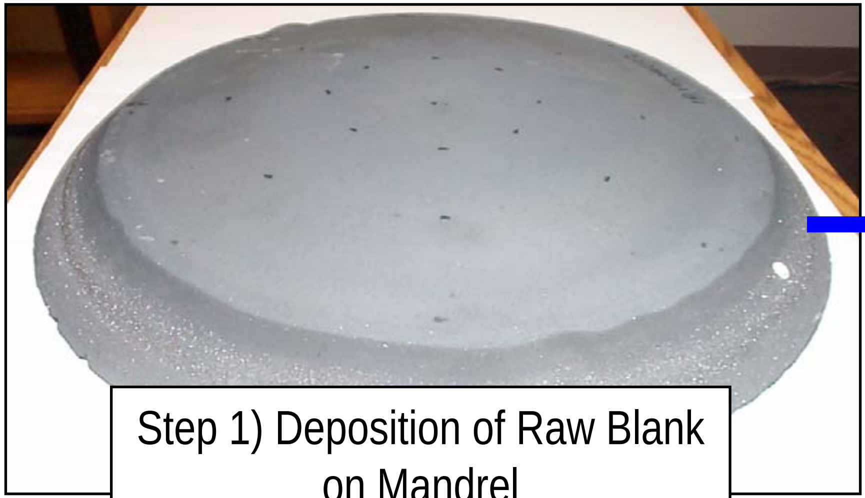
Aperture Sizes (mm)	*Areal Density (Kg/M^2)*
100 to 200	10 to 12
200 to 350	12 to 15
350 to 750	15 to 23



Aspect Ration Performance:

- Thickness to Diameter Ratio for Optimized Mirror Configurations: 24 to 1

CVC SiC Mirror Fabrication Process Steps



Step 1) Deposition of Raw Blank on Mandrel

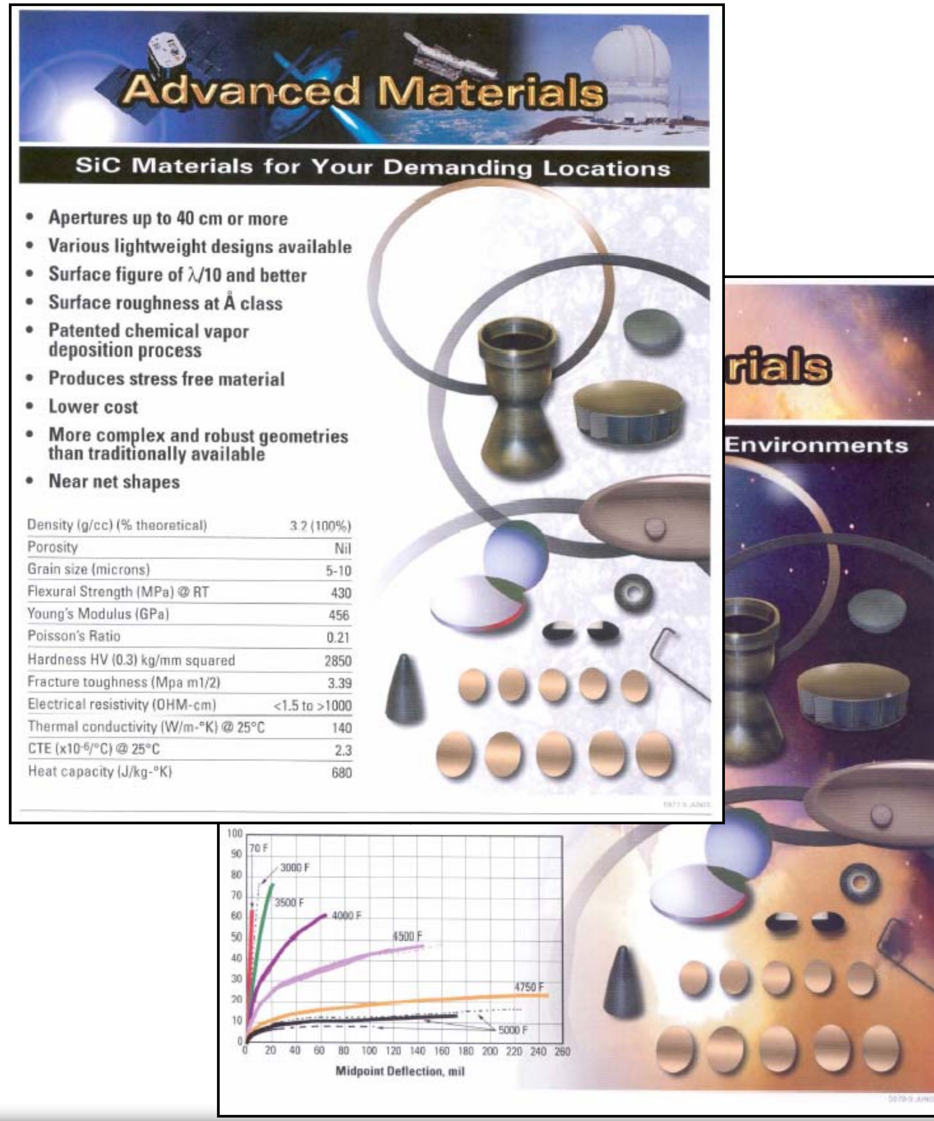
Step 2) Fabricate Mirror Blank from Raw as Deposited Blank

Step 3) Fabricated Mirror Detail With Final Dimensions & Tolerances

Step 4) RAP Subsurface Damage Removal Process Follow by Polishing & Coating Processes

CVC SiC Material Properties

Property	Value
Density	3.2 g/cm^3
Young's Modulus (300 K)	450 GPa
Flexural Strength (300K)	400 MPa
Thermal Conductivity (RT)	150 - 200 W/mK
Coefficient of Thermal Expansion	2.3 x10^{-6}/^{o}C
Hardness HV (0.3) kg/mm^2	2850
Poisson's Ratio	0.21
Fracture Toughness	3.39 MPa-m$^{1/2}$
Total metal impurity	<5 ppm



Trex CVC Silicon Carbide