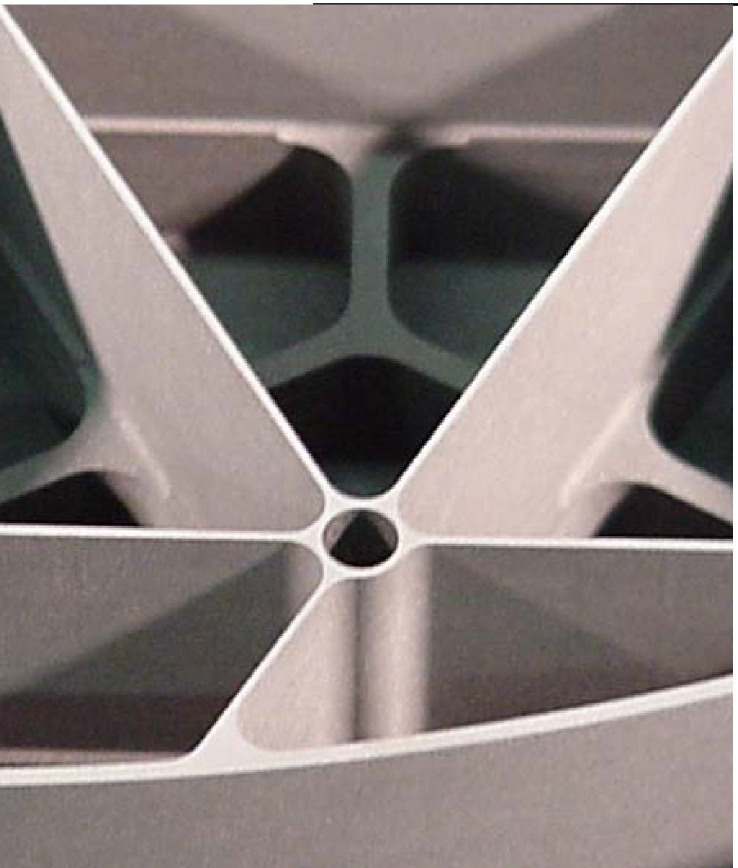
A Low-Cost Innovative Approach for the Fabrication of Net-Shape SiC Components for Mirror Substrates



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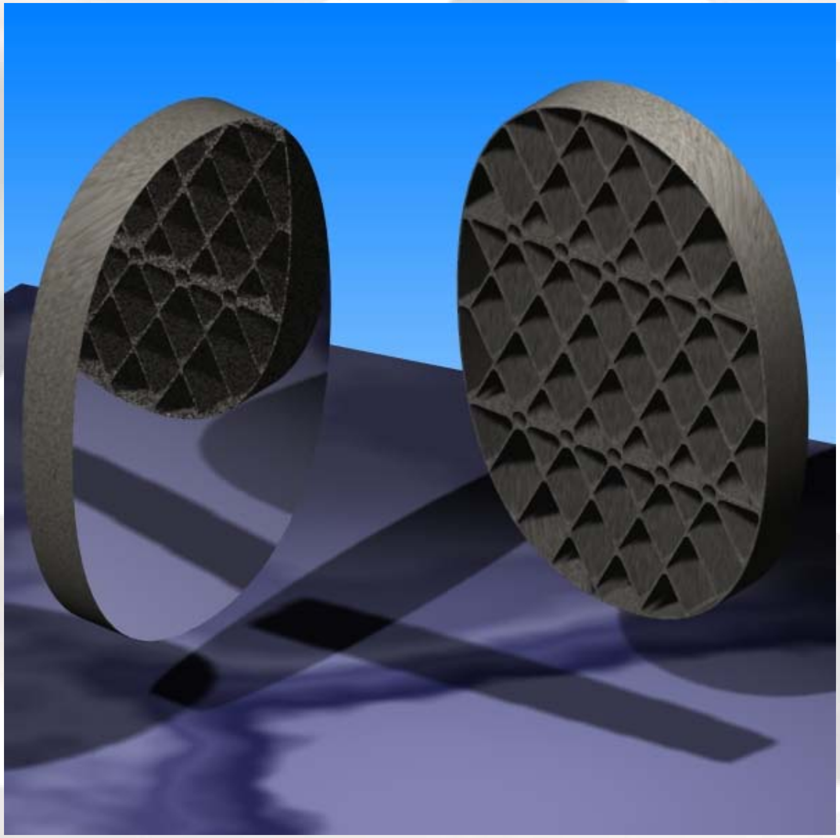
Opportunity



SiC Mirror Substrates Recently Manufactured by POCO

- Beryllium is being phased out due to mounting health concerns and cost.
- There is a need for a new replacement material with comparable properties desirable for optics applications.

Selection Criteria

- Property requirements as compared to beryllium such as specific stiffness, thermal stability, etc.
- Property Comparison of Candidate Materials
- Ease of Complex Net-Shape Manufacturing
- A Low Cost Manufacturing Process

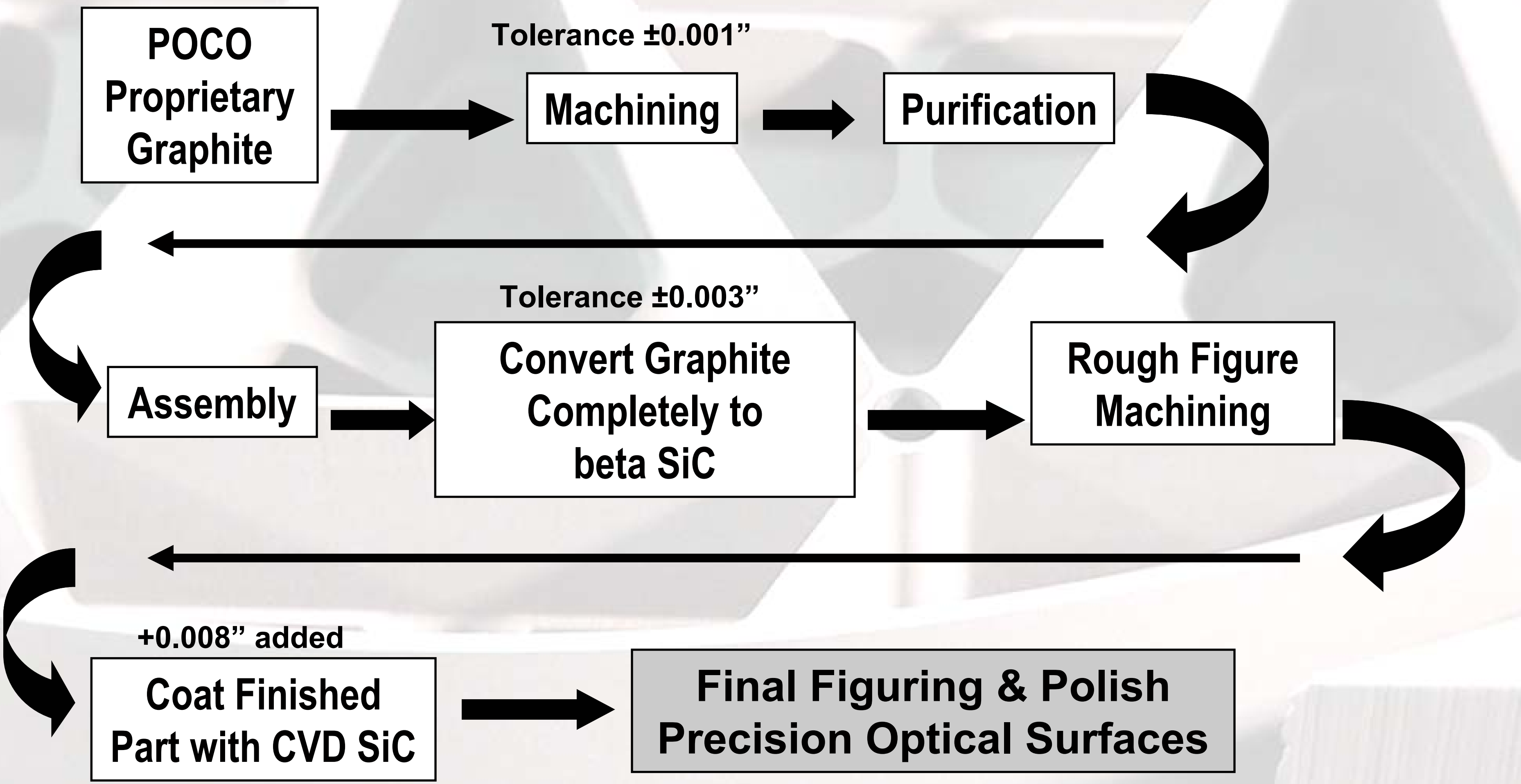
Property Requirements for Materials in Optics

Low	High	Benefit
Density (ρ)	Elastic Modulus (E)	High Specific Stiffness (E/ρ)
CTE (α)	Thermal Conductivity (κ)	High Stability Factor (κ/α)
	Thermal Diffusivity (D) & Heat Capacity (C)	High Thermal Conductivity
Poisson's Ratio	Strength & Fracture Toughness	Long-Term Stability

Material Property Comparison

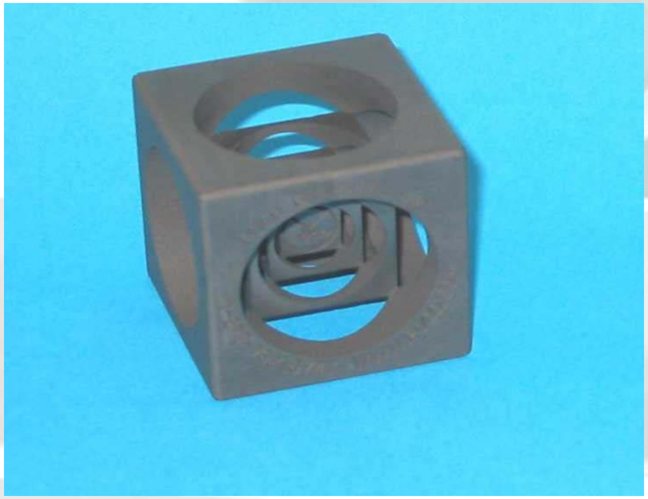
Material	Density (ρ)	Elastic modulus (E)	Thermal expansion (α)	Thermal conductivity (κ)	Specific Stiffness (E/ρ)	Thermal Stability Parameter (κ/α)
Units	g/cm^3	GPa	$x\ 10^{-6}/K$	W/m-K	kN-m/g	W/μm
RB SiC	2.92	310	2.4	157	106	65
CVD SiC	3.21	466	2.2	300	145	136
HP SiC	3.20	455	2.6	155	142	60
Sintered SiC	3.16	415	2.5	114	131	46
Beryllium	1.85	303	11.4	216	164	20
Zerodur®(7)	2.53	91	0.05	1.64	36	33
BK7 (glass)	2.53	81	7.1	1.12	32	0.16
SXA	2.91	117	13.0	125	40	9.62
Aluminum	2.7	68	23.6	170	25	7.20
POCO SiC	2.53	218	1.2	170	85	142

POCO SuperSiC™ Process



SUPERSiC™ Conversion Process

Purified, Net-Shape (Machined) Graphite



Polycrystalline, Stoichiometric ß-SiC

$2C + SiO \rightarrow SiC + CO$

No Additives (High Purity)

POCO Manufacturing Capability

POCO has been supplying different industries with numerous SiC products, such as wafer carriers, of high purity and excellent mechanical and thermal properties

Advantages of POCO's Process

- Manufacturing capability
  - Near net-shape – Consistent dimensional changes as a result of C $\Rightarrow$ SiC conversion and CTE change
  - High shape complexity due to ease of graphite machining – Comparable to Aluminum
  - Low cost due to absence of tooling charges and post machining
- High purity due to absence of any additives
- Short lead time due to the unique nature of the process
- POCO engineers and produces own graphite for conversion to SiC
  - Continuous improvement
  - SiC properties can be controlled by controlling graphite properties
  - Quality control is under our control.

Objectives and Benefits of the Proposed Work

Objective:

- Develop a post process for the DENSIFICATION of POCO's porous SuperSiC™ material without sacrificing near net-shape manufacturing capability.

Benefit:

- Capability of producing dense near net-shape SiC products with cost/performance attributes comparable to other commercially available SiC products.

Outline of the Proposed Process

- Produce the desired near net-shape porous SuperSiC™ part using POCO's conversion process (No development needed)
- Impregnate the part with a carbon precursor mixture, the composition of which is to be developed in this Phase I; cure and pyrolyze
- Repeat impregnation cycle, if needed, ⇒ The result is a carbon structure with interconnected microporosity residing in the open pores of the part to be densified.
- Infiltrate with silicon to convert the carbon to SiC resulting in a net-shape dense SuperSiC densified with the new RFSC phase.
- Apply CVD SiC coating or silicon cladding, if needed.

Phase I Work Plan

- Define mirror requirements (Raytheon)
- Prepare porous SiC preforms and test specimens
- Select an array of resin compositions most suitable as the carbon precursor
- Develop impregnation conditions and prepare carbon-impregnated samples
- Develop silicon infiltration conditions
- Characterize RFSC-Densified samples for density, porosity, strength, stiffness, fracture toughness, thermal conductivity, CTE, microstructure & free Si
- Final technical report in addition to monthly progress reports

Some Preliminary Results as Compared to SuperSiC™

Property		As-Converted (SuperSiC™)	SiC-Densified (Proposed)
Bulk Density, ρ_b (g/cm^3)		2.53	3.07
Total Porosity, P_t (%)		20	
Open Porosity, P_{op} (%)		18-19	0
Flexural Strength (MPa/ksi) *m is Weibull modulus*@ RT		147/21.3 (m=17)	200/29-275/40 **(up 36-87%)**
Tensile Strength (MPa/ksi)		129/18.7 (m=16)	
Young's Modulus, E (GPa/msi)		218/32	375/54 **(up 72%)**
Specific Stiffness, E/ρ_b (kN-m/g)		85	121 **(up 42%)**
Poisson's Ratio, ν		0.17	
Dynamic Shear Modulus, G (GPa/msi)		96/14	
Fracture Toughness, K_{IC} ($MPa{\cdot}m^{0.5}$)		2.3	
Hardness (kg/mm^2)		2000	
Thermal Conductivity, κ (W/m·K)		170	
Mean Coefficient of Thermal Expansion (CTE), α_m (10^{-6}/K)	@ 500°C	4.0[(1)]	
	@ 1000°C	4.4[(1)]	
	@ 25	1.2[(2)]	

Further Development

- Demonstrate repeatability of the developed process
- Scale up the process for the densification of complex shapes and large parts
- Test the developed process for the manufacturing of SiC fiber-reinforced SiC matrix composites
- Demonstrate the CVD SiC coating of densified plates and their polishability
- Develop correlation between material properties and mirror performance

Commercialization and Other Applications

- POCO will continue to support the development of the proposed process and the commercialization of the produced SiC material
- In addition to optics, there is a definite need for a dense low-cost SiC material for a number of other applications such as in the semiconductor industry where corrosion resistance is desirable

Summary

- Silicon carbide is the material of choice to replace Beryllium
- POCO's process has the advantage of manufacturing capability to produce complex shape SiC products at lower cost
- POCO has the advantage of producing own graphite for conversion to SiC ensuring a continuous quality control
- Although POCO's SuperSiC™ material has good mechanical and thermal properties needed for optics and other applications, there is still room for improvement via the proposed densification process
- Preliminary results showed a significant increase in flexural strength and stiffness for the densified SiC material

Acknowledgement

- Poco Graphite, Inc. wishes to thank the Missile Defense Agency for funding this Phase I program
- POCO is looking forward to working with Dr. Arup Maji (Technical Monitor), AFRL/VSSV, Kirtland AFB, NM, and utilize his technical support and guidance towards achieving the objectives and goals of this project