Mirror Technology SBIR/STTR Workshop

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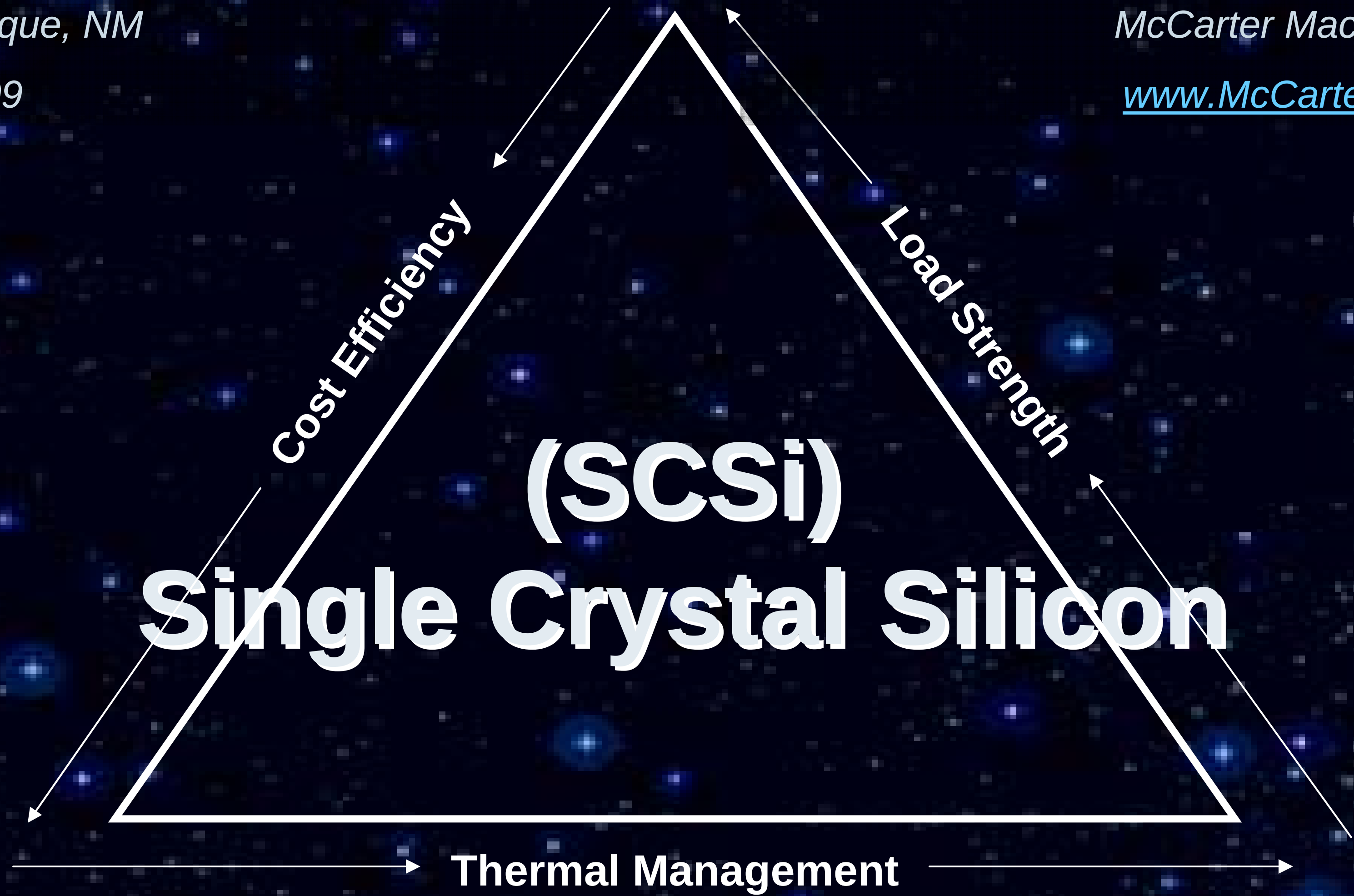
Presented by Doug McCarter, VP/TI

McCarter Machine Inc

www.McCarteret.com



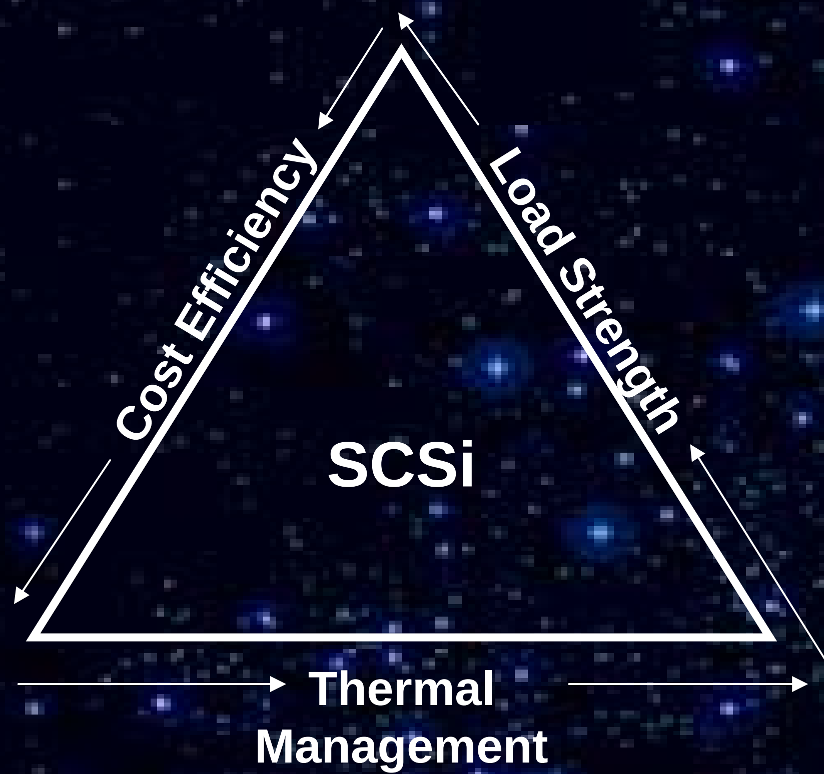
(SCSi) Single Crystal Silicon

The Pre-Eminent Material for Uncooled Mirrors and Structures for Space Systems

Advantages for Advanced Aerospace Systems

The single crystal silicon mirrors and structures supplied by McCarter Machine offer:

- Thermal Management
  - *hot and cold*
- Load Strength
  - *design and fabrication*
- Cost Efficiencies
  - *materials and processes*



Optical Materials Data

THE USUAL PROPERTIES

Property*	ρ	E	s	E/ρ	$(\rho^3/E)^{1/2}$	α	k	α/k	α/D
Units	g/cm^3	GPa	Mpa	Arbitrary	Arbitrary	$10^{-6}/K$	W/m K	$10^{-8}m/W$	s/m^2 K
Prefer	Small	Large	Large	Large	Small	Small	Large	Small	Small
6061 Al	2.70	69	275	26	5.34	22.5	167	13.5	0.325
O-30 Be	1.85	303	207	163	1.45	11.4	216	5.3	0.188
I-220 Be	1.85	303	345	163	1.45	11.4	216	5.3	0.188
SCSi	2.32	131	339	56	3.11	2.6	156	1.67	0.027
SiC Sintered	3.15	410	480	130	2.76	2.1	175	1.20	0.026
SiC CVC	3.20	466	433	146	2.66	3.5	205	1.56	0.032
SiC RB 30%Si	2.89	330	300	114	2.70	2.6	155	1.68	0.032
SUPERSIC-SiC	3.07	379	269	123	2.76	2.4	218	1.10	0.022

* ρ - density; E - Elastic modulus; s - Strength: tensile yield for Al & Be, flexural strength for Si & SiC; E/ρ - Specific stiffness; $(\rho^3/E)^{1/2}$ - Mass-deflection proportionality factor; α - Coeff. of thermal expansion; k - Thermal conductivity; α/k - Steady state thermal distortion coeff.; α/D - Transient thermal distortion coeff.

Current Available Data

Compiled (2009) by Roger Paquin, Material Stabilization Scientist

Thermal Management - Hot

SCSi will not distort during and after exposure to heat

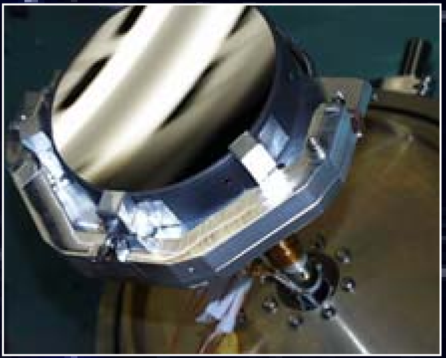
- SCSi is the best available material for use in uncooled laser optics due to its very low thermal distortion index (SCSi = 0.027)
  - The thermal distortion index *measures the distortion due to a temperature gradient* and is the ratio of the thermal coefficient of expansion (SCSi = 2.6) to thermal conductivity of a material (SCSi = 156).
  - For single crystal silicon this index is smaller than that of a “zero coefficient of expansion” material such as Schott Zerodur™
  - Superior to Beryllium (Be = 0.188) and comparable to that of silicon carbide (SiC = 0.029)
  - SCSi has no internal defects or second phases to cause distortions when heated, or cooled

Thermal Management - Cold

SCSi cools rapidly which is useful in defense and space applications

- Seeker optics are often subjected to cryogenic temperatures and must reach equilibration in a matter of minutes or less. With SCSi, a cooler is not required.
  - SCSi's very high thermal transport means rapid cooling with minimal transient gradients
  - Zero-D single crystal homogeneity
  - SCSi's low CTE and very low ΔL/L to cryo temps combined with its extremely high thermal conductivity and diffusivity almost completely eliminates the possibility of thermal gradients and distortions at cryo

McCarter's SCSi Lightweighted Mirror



Tested at 70K

McCarter 12.5 cm SILICON SPHERICAL MIRROR			
100% (full) aperture			piston/ tilt removed
subtraction	PV	RMS	PWR
cold - (pre cold) warm	0.436	0.071	-0.047
cold - (post cold) warm	0.598	0.071	-0.053
80% (clear) aperture			piston/ tilt removed
subtraction	PV	RMS	PWR
cold - (pre cold) warm	0.345	**0.057**	0.068
cold - (post cold) warm	0.325	**0.053**	0.066
post cold - pre cold	0.094	0.014	0.001

Load Strength - Design

The load strength of SCSi has as much to do with the design and fabrication as it does with its inherent properties.

- The components must be able to support loads
  - with no permanent deformation within limits set by the error budget
  - and certainly with no fracture.
- Selected strength properties
  - The *flexural strength*
    - the breaking strength in bending
    - SCSi of ≥330 MPa competes with the average of all four SiC at 371MPa
  - The *mass-deflection proportionality factor*, defined as (ρ3/E)1/2,
    - is a measure of deflection of a component with fixed mass. That is, when comparing components with the same mass, the factor gives the relative deflections.
    - 3.11 for SCSi competing with the average all four SiC pedigrees of SiC 2.76.
- Design issues
  - Density
    - SCSi = 2.33g/cm^3 which is 26% lighter than SiC at 3.15g/cm^3
    - Allows for thicker cross sections for comparable weight
  - Stiffness
    - Using McCarter's frit bonding method, back sheets can be added to large mirrors to increase stiffness 4 to 5 times
    - SCSi small mirrors are inherently stiff and do not require a back sheet

Load Strength - Fabrication

Load strength is affected by the fabrication methods used and the associated material properties

- SCSi is a stress free material
  - Extreme homogeneity, a single crystal
  - Daily grown as Zero-Defect Material from multiple sources
- Fabricate to further reduce possibility of thermal distortion
  - Eliminate sub-surface damage using McCarter Superfinish
  - Eliminate residual stress induced during manufacturing

- Using **McCarter Proprietary Frit Bonding** it is possible to build large, lightweight silicon mirrors that can be launched warm, and then cooled "on orbit" .

Cost Efficiencies - Material

- Single crystal silicon is lower in cost than other IR materials and is much easier to fabricate.
  - SCSi 2009 price $50/kg and
  - machining rate 16x that of SiC
- Cooling capacity on space systems is limited and the thermal properties of silicon minimizes the need for large, heavy, and expensive cooling systems on orbit.
- 95% yield per boule

Zero-D SCSi Boule

6” McCarter Frit Bonded SCSi Mirror

Cost Efficiencies - Processes

- McCarter Superfinishing – Patented
  - Eliminates costly Sub Surface damage
  - Prepares surface for SPDT without further processing, eg. lapping
- McCarter Proprietary Frit bonding – Proprietary
  - Eliminates the weight penalties associated with more conventional optical materials
  - Dampens vibration
  - Radiation resistant bond
  - Makes large and/or complex geometries possible
  - Enables direct mounting with metal inserts
  - Enables repair and rework
  - Stable over the long-term
  - Frit bonded assemblies minimizes material and machining time from machining a monolithic part
- No thermal processing required saving schedule days and processing costs
- SCSi can be polished without cladding or plating saving cost and schedule.

In Conclusion

The strength of SCSi mirror technology are derived from the unique properties of SCSi. These are:

- Extreme homogeneity
- Absence of internal stress
- Superior thermal properties
- The ability to be diamond turned or polished without cladding for optical or infrared applications.

These characteristics are responsible for:

- Floor-to-floor advantage in shorter schedule, less cost, and rapid component fabrication
- Cryogenic performance
- No detectable change in optical figure down to temperatures of 10K
- Distortion by lightweighting is negligible for most applications ($<1/40^{th}$ wave RMS @ 633nm)
- No need for cladding layer

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