Large-Scale Silicon Oxycarbide Composite Component for Ultra-Low Cost, Lightweight Mirrors

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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
- Commercial Possibilities
- New Material Developments
- Conclusions

Who is Semplastics?

- 17 year old company focused on high performance plastics in electronics
- Recent development activities in novel high performance materials- X-MAT®
- US patents #8,961,840,#9,434,653 and #9,764,987 issued- multiple patents pending
- Phase I NASA SBIR granted in May 2015
- Phase 2 NASA SBIR granted in April 2016
- Space Florida Grant for 3D printing Ceramics in June 2017

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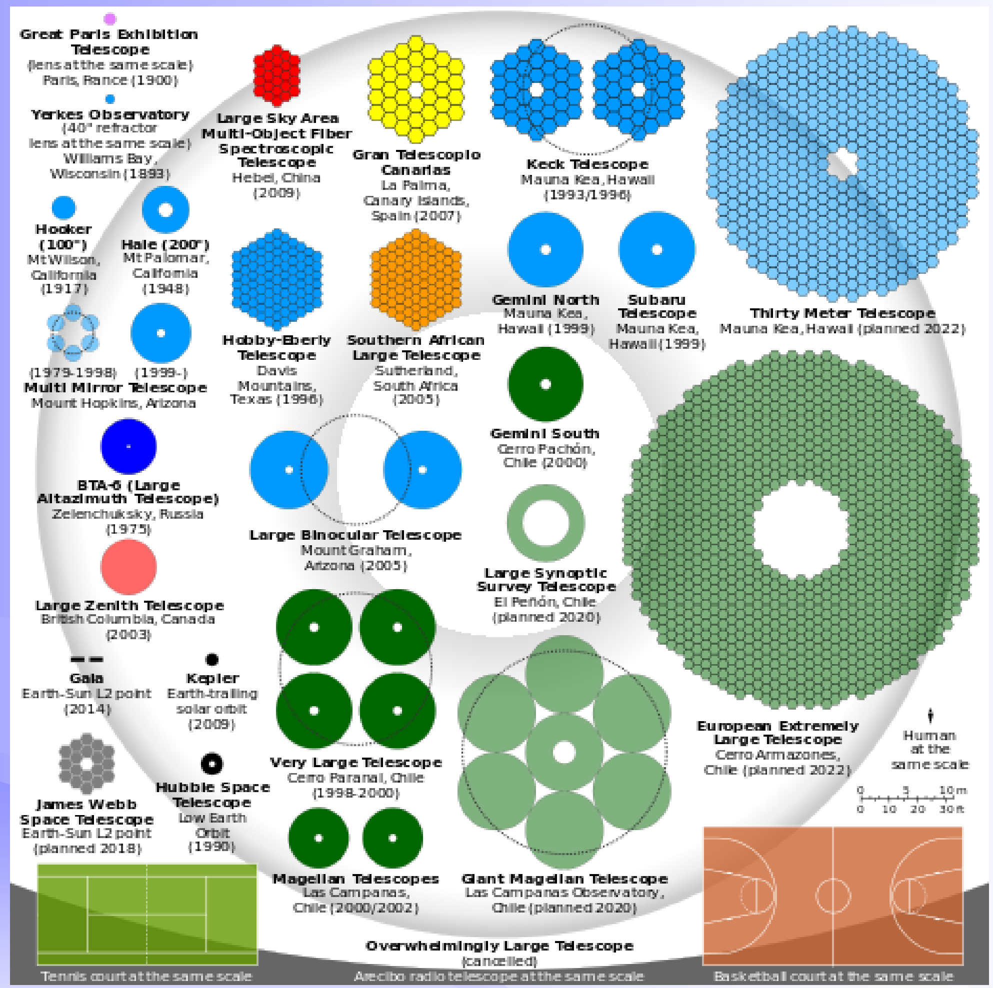
Comparison of Optical Telescopes



https://commons.wikimedia.org/wiki/File:Comparison_optical_telescope_primary_mirrors.svg

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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

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NASA SBIR Phase 2 Technical Objectives

- Demonstrate Scalability by producing both 14” and 24” diameter mirrors
- 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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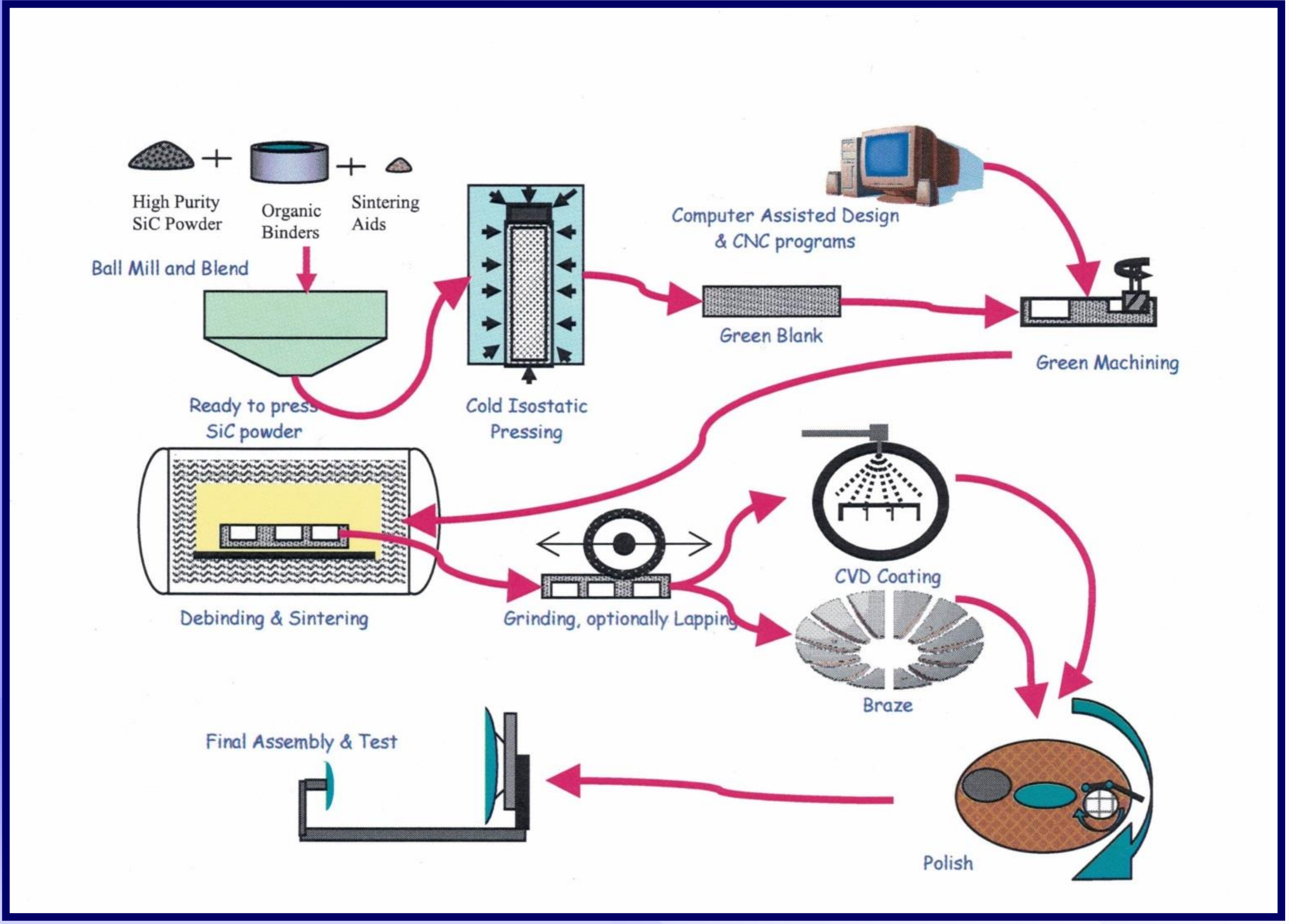
Advantages of X-MAT® OC1

- 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!!

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]

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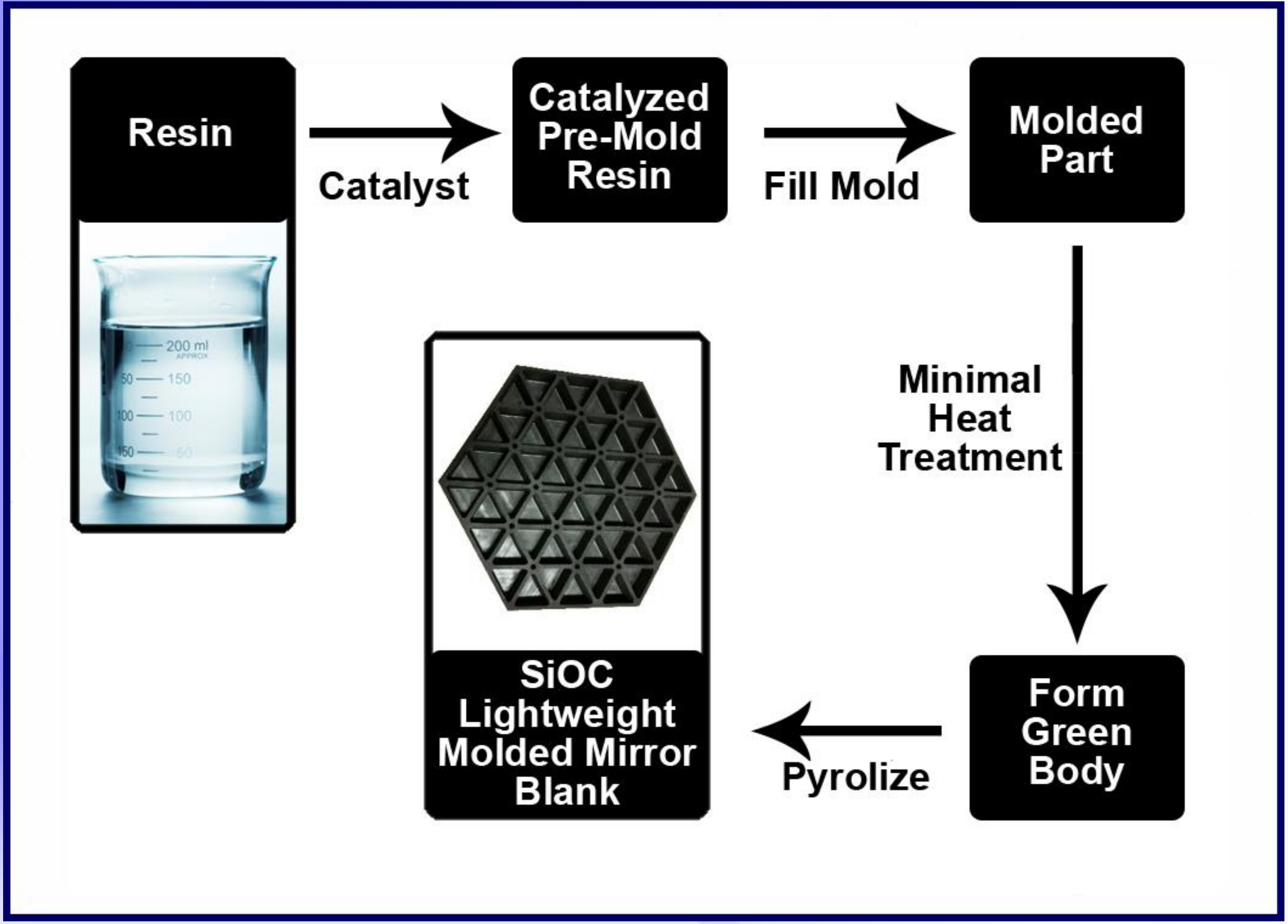
X-MAT® Mirror Blank Process



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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

Significance/Review of Polymer-Derived Ceramics (PDCs)

- 40 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

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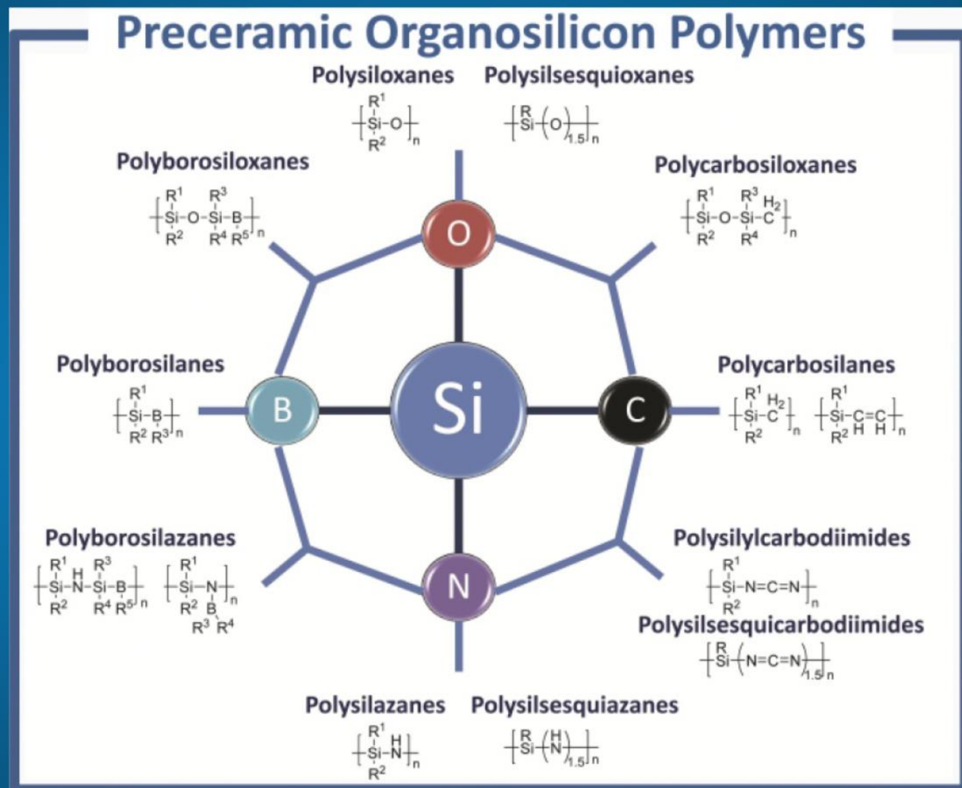
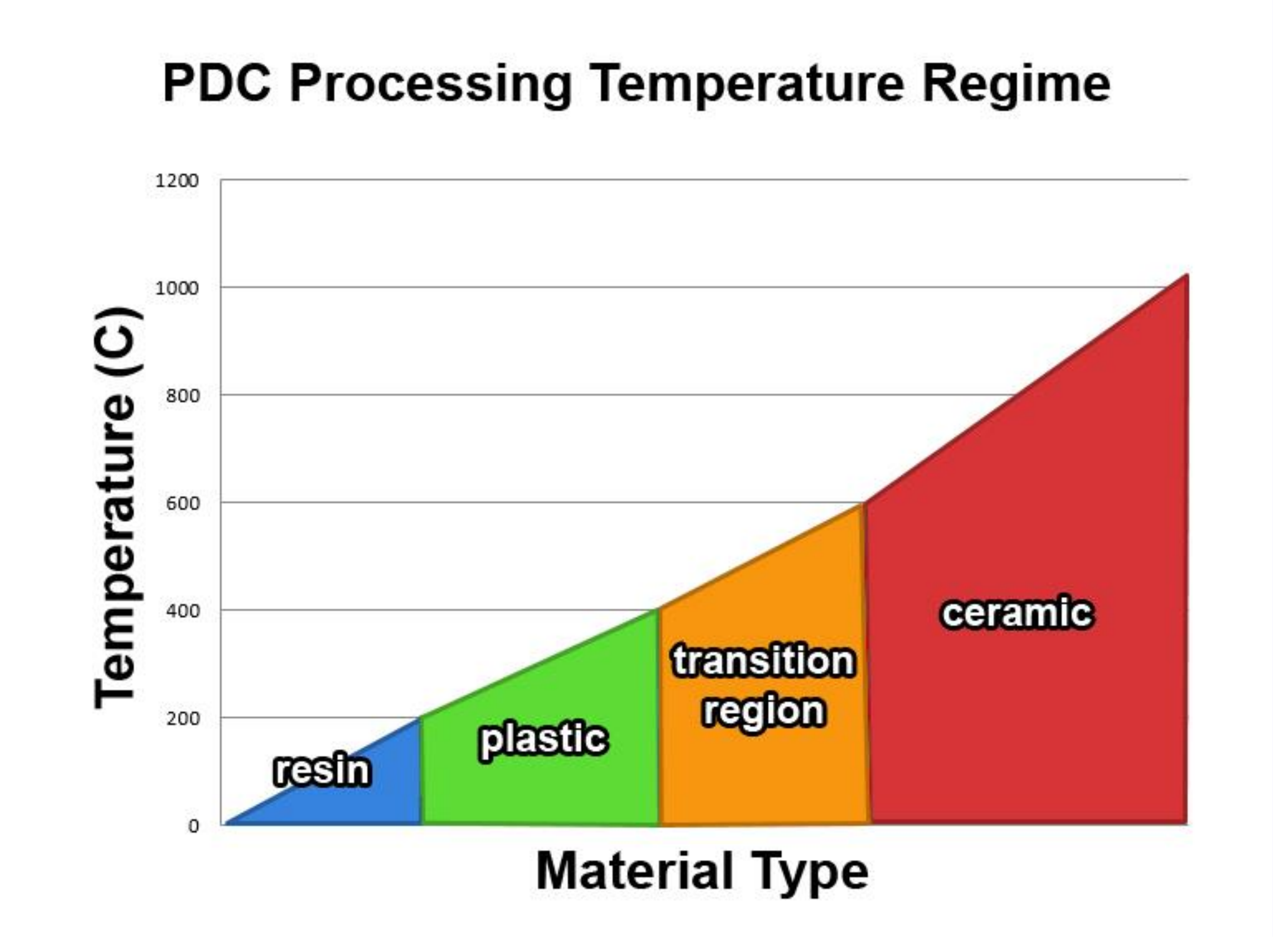
PDC Technologies

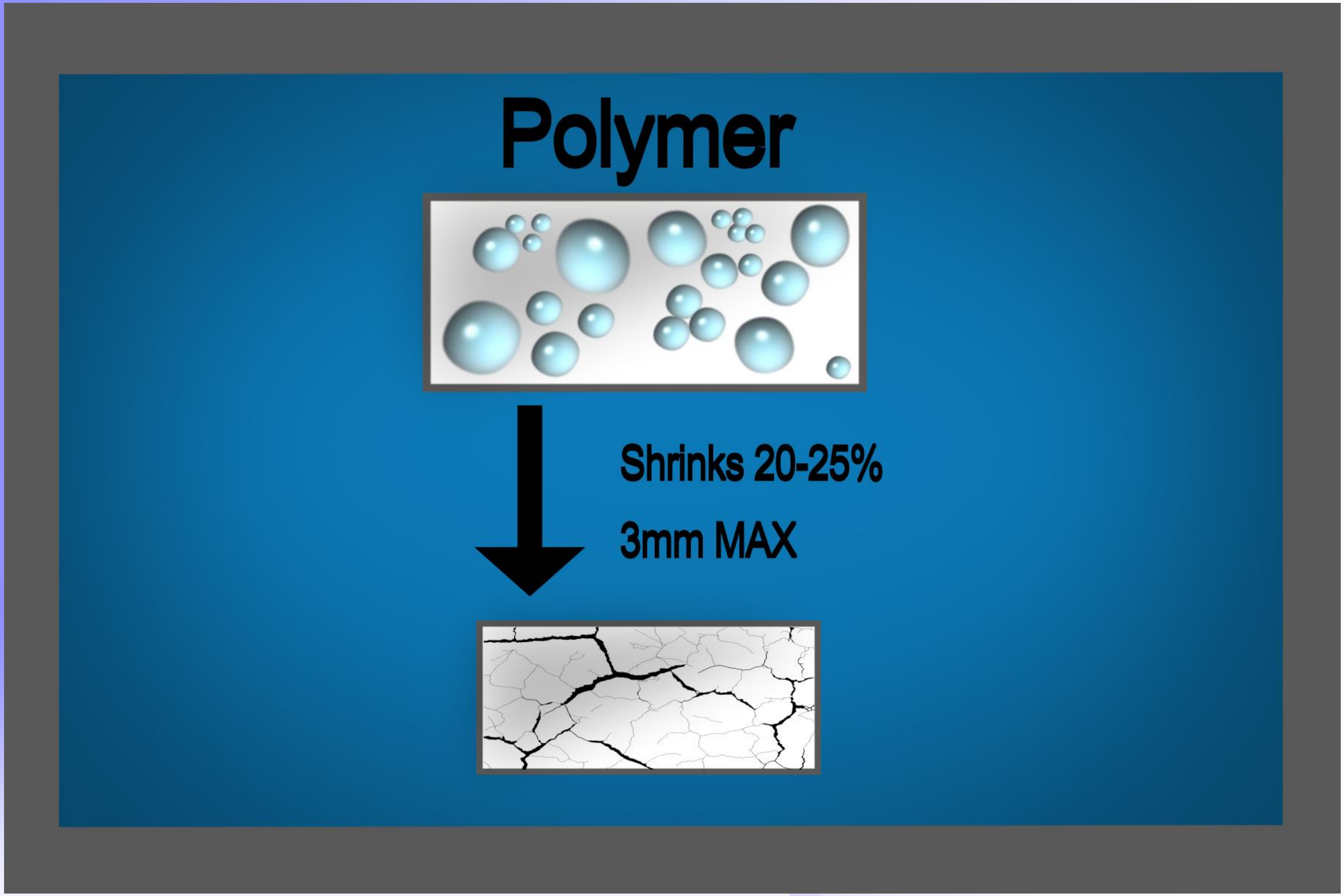


J. Am. Ceram. Soc. 93 [7] p.1807 (2010)

Polymer-Derived Ceramics Processing Cycle



Polymer to Ceramic Processing



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Historic 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 <u>below a few hundred micrometers</u>(as in the case of fibers, coatings, or foams.) J. Am. Ceram. Soc. 93 [7] p.1811 (2010)

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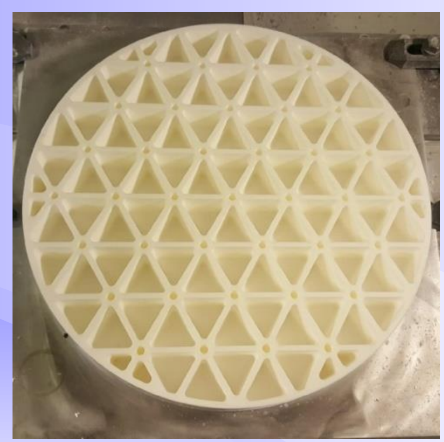
Scaling of X-MAT Technology- Largest Bulk PDC Made(No Fibers)-"Virtually Unachievable"

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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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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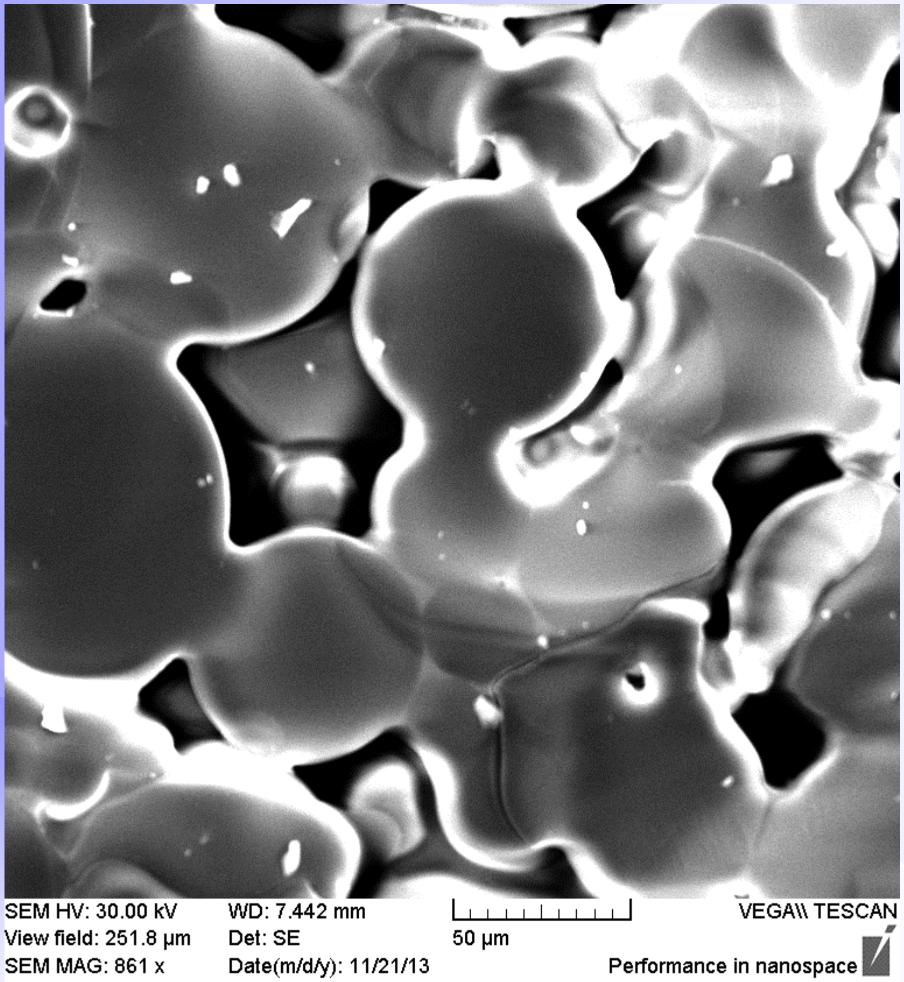
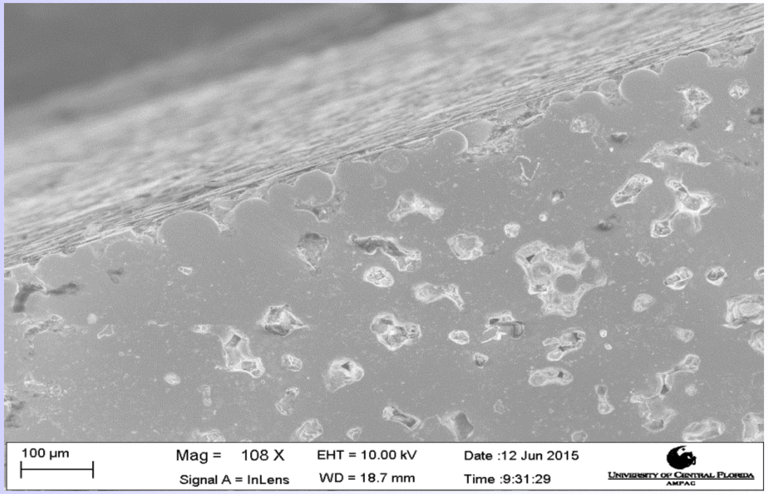
SEM of X-MAT® OC1

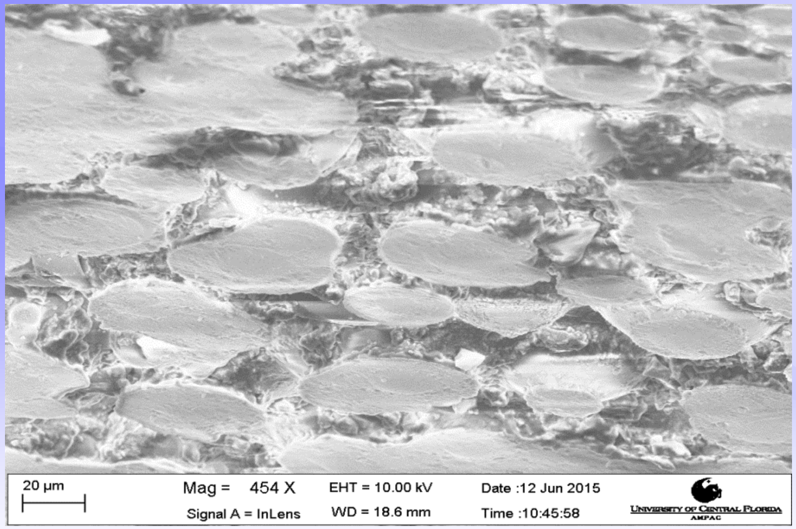


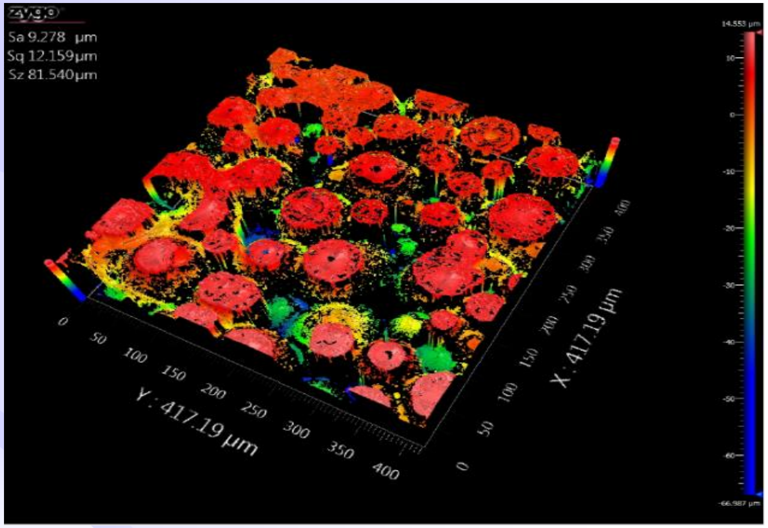
SiOC PDC Uncoated Substrate

Uncoated SiOC PDC

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

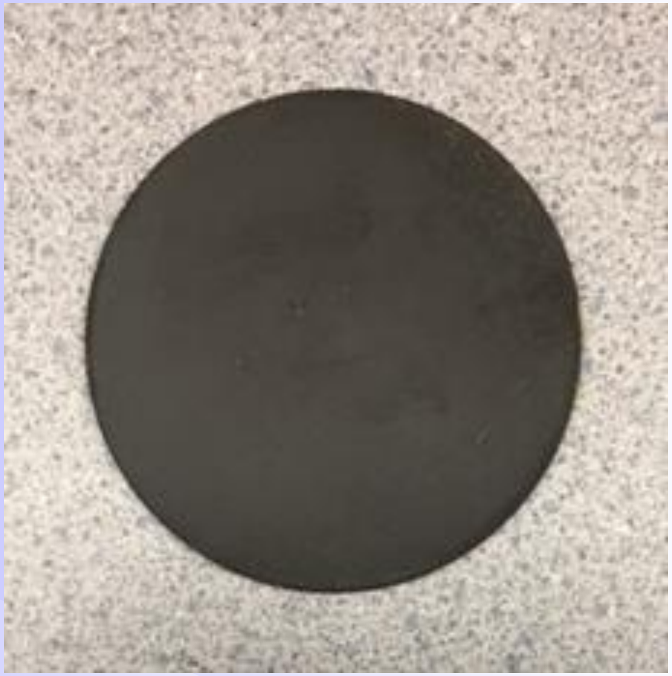






Test Disc Photos

X-MAT® Disc – No Coating



Polyimide Coated X-MAT® Disc with Sealed Pores

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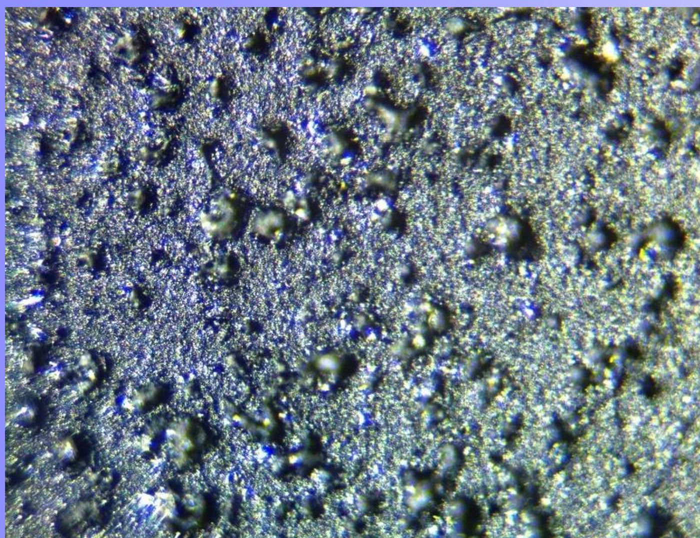
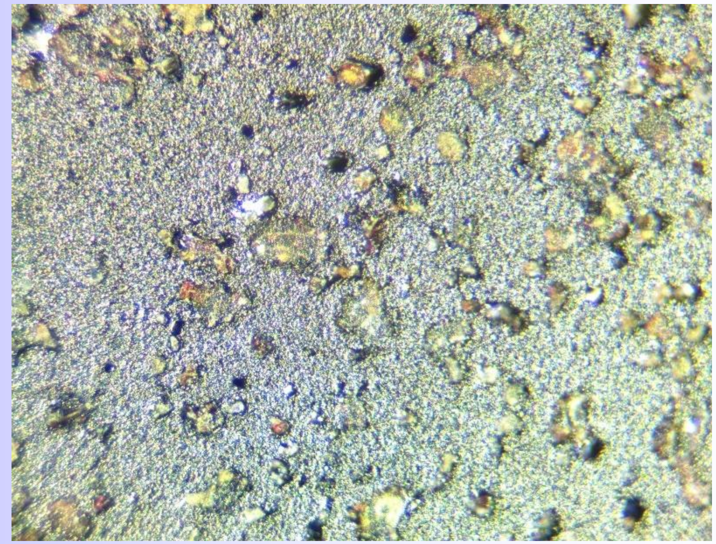
Test Disc Pore Photos



X-MAT® Disc – No Pore Filling



X-MAT® Disc with Polyimide Filled Pores

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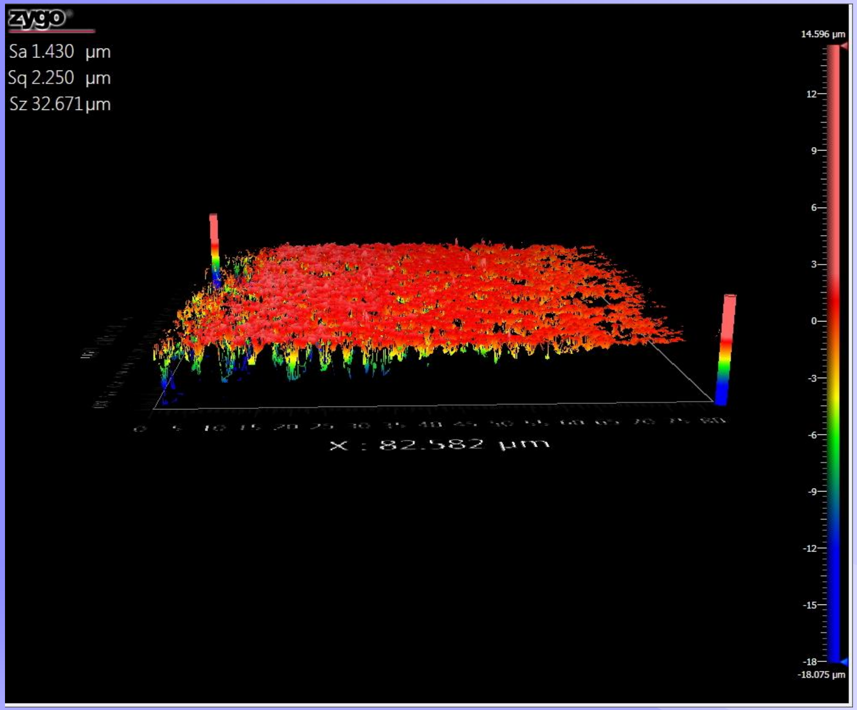
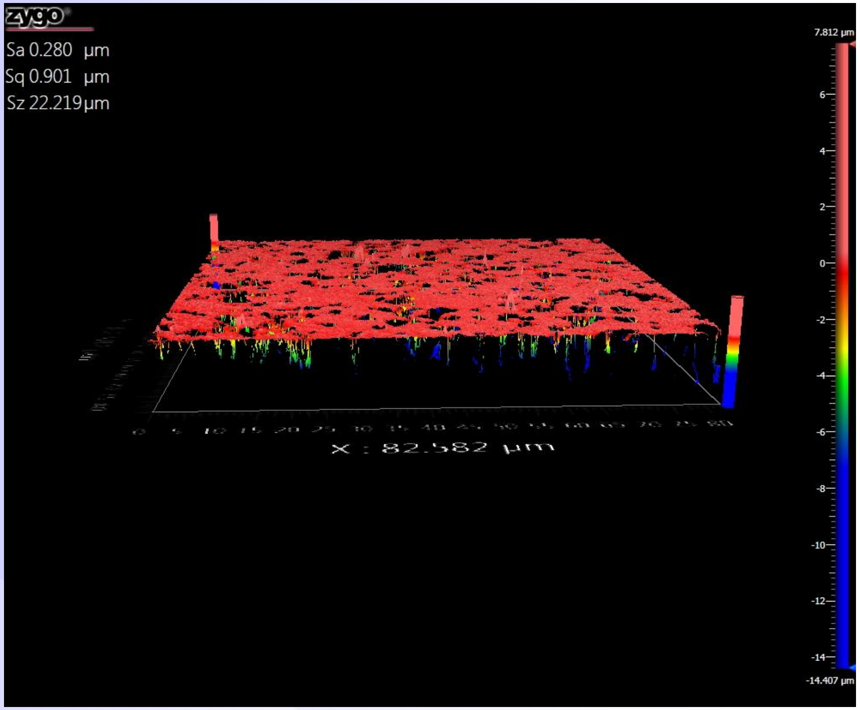
Zygo Process Figures



Unground Disk



Ground Disk

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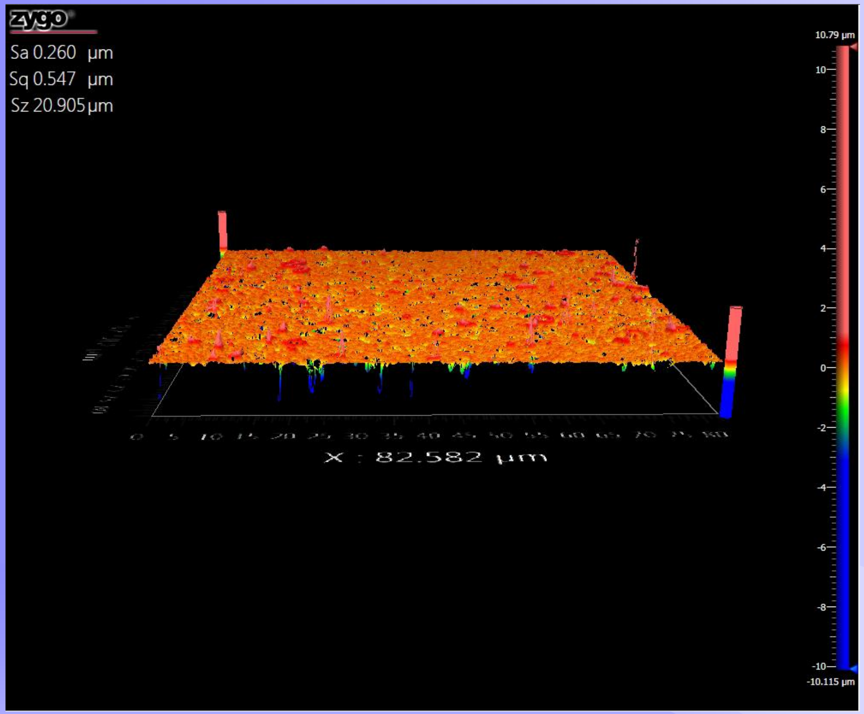
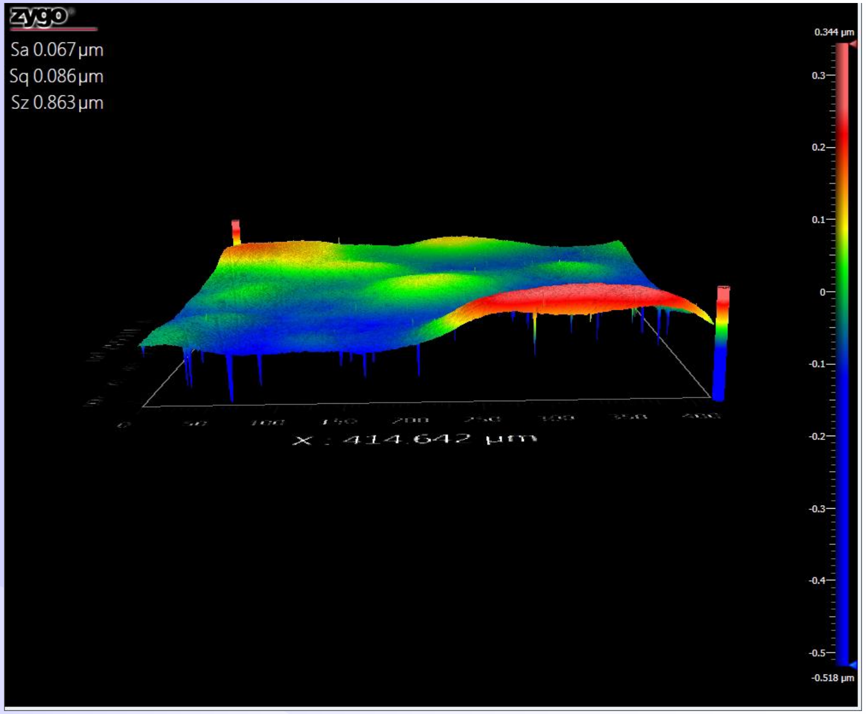
Zygo Process Figures (Cont.)



Polyimide Coated Disk



Aluminum Coated Disk

6 inch Mirror- Demonstration Sample

Additional Cladding/Sealing Techniques to be Evaluated

- Low CTE oxide glasses.
- Fully dense green cast SiOC ceramic.
- CVD SiC coating.
- Silicon monoxide coating.
- Slumped glass top layer.

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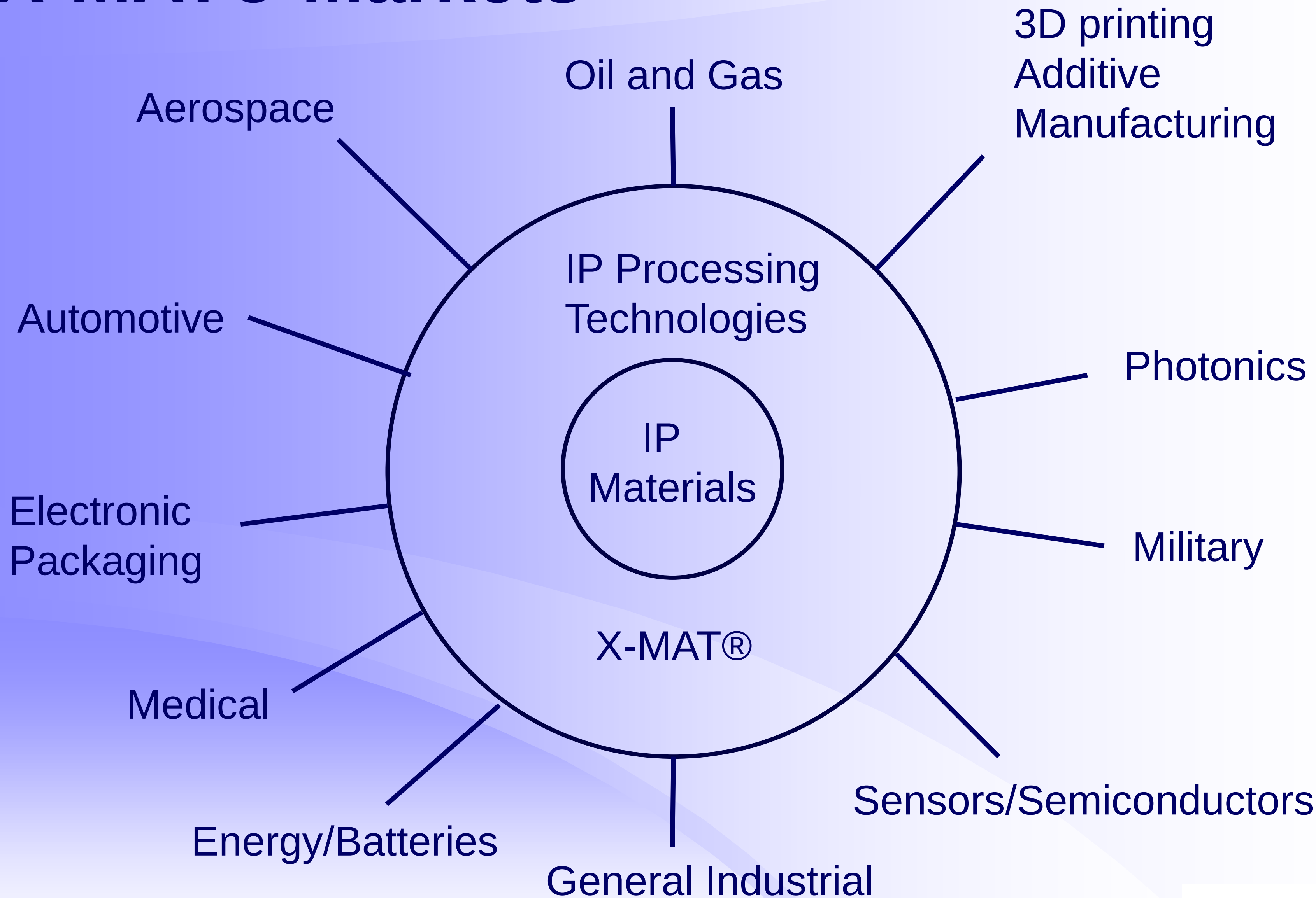
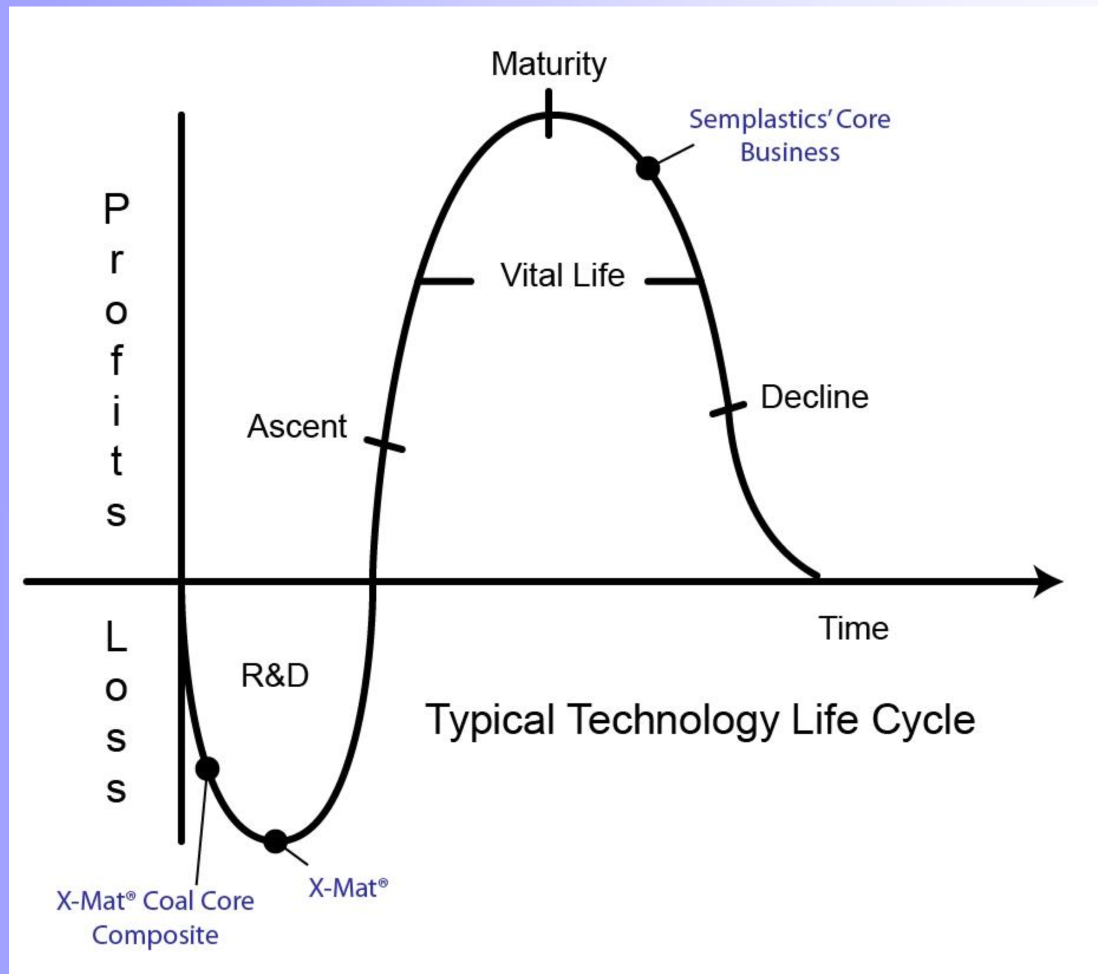
X-MAT® Markets



Typical Technology Life Cycle



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Commercial Possibilities

- Purchase X-MAT® Lightweighted blanks from Semplastics
  - Advantages
    - Lower Cost
    - Faster Turnaround – 1-2 months in production
    - Lightweighted Structures Molded-In
- License X-MAT® mirror technology from Semplastics
- Joint Development Project for Specialized Mirrors

IR&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

- Thick Bulk X-MAT® SiC structures

- X-MAT® 3D Printing

- Stronger and Tougher SiOC ceramics

Video of Coal Core Composite

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Conclusions

- Both Silicon and Polyimide Coating Processes are being developed and scaled
- Initial Grinding, Polishing, and Shaping Processes have been developed, Further refinements on-going
- 14.5” Bulk Component Produced/ 6” Mirror Demonstration Sample
- Continuing Advances of X-MAT® Technology in Scale, Performance, and Material System Types

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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