Large Scale, Low Cost, Molded SiOC Mirror Component

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Team

- NASA SBIR Advisors - Phil Stahl, Ron Eng
- ZeCoat Corporation – David Sheikh
- Optical Mechanics, Inc. (OMI) – James Mulherin, Chris Mulherin
- UCF – Kathleen Richardson, Myungkoo Kang
- Semplastics

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Talk Outline

- Technology Background
- NASA SBIR Phase 2 Activities
  - Thick Bulk Component Scaling
  - Sealing/Coating Development
- Lessons Learned
- New Material Developments
- Key Milestones/Conclusions

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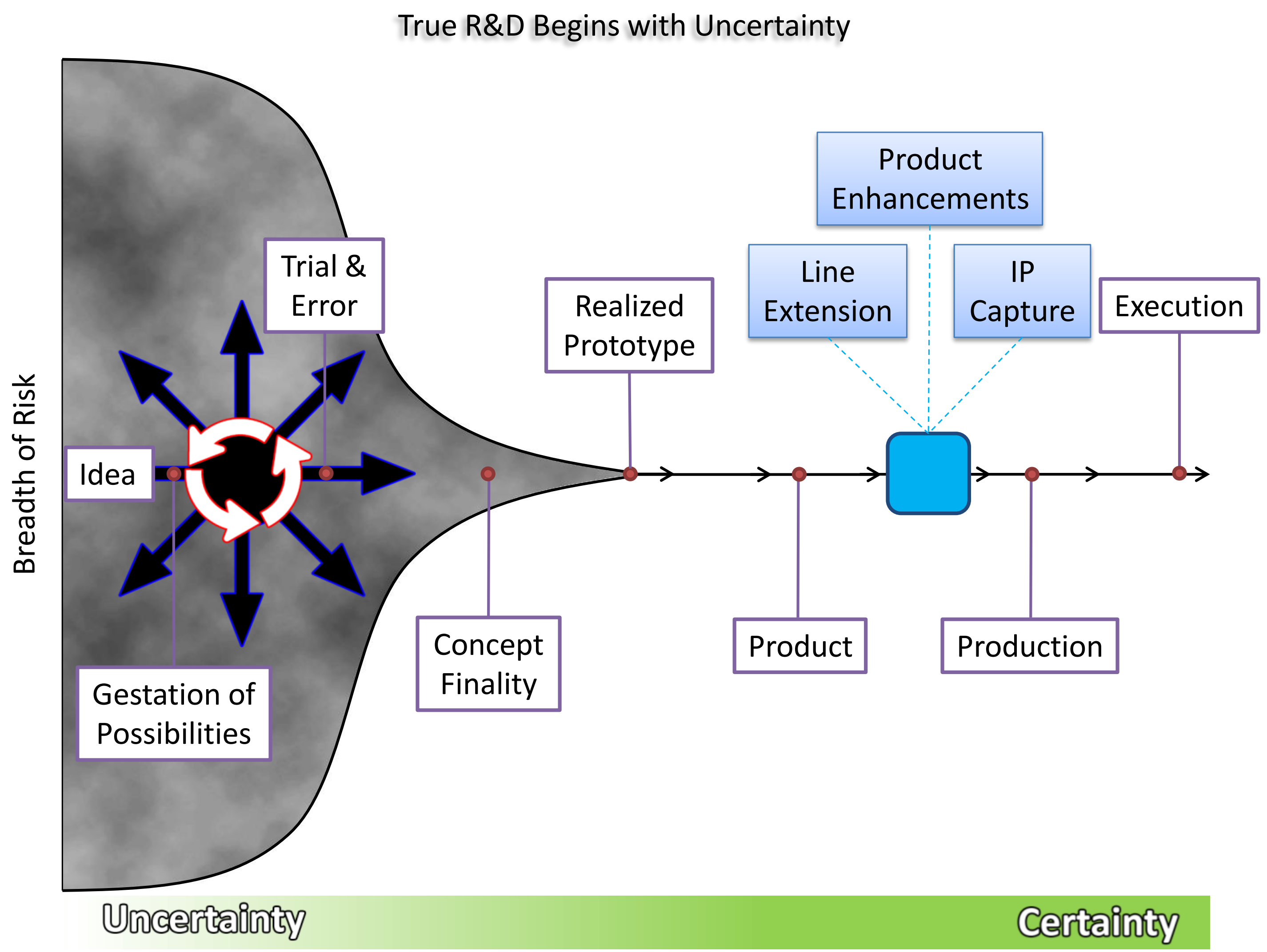
Who is Semplastics?

- 18 year old company focused on high performance plastics in electronics
- Recent development activities in novel high performance materials- X-MAT®
- US patents issued- #8,961,840,#9,434,653, #9,764,987,#9,944,021- multiple patents pending
- NASA Phase 2 SBIR granted in April 2016
- Space Florida Grant for 3D printing Ceramics in June 2017
- DOE Phase 1 SBIR for CCC Roof Tiles June 2018

The Uncertainty of Early Stage R&D



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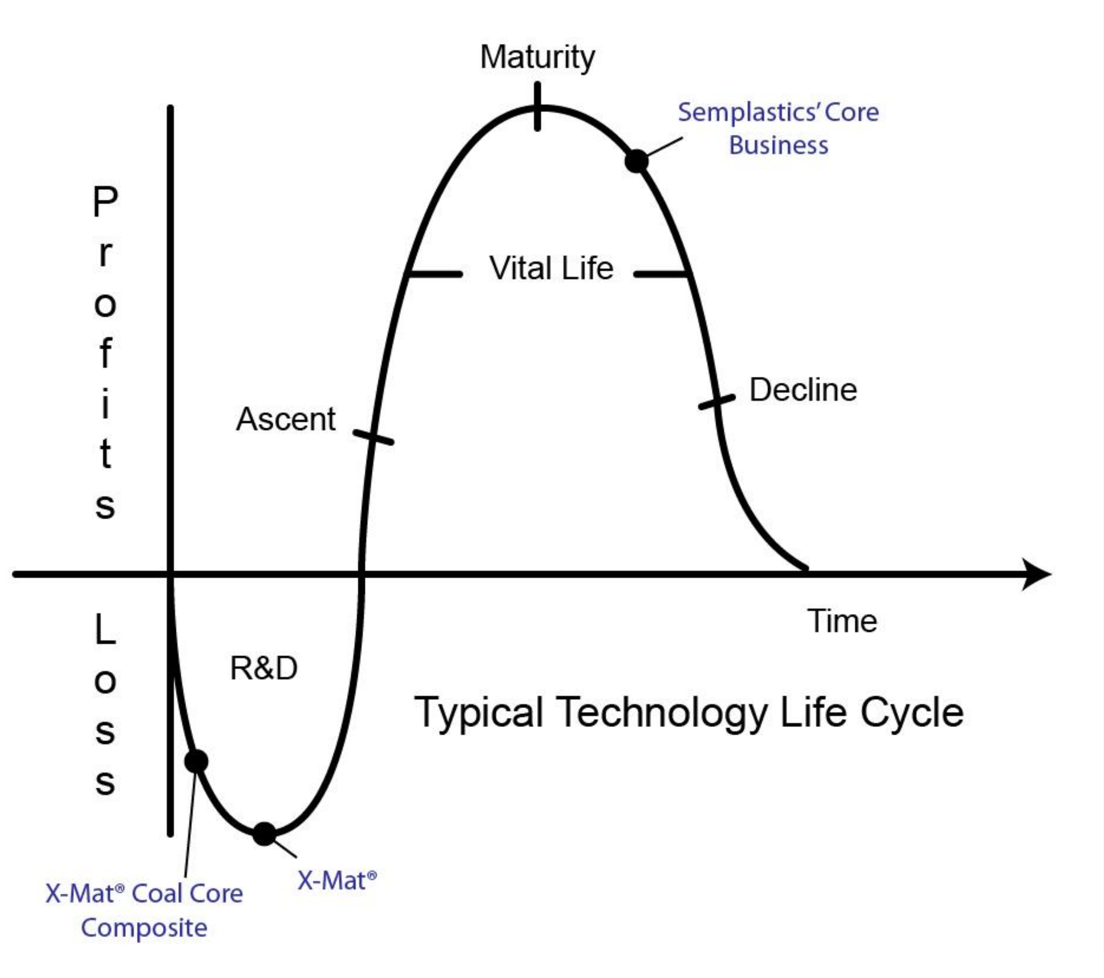
Typical Technology Life Cycle



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What are the main goals of the project?

- Reduce areal costs to less than $\$250K/m^2$ for UV/Optics and less than $\$75K/m^2$ for IR systems
- Reduce the weight of mirror substrate through molding lightweighted structures using lighter X-MAT® materials (SiOC)
- Make a high performance mirror component that can meet NASA's requirements

NASA SBIR Phase 2 Technical Objectives

- Demonstrate Scalability by producing a 14” diameter mirror
- Implement and Characterize Two Different mirror coating systems
  - Polymer Based Coating System- Zero CTE Composite
  - Silicon cladding system using baseline process developed to coat SiC mirror substrates

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Advantages of X-MAT® OC1

- Lightweight- 1.69 g/cc (SiC- 3.2 g/cc)
- High Temperature performance- capable of 1100C continuous usage
- Low Coefficient of Thermal Expansion- 0.60-1.27 x10E-6 in/in C (-150C-300C)- Similar to Quartz
- Amorphous structure provides isotropic properties
- Very Green technology- Uses 20X less energy than typical SiC manufacturing processes!!

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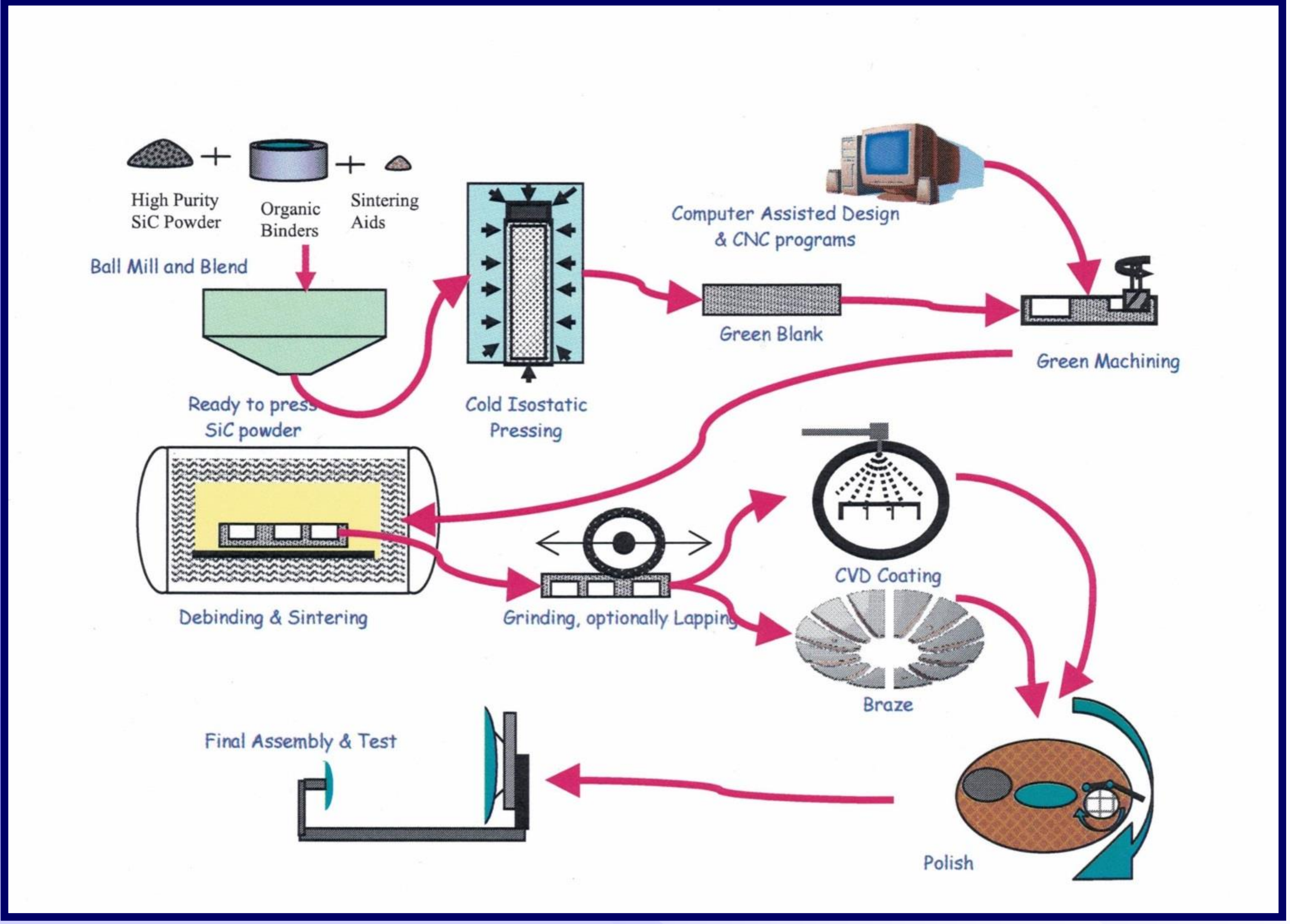
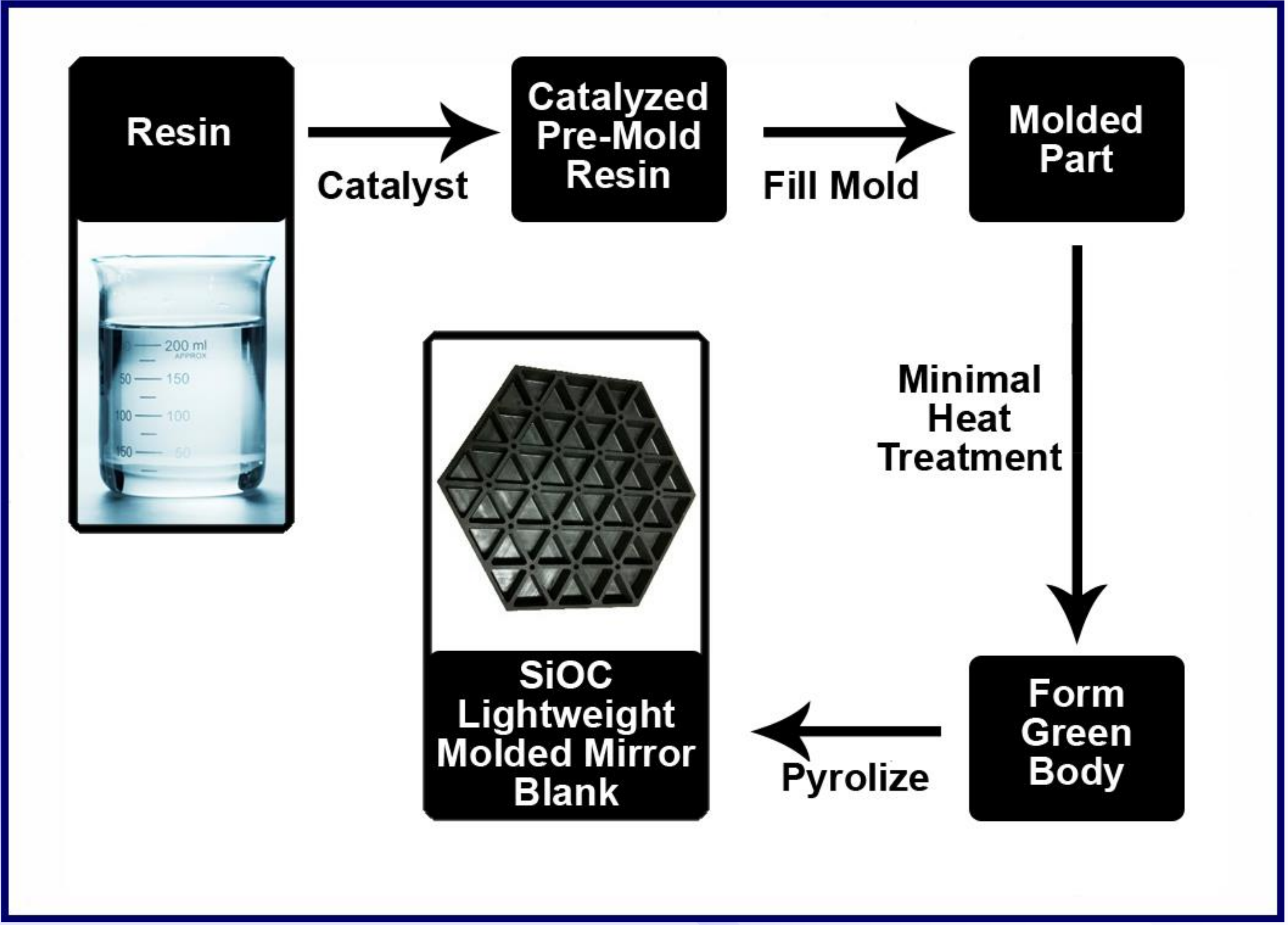
SiC Manufacturing Process*



***Overview of the production of sintered SiC Optics and optical sub-assemblies**, S. Williams, CoorsTek, Inc.; P. Deny, BOOSTEC Industries (France) [5868-04]

X-MAT® Mirror Blank Process



So What is the Big Deal with X-MAT®?

- Polymer resin instead of ceramic powders
- Typical plastic processes (3D printing, molding,machining, etc.) possible
- Shorter Manufacturing Intervals
- Chemical Bonding of the Materials rather than Sintering (Significantly Lower Energy)
- Tailored Material System Properties

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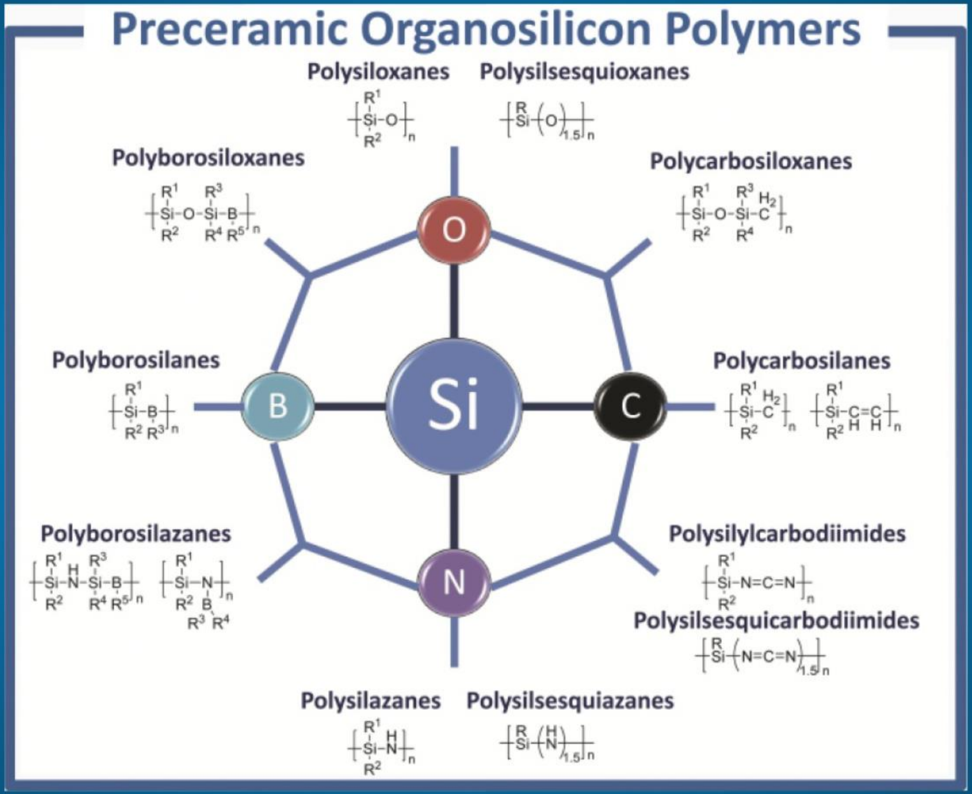
Significance/Review of Polymer-Derived Ceramics (PDCs)

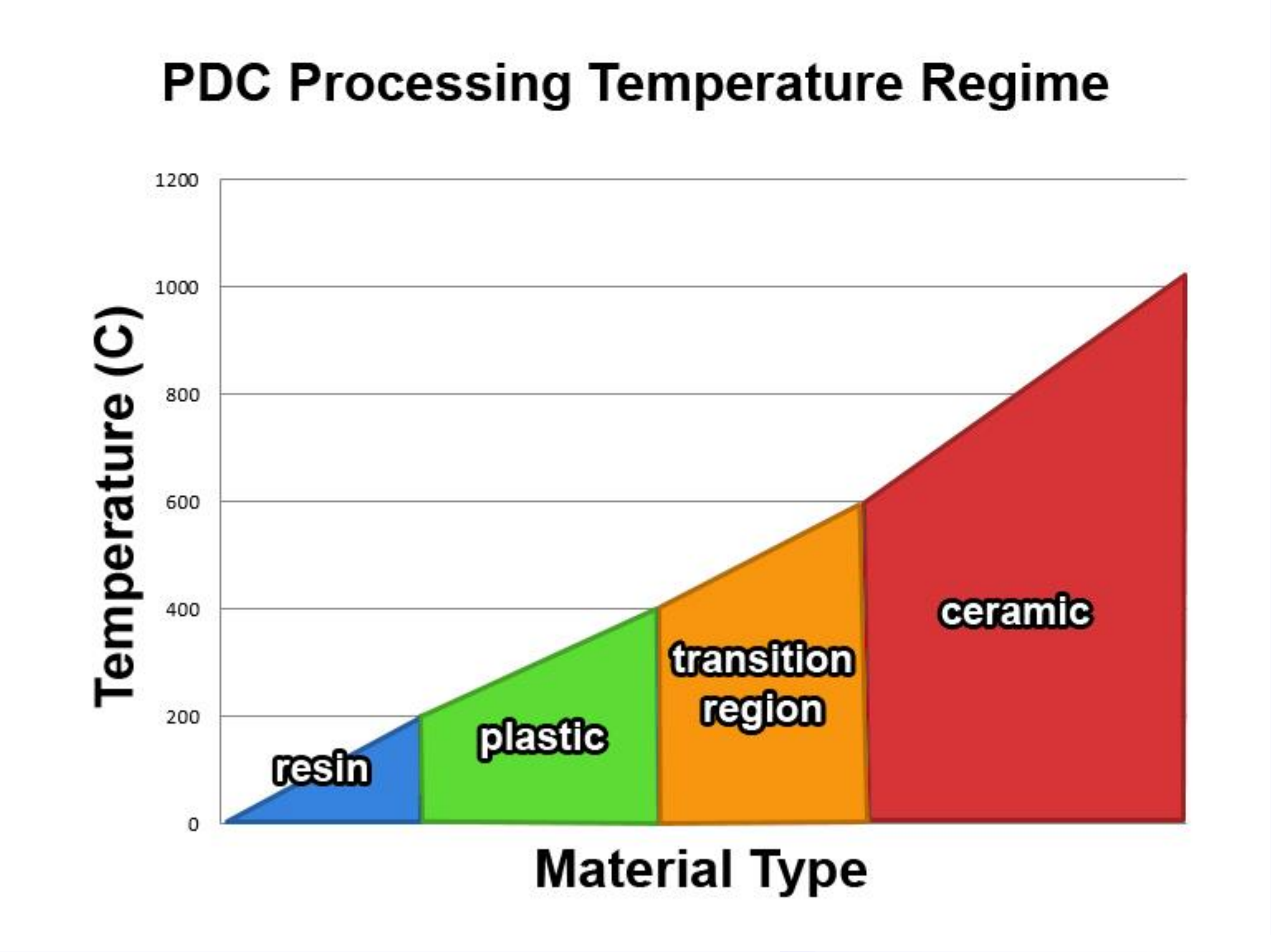
- 45 year history of PDC Development activities
- Commercially Available Resins
- Current commercial usage limited to ceramic fibers, polymer coatings and thin ceramic films
- Multiple resin types and processes produce unique ceramic types and properties

PDC Technologies



J. Am. Ceram. Soc. 93 [7] p.1807 (2010)

Polymer-Derived Ceramics Processing Cycle



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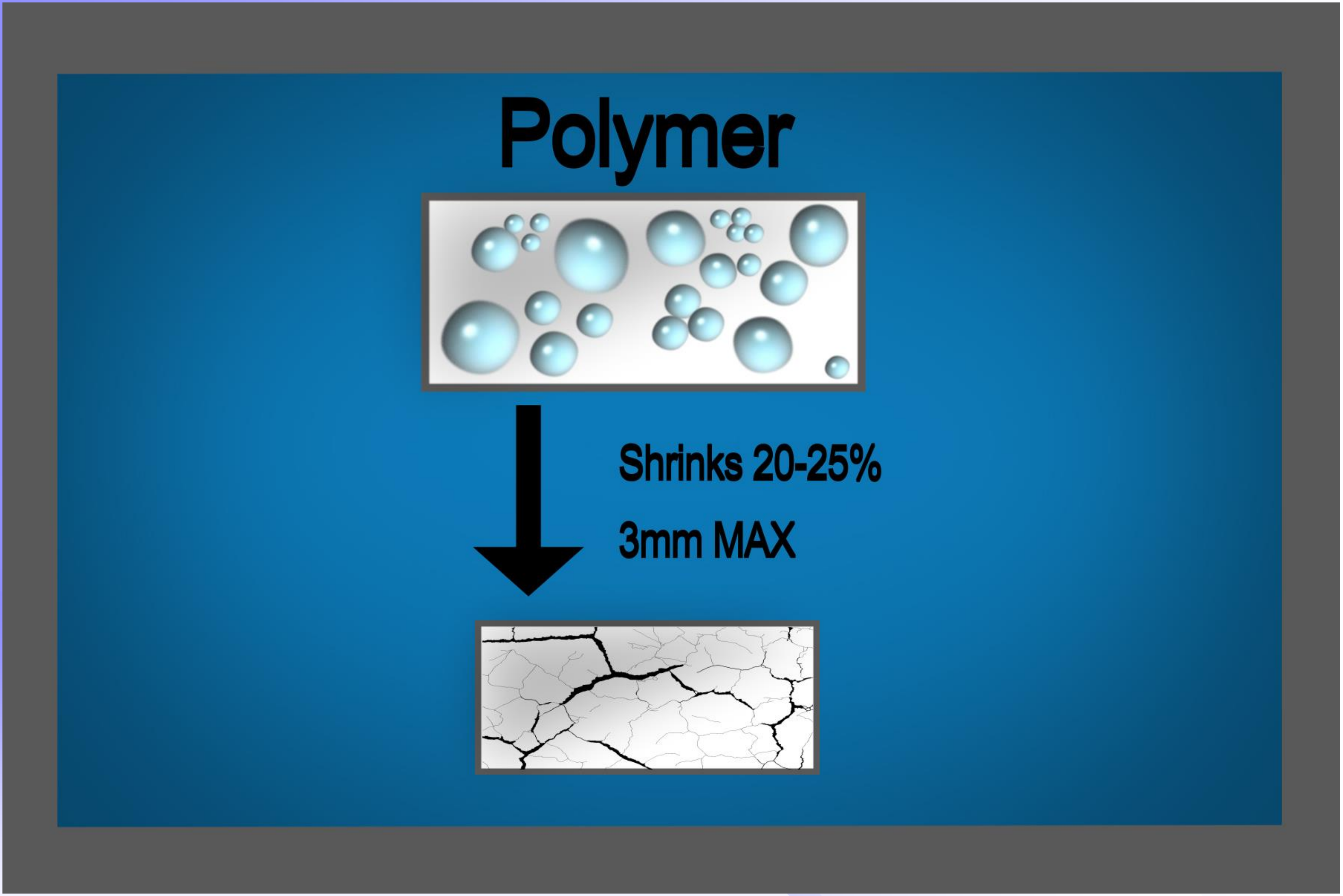
Polymer to Ceramic Processing



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Current PDC Limitations

Can only produce thin films or fibers due to cracking and degradation of films thicker than several hundred microns

" The polymer to ceramic conversion occurs with gas release which typically leads to cracks or pores which make the direct conversion of a preceramic part to a dense ceramic **virtually unachievable**, unless its dimension is typically below a few hundred micrometers(as in the case of fibers, coatings, or foams.) J. Am. Ceram. Soc. 93 [7] p.1811 (2010)

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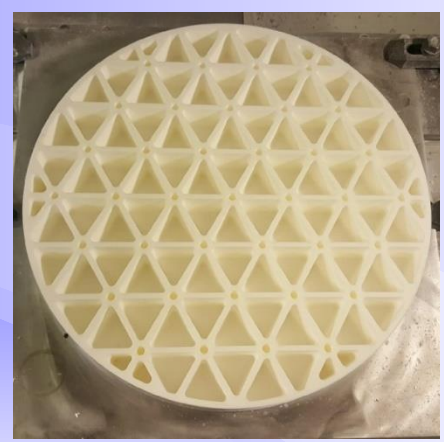
Scaling of X-MAT® Technology- Largest Bulk PDC Made(No Fibers)-”Virtually Unachievable”

3” Test Coupon

6” Mirror Blank

Curved Surface of 6” Mirror Blank

9.25” Hex Mirror Blank



19” Green Body

14” Mirror Blank

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PDC Pyrolysis Furnace

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Properties of X-MAT® OC1

TEST	VALUE	UNITS
Fracture Toughness	.96	Mpa-m^1/2
Flexural Strength	43.5	Mpa
CTE	0.75	1E-6in/in˚C
Young's Modulus	56	Gpa
Poisson's Ratio	.53	-
Density	1.69	g/cc

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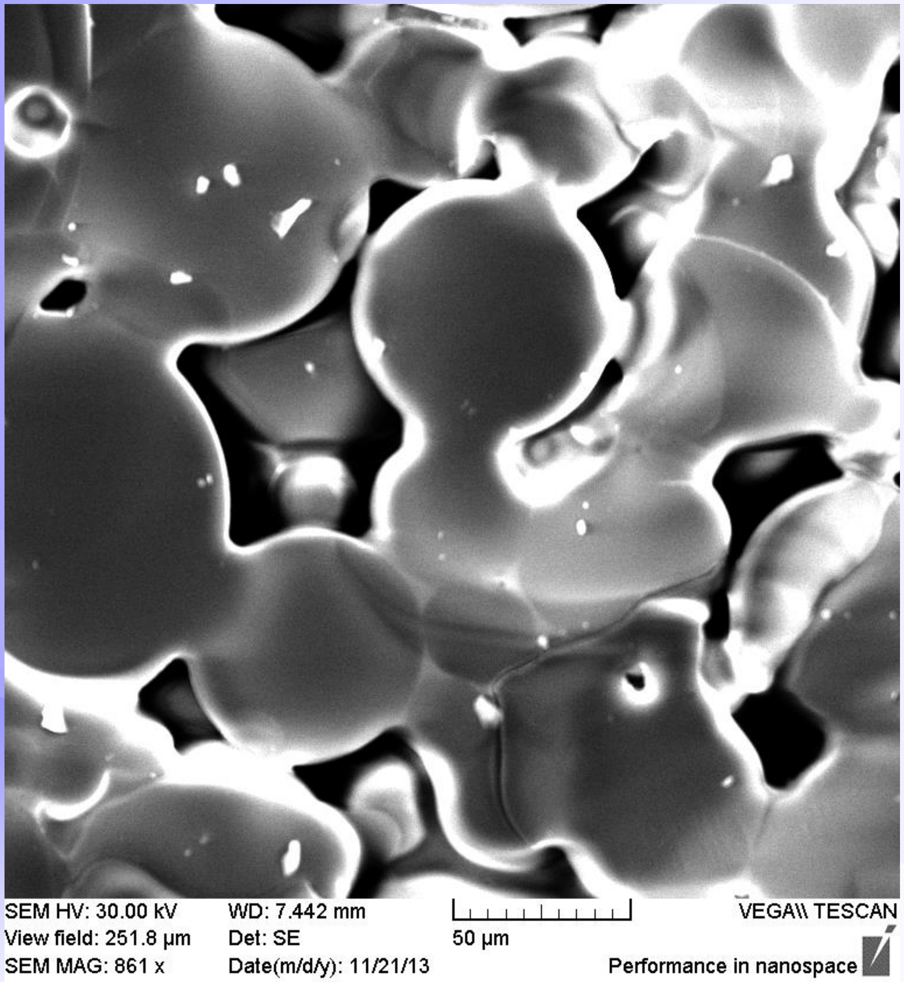
SEM of X-MAT® OC1



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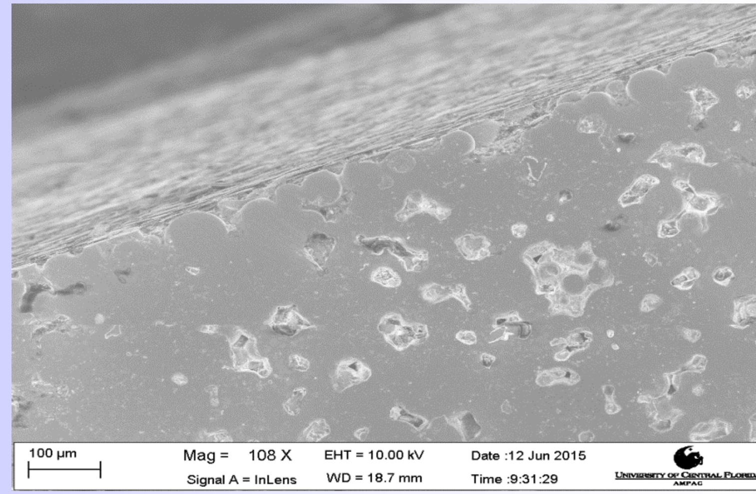
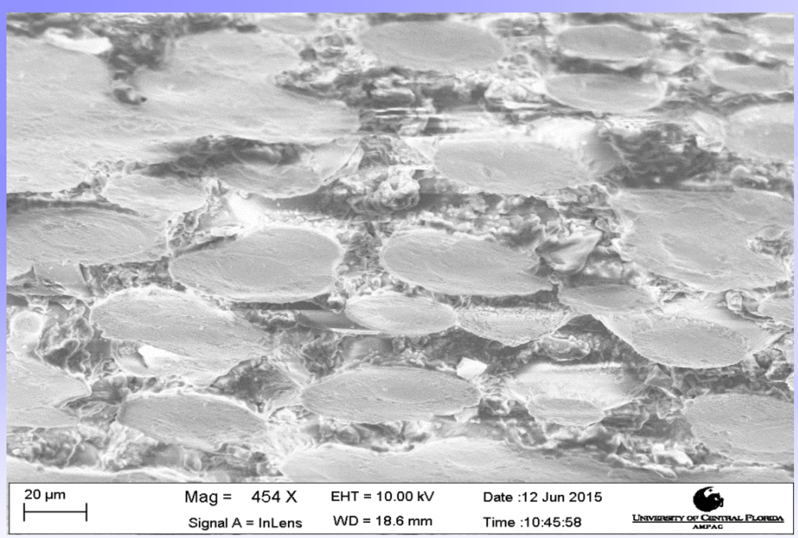
University of Central Florida

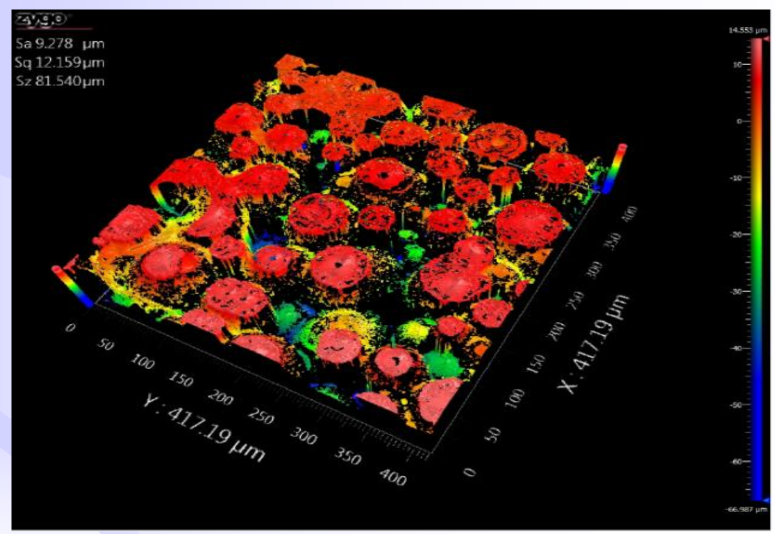
SiOC PDC Uncoated Substrate

Uncoated SiOC PDC

- Highly porous
  - ~80% dense
- Highly Rough Surface
  - RMS roughness of ~12 µm







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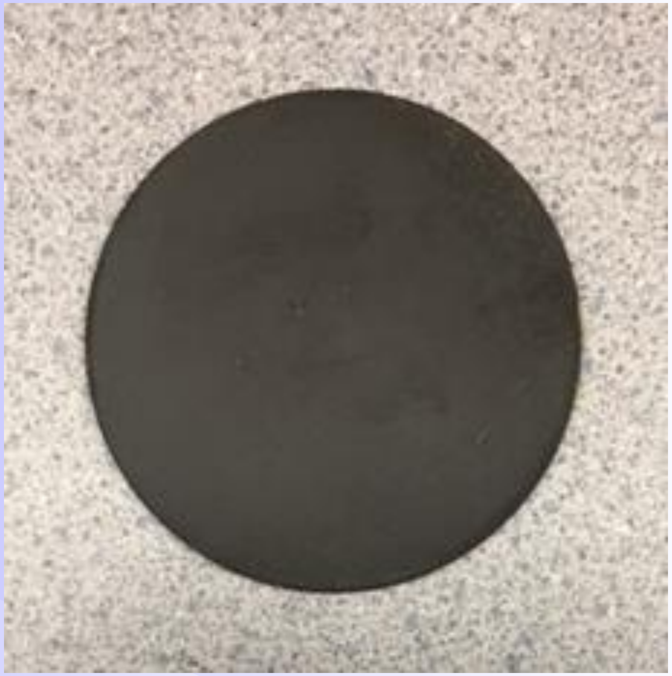
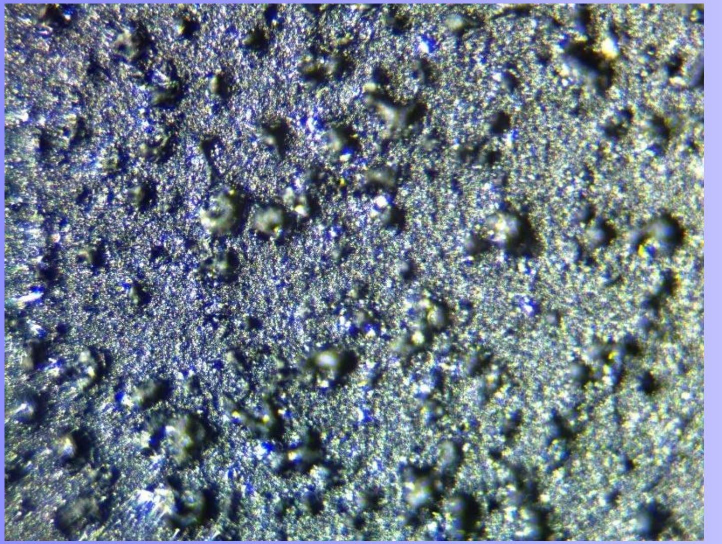
Test Disc Photos

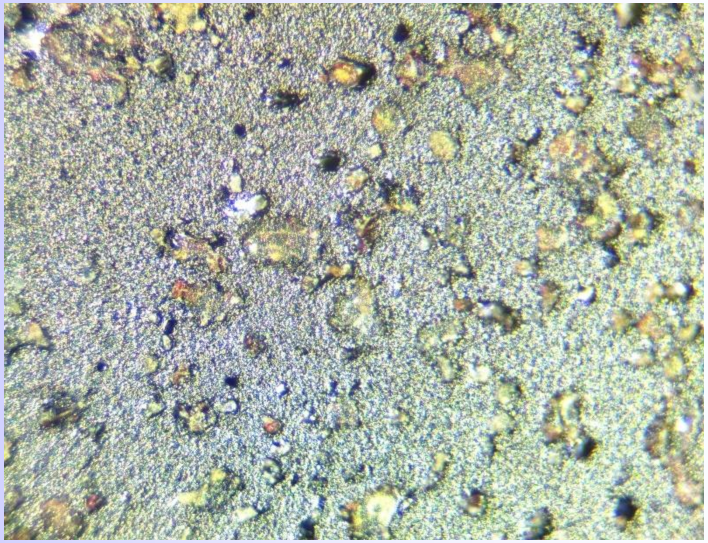
X-MAT® Disc – No Coating



Polyimide Coated X-MAT® Disc with Sealed Pores

Test Disc Pore Photos

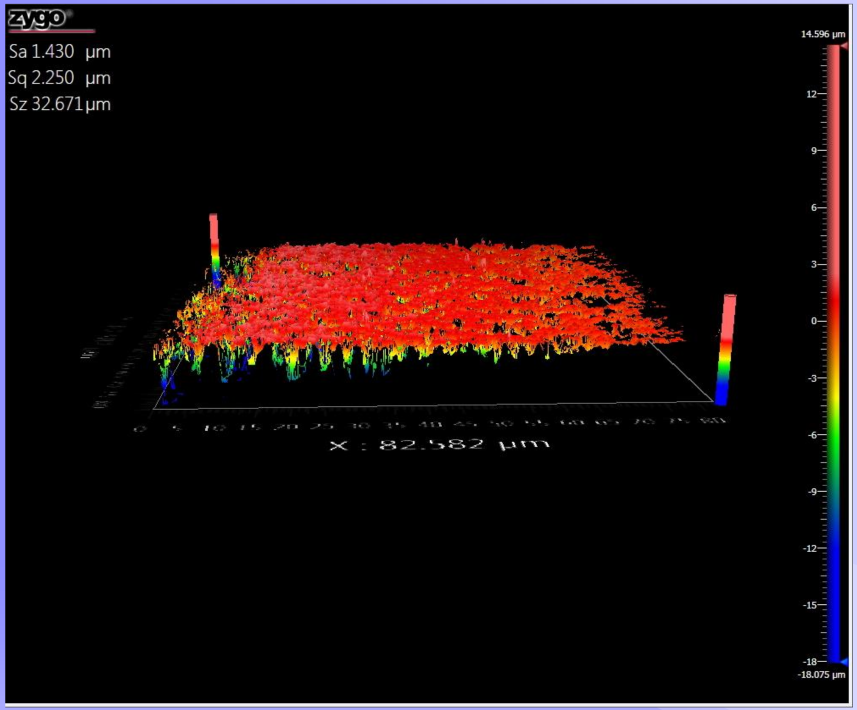




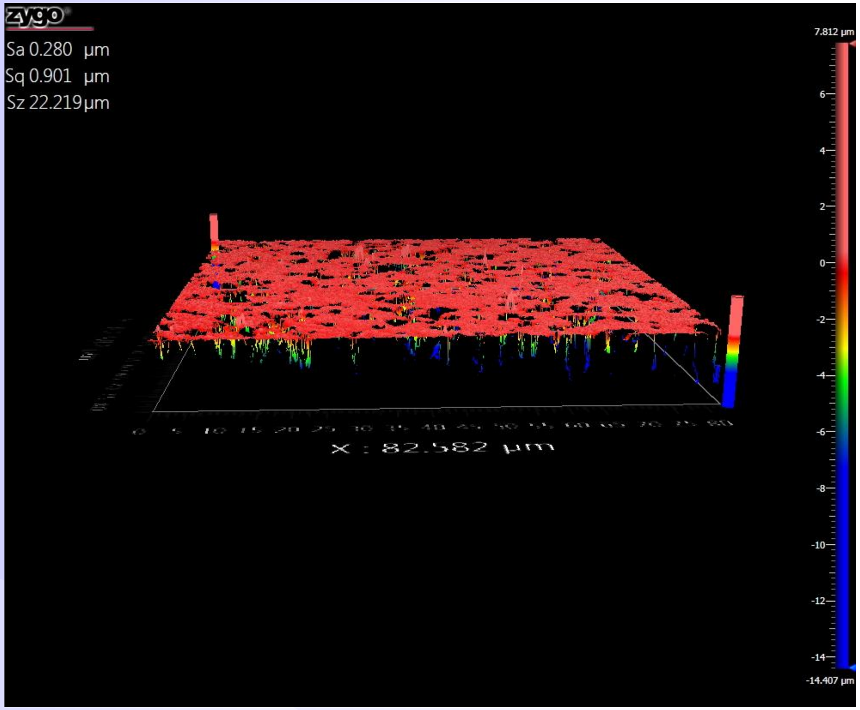
X-MAT® Disc – No Coating

Polyimide Coated X-MAT® Disc with Sealed Pores

Zygo Process Figures

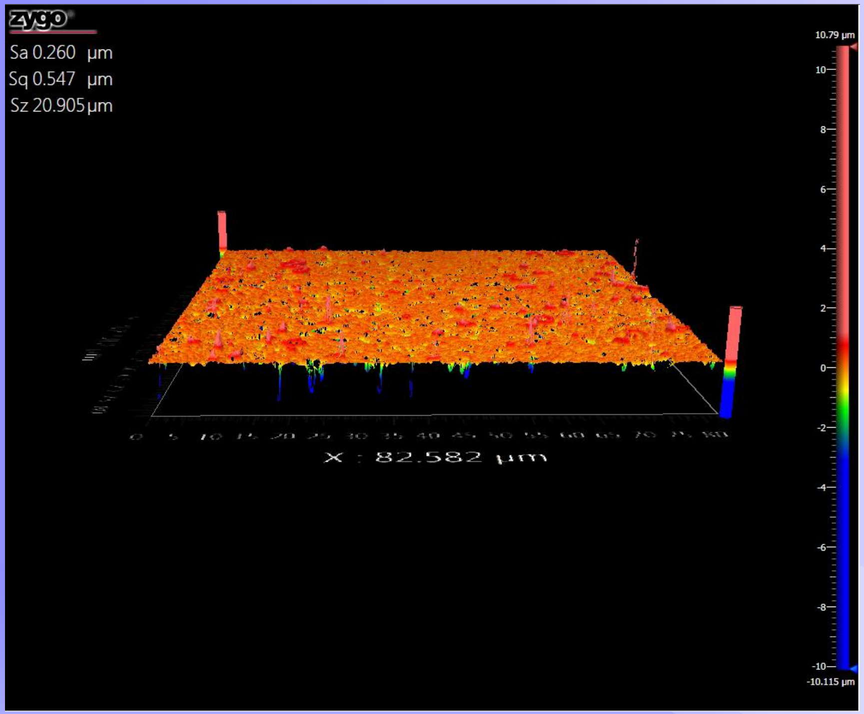


Unground Disk

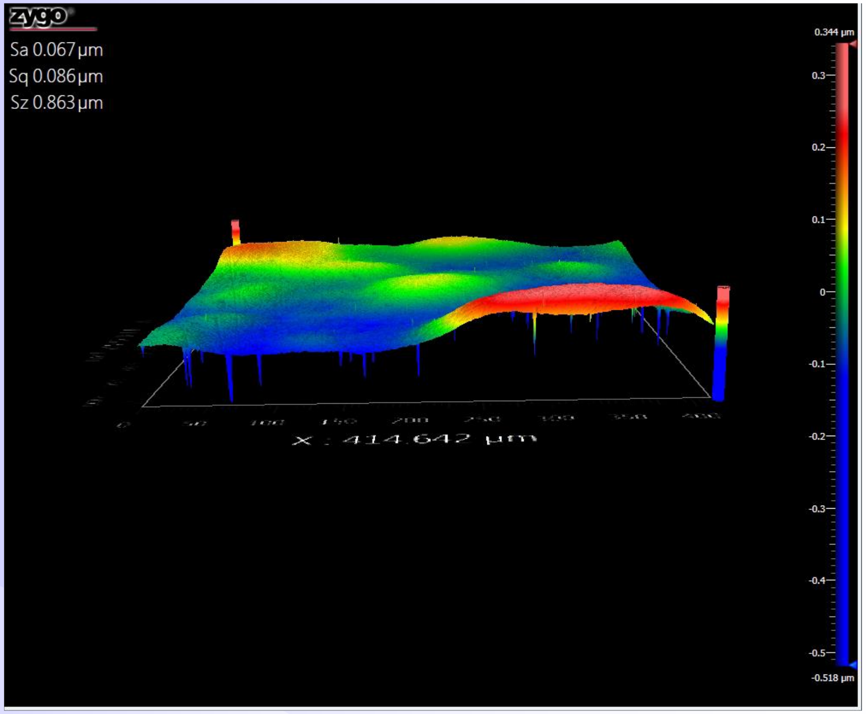


Ground Disk

Zygo Process Figures (Cont.)



Polyimide Coated Disk



Aluminum Coated Disk

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Silicon Cladding Chamber

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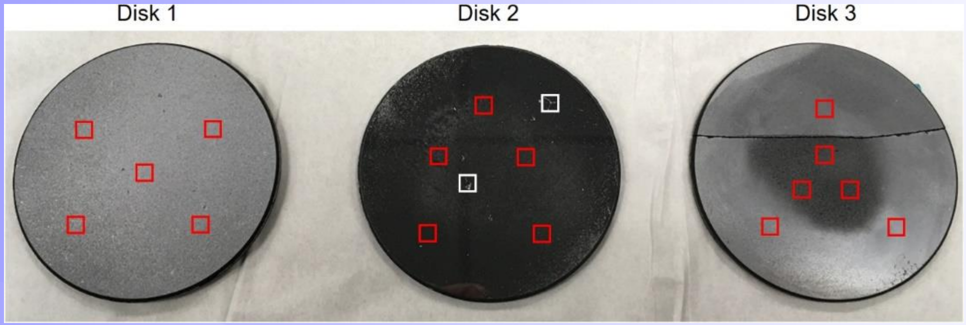
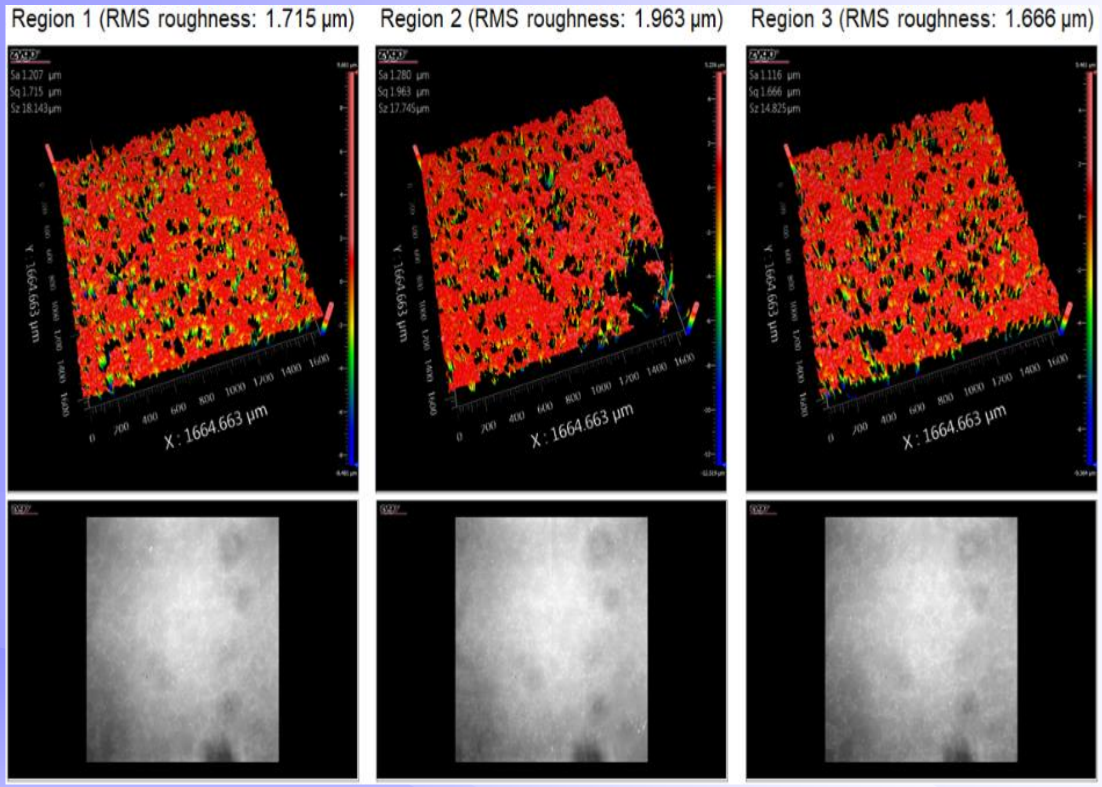
Silicon Cladding Coating Evaluation



Zygo Evaluation of Silicon Cladding



6 inch Mirror- Demonstration Sample

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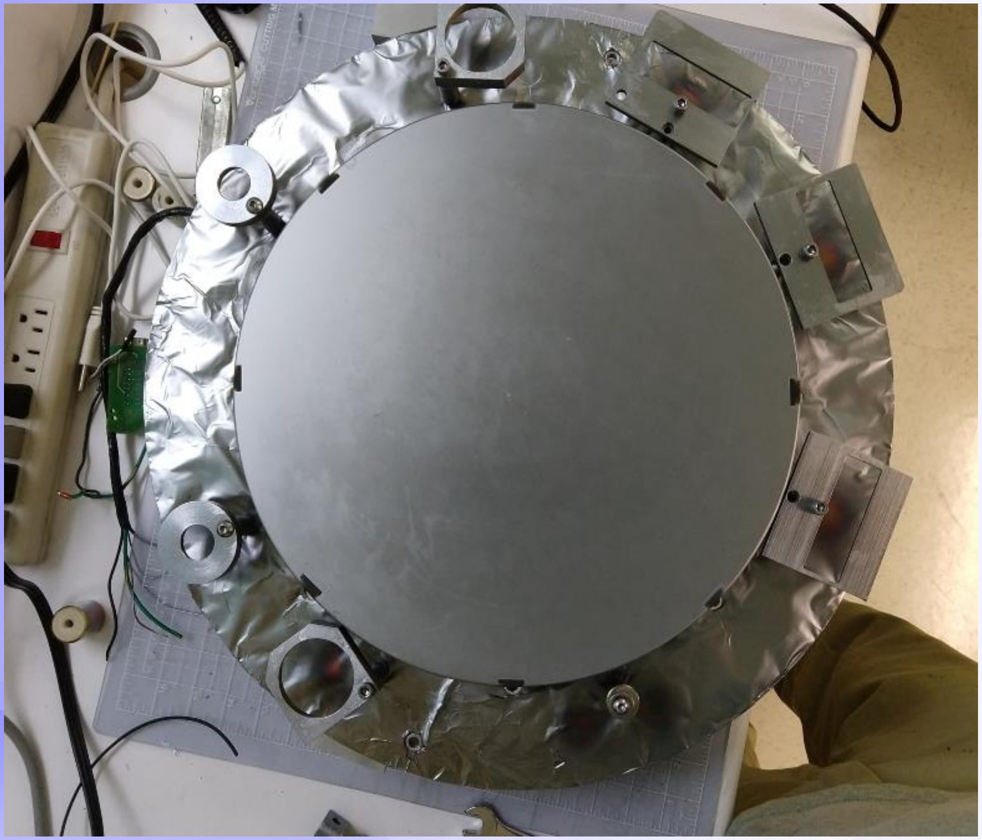
14” Mirror Silicon Cladding



Mirror substrate after silicon cladding by ZeCoat (14” dia.).

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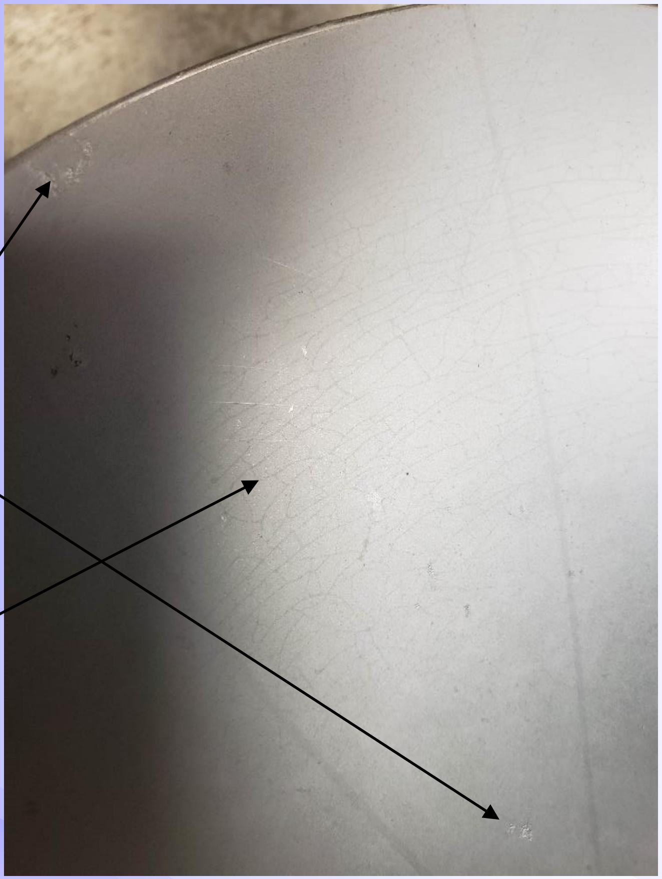
Pore Sealing Affects and Defects

Examples of low areas

Sub-surface stress cracks visible over entire surface



Fine-ground mirror surface with Si cladding, ready to be polished by OMI.

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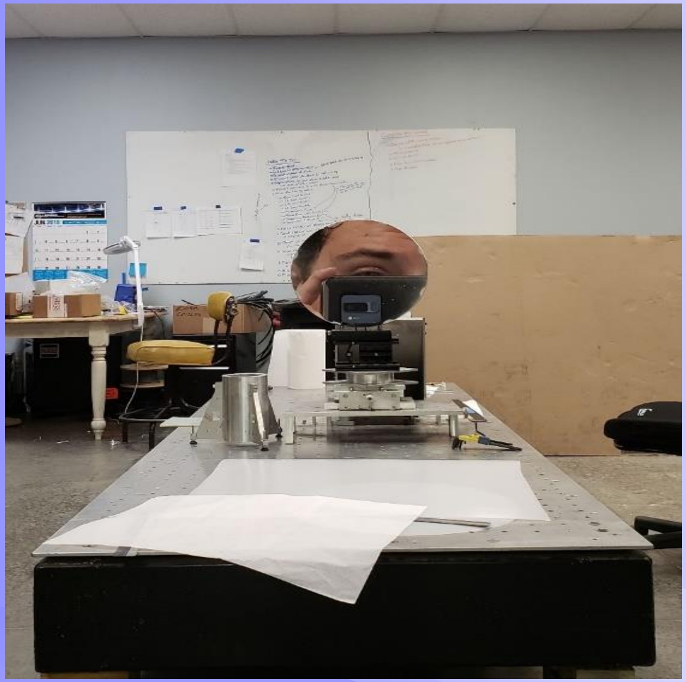
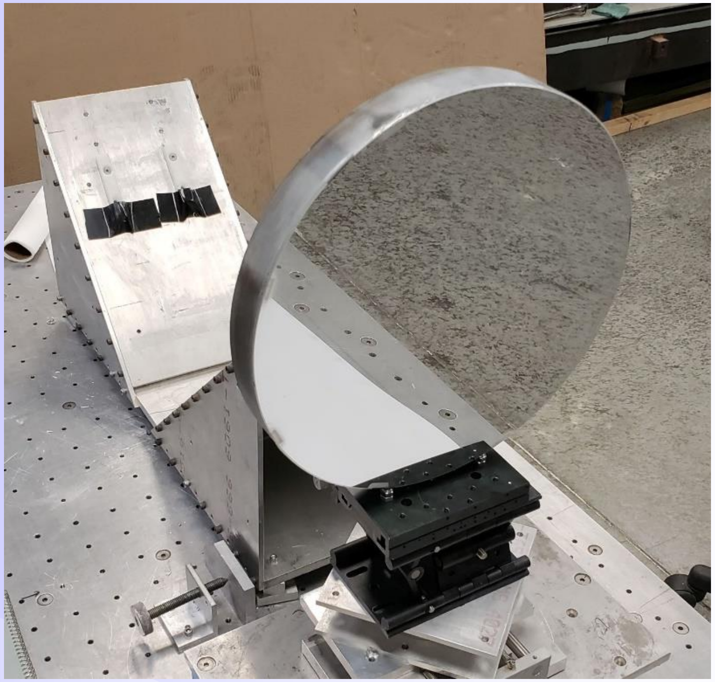
Finished Mirror Image from OMI





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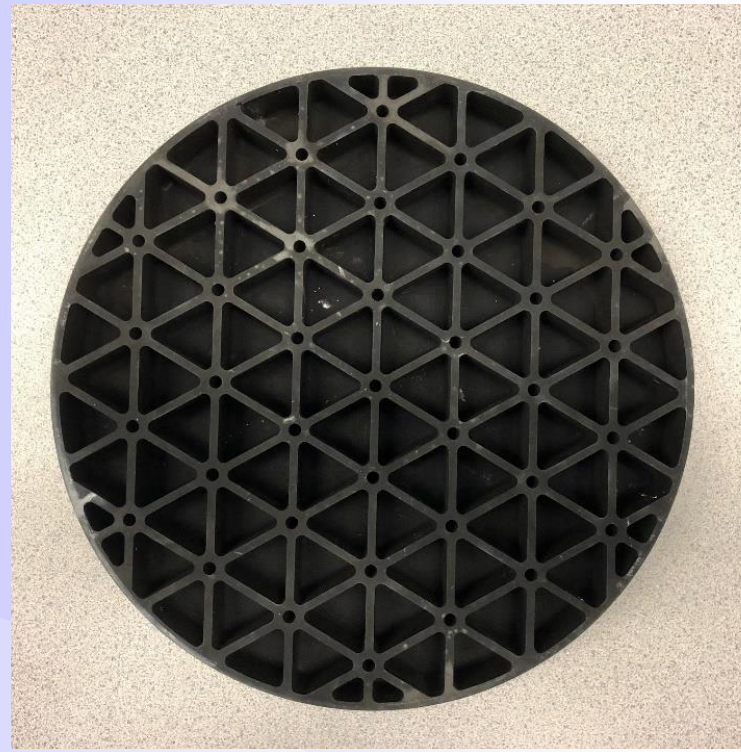
14” Completed Mirror(5.7 lbs)



Deliverable 14” coated and aluminized ceramic mirror (front and back).

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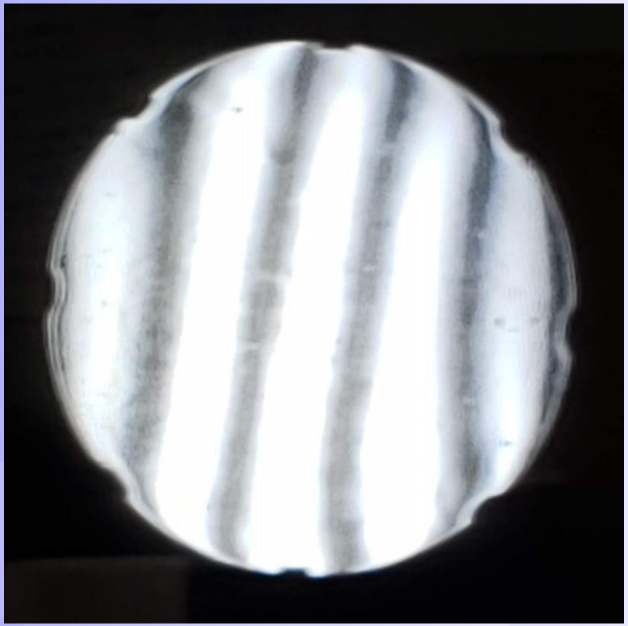
Ronchi Grating Test



Ronchi grating test, 60 lpi, inside Rc.

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Major Lessons Learned

- Polyimide system for sealing/coating very sensitive to process T range and water
- X-MAT® process successfully built large scale PDC parts
- Furnace process and configuration critical to consistent results
- Need a better sealing/coating process for porous mirror component(reduce defects)

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Additional Cladding/Sealing Techniques- Future Developments

- Low CTE Glass to match the SiOC CTE
- Fully dense SiOC ceramic to identically match bulk SiOC CTE
- Current production cladding processes

R&D Material Developments

- X-MAT® Coal Core Composites

    www.x-materials.com

CCC Density- 1.2-1.7 g/cc CTE- 2.35 10-6/C (100 C)

SiC Density- 3.1-3.2 g/cc CTE- 3-4 10-6/C

- Engineered Anodic Particles

Specific Capacity 900 mAh/g vs 372 mAh/g for graphite

- X-MAT® 3D Ceramic Printing including SiC

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What are Coal Core Composites?

- Raw coal powder mixed with proprietary ceramic-forming resin to form materials that are:
  - Lightweight - bulk density of 1.2-1.7g/cc
  - Low cost – Coal is 2-3¢/lb
  - “Unburnable”
  - Easily manufactured compared to typical ceramics – no sintering needed
  - “Green” low energy processing

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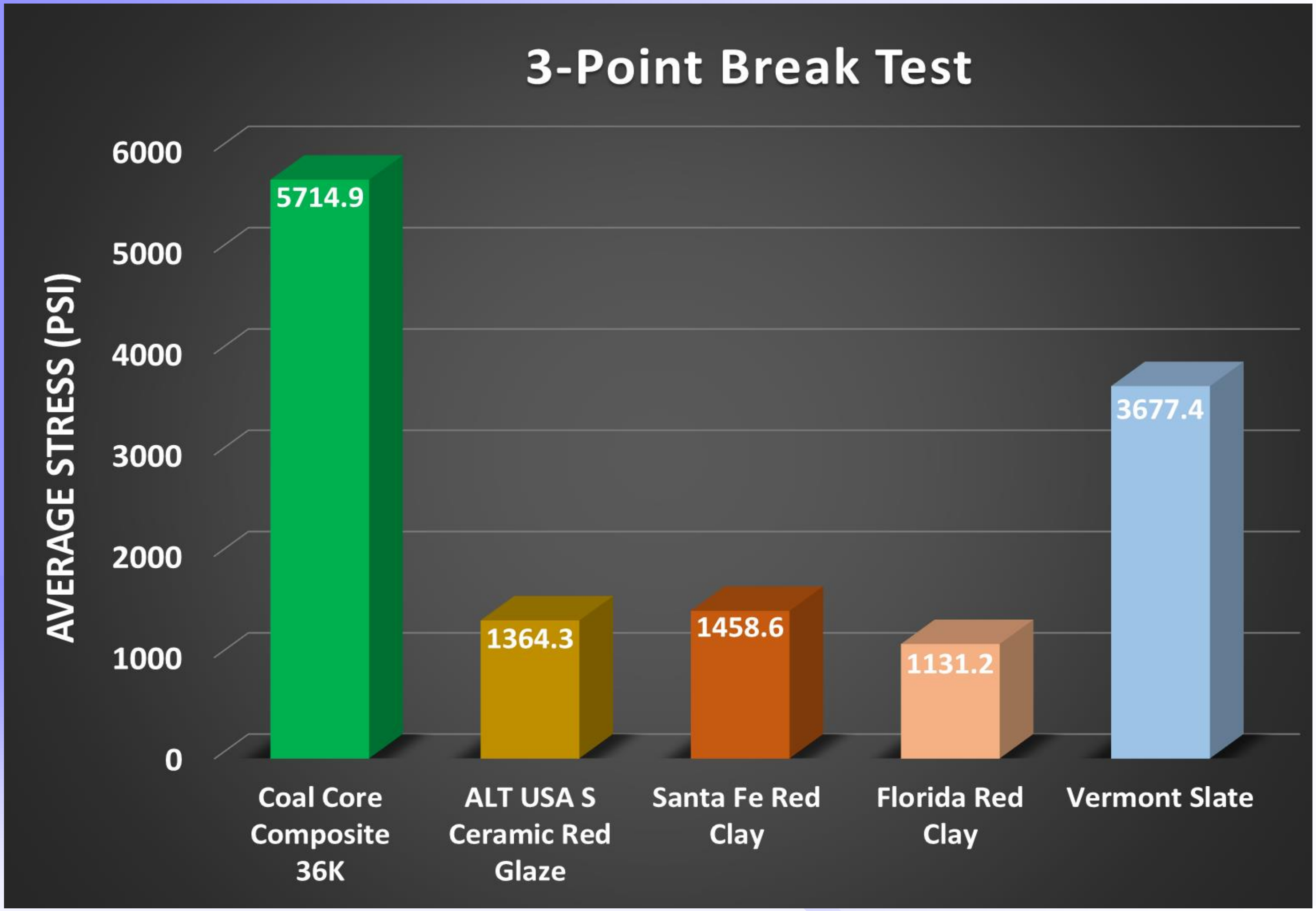
Comparison of a Coal Core Composite Plate to Ceramic Tile and Slate



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3D Printing PDC Process

Pre-ceramic Part | Transition 400C | Final Ceramic Part

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3D Printed Ceramic Components

1

3

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Key Milestones Met

- Demonstrated Bulk-scale Polymer-Derived Ceramic Process – First of Kind
- Demonstrated 14” diameter Bulk-scale Part from Polymer-Derived Ceramics – First of Kind
- Produced Lightweight Polymer-Derived-Ceramic Mirror that measured 1.6” thick with a 14” diameter that weighed only 5.7 lbs. – First of Kind

Progress/Conclusions

- Both Silicon and Polyimide Coating Processes were evaluated
- 14.5” Bulk Component Produced/ 6” Mirror Demonstration Sample
- 14.5” Silicon Cladded Mirror Completed
- Continuing Advances of X-MAT® Technology in Scale, Performance, and Material System Types

Acknowledgements

NASA- Phil Stahl, Ron Eng

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UCF- Kathleen Richardson, Myungkoo Kang

Semplastics- Arnie Hill, Todd Hubert, Matthew Stephens, Barbara Hopkins, Greg Yatko

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