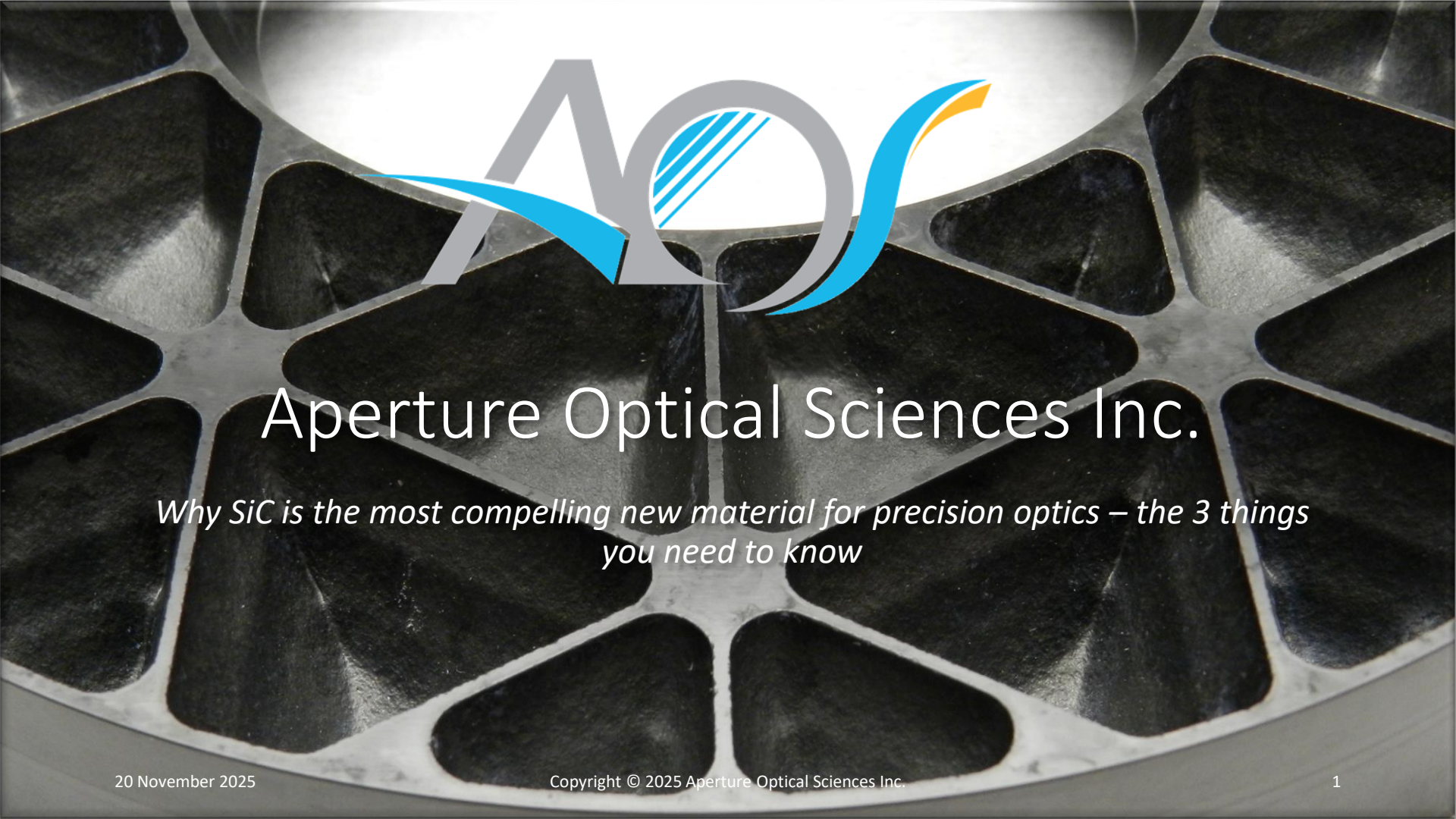

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Why SiC is the most compelling new material for precision optics – the 3 things you need to know

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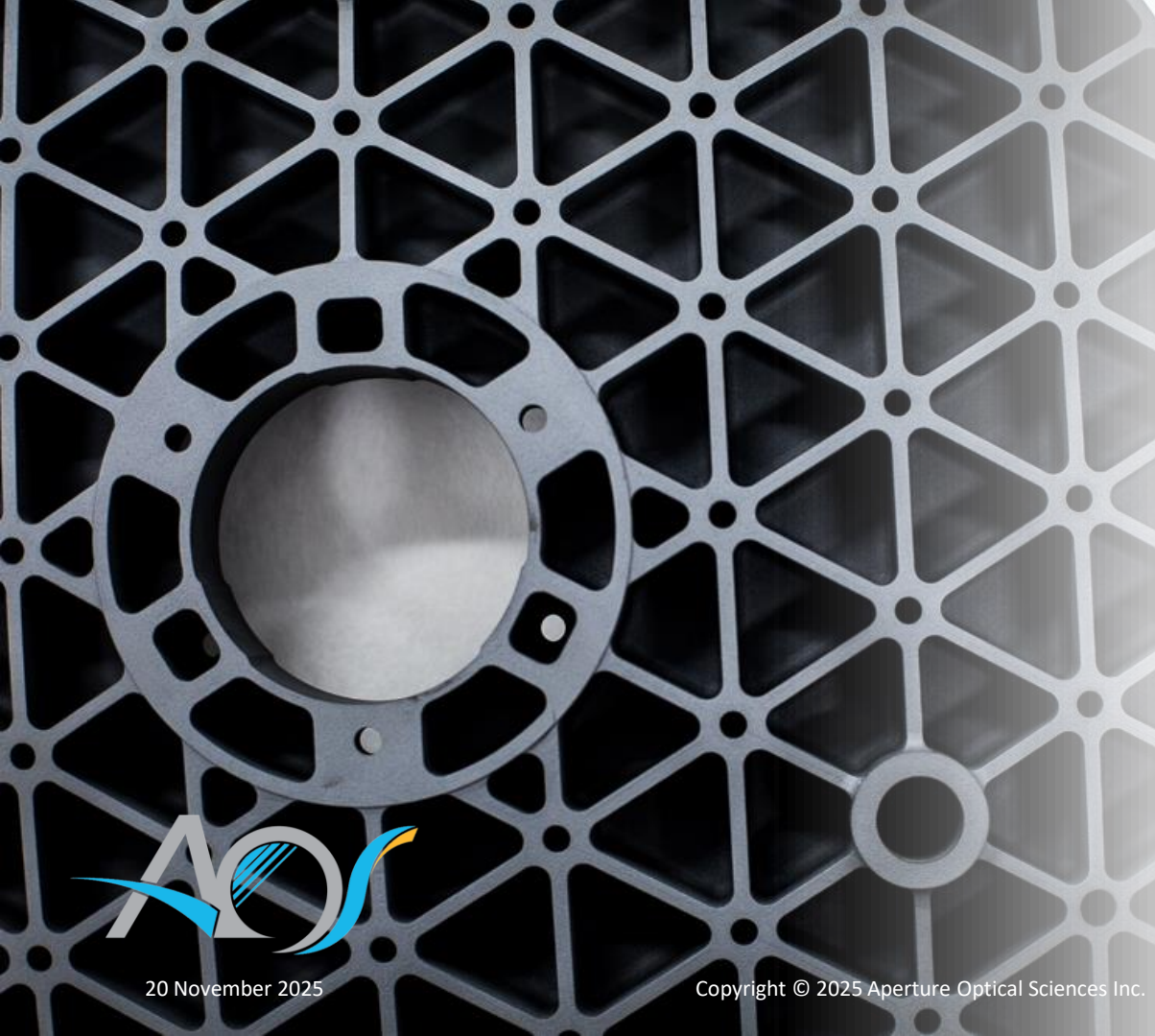

Key Benefits of SiC Mirrors

- Resistant to dynamic & gravitational deflection
- Fast thermal stabilization
- Optically finished to-state-of-the art surface specs
- Lightweight
- Can be directly machined with integrated mechanical datums
- High reflectivity
- Advantages over glass, glass-ceramics, beryllium and silicon
- Material cost is higher than glass, but often results in lower total system cost

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Q: Why Choose Silicon Carbide?

A: High Bending Strength is one answer…

- Common commercial application: Scan Mirrors
- Because of the high Modulus of Elasticity, SiC Scan Mirrors bend less under dynamic loading

COMPARATIVE MATERIAL PROPERTIES

Process			Fused quartz	Zerodur	Silicon	Engineered Be	SiO converted, CVD coated SuperSiC	Carbon fibre reinforced SiC	Methyl-Trichloro-Silane reactor deposition	Large oven sintered SiC	Sintered, CVD coated SiC	optoSiC+
Density	DIN EN 623-2	g/cm3	2,19	2,53	2,33	1,85	3,07	2,97	3,21	3,21	3,21	3,16
Young's Modulus	DIN EN 843-2	E [GPa]	73	92	130	303	330	347	457	420	410	420
Flexural Strength, 4-pt bending	DIN EN 843-1	MPa	48	50	69	207	233	254	402	450	480	510
Poisson Ratio		v	0,10	0,10	0,24	0,25	0,17	0,18	0,17	0,16	0,21	0,17

The whole family of SiC shows significant improvement over traditional materials

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Specific Stiffness, (E/ρ) is another reason to choose SiC

- When the modulus of Elasticity is divided by Density (ρ), we can define a new property called **specific stiffness**.
- For lightweight mirrors we want low density – yet high stiffness. Therefore, the higher E/ρ, the more efficient the material is for lightweight mirror applications.

Property	Symbol	Units	Preferred Value	SCSi	Fused Silica	Zerodur / Clearceram	SiC
Density	ρ	kg/m^3	Small	2330	2190	2530	3210.00
Young's Modulus	E	Gpa	Large	130	73	90	457.00
Specific Stiffness	E/ρ	$Mpa\text{-}m^3/kg$	Large	56	33	36	142.00

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Q: Why Choose Silicon Carbide?
A: SiC has very High Thermal Conductivity

- High Thermal conductivity means that the material adjusts quickly to rapidly changing thermal conditions – this allows for high stability.

Property	Symbol	Units	Preferred Value	SCSi	Fused Silica	Zerodur / Clearceram	SiC
Thermal Conductivity	k	W/m-K	Large	148	1.4	1.6	200.00
Specific Heat	C_p	j/kg-K	Large	640	750	810	670.00
Thermal Diffusivity	$D=k/\rho C_p$	$10^{-6}/m^2/s$	Large	99.25	0.85	0.78	99.50

Thermal conductivity is two orders of magnitude better than glass!

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Q: Why Choose Silicon Carbide?

A: SiC can enable very high thermo-optical stability

- When the Thermal Conductivity (k) is divided by the expansion coefficient (α), we can define a new property called Thermal Stability.
- For mirrors operating in variable environments we want changes to the mirror to be small, and we want changes to stabilize fast. Therefore, the higher k/α, the more stabile the mirror will be in environments with rapid thermal changes.

Property	Symbol	Units	Preferred Value	SCSi	Fused Silica	Zerodur / Clearceram	SiC
Thermal Expansion	α	10^{-6}/K	Small	2.5	0.5	-0.09	2.60
Thermal Conductivity	k	W/m-K	Large	148	1.4	1.6	200.00
Specific Heat	C_p	j/kg-K	Large	640	750	810	670.00
Thermal Diffusivity	$D=k/\rho C_p$	$10^{-6}/m^2/s$	Large	99.25	0.85	0.78	99.50
Steady State Distortion	α/k	$\mu m/W$	Small	0.02	0.36	-0.06	0.01
Transient Distortion	α/D	s/m^2-K	Small	0.03	0.59	-0.12	0.03
Thermal Stability	κ/α	W/μm	large	59	3	-18	77

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Silicon Carbide is sometimes a better choice than Zerodur

Property	Symbol	Units	Preferred Value	Fused Silica	Zerodur / Clearceram	SiC (best values available)
Density	ρ	kg/m^3	Small	2190	2530	2930.00
Young's Modulus	E	Gpa	Large	73	90	457.00
Specific Stiffness	E/ρ	$Mpa\text{-}m^3/kg$	Large	33	36	142.00
Shear Modulus		Gpa	Large			
Flexural Strength		Mpa	Large	48	50	402.00
Fracture Toughness	K_{Ic}	$Mpa\text{-}m^{0.5}$		0.8	0.9	4.00
Specific Strength	σ_t/ρ	$Mpa\text{-}m^3/kg$	Large			
Thermal Expansion	α	$10^{-6}/K$	Small	0.5	-0.09	2.60
Thermal Conductivity	k	W/m-K	Large	1.4	1.6	200.00
Specific Heat	C_p	j/kg-K	Large	750	810	670.00
Thermal Diffusivity	$D=k/\rho C_p$	$10^{-6}/m^2/s$	Large	0.85	0.78	99.50
Steady State Distortion	α/k	$\mu m/W$	Small	0.36	-0.06	0.01
Transient Distortion	α/D	$s/m^2\text{-}K$	Small	0.59	-0.12	0.03
Thermal Stability	κ/α	$W/\mu m$	large	3	-18	77

5x better

125x better

6x better

High specific stiffness, **high thermal conductivity** and **low steady state distortion** make SiC an ideal material operating in rapidly changing thermal environments while maintaining both optical and mechanical performance.

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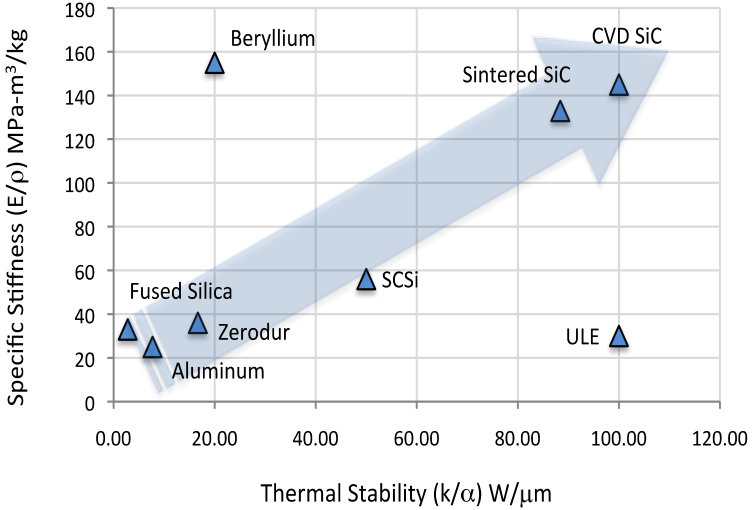
Compare SiC with Other Materials

High specific stiffness, high thermal conductivity and low thermal expansion make SiC an ideal material for maintaining both optical and mechanical performance in rapidly changing thermal environments.

SiC Optical Mirrors resist dynamic & gravitational deflection and enable athermal opto-mechanical designs for maintaining performance in thermally variable environments.



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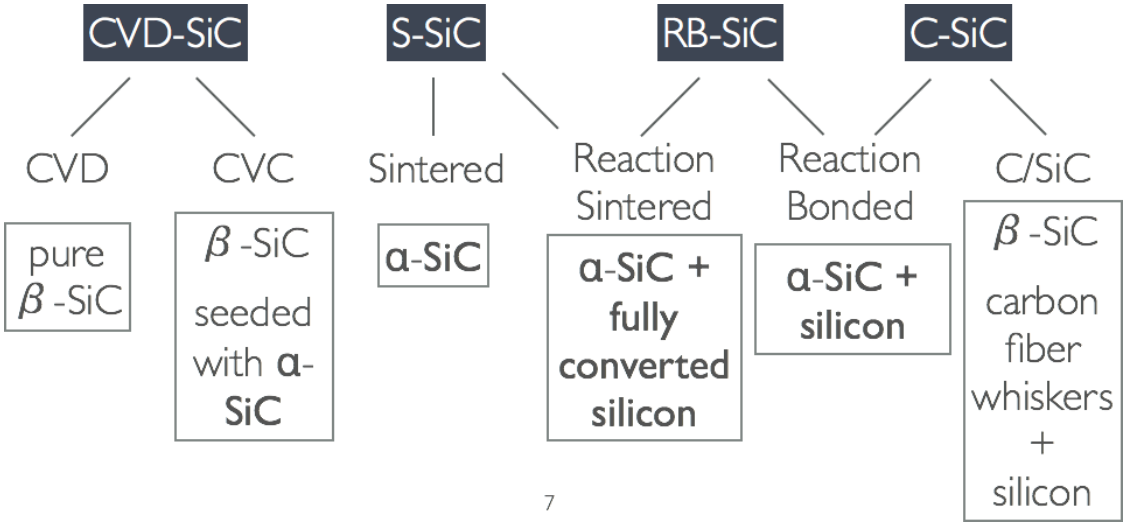
Which SiC material form is best?

- AOS works with multiple SiC material producers – each has special advantages.



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Properties of SiC vary by Mfg. Method

*Room Temperature**	Density	Young's Modulus	Flexural Strength	Tensile Strength	Thermal Expansion	Thermal Conductivity	Specific Heat	Thermal Diffusivity	Poisson's Ratio
Units:	kg/m^3	Gpa	Mpa	Mpa	$10^{-6}/K$	W/m-K	J/kg-K	$10^{-6}/m^2/s$	
Preferred Value:	Small	Large	Large	Large	Small	Large	Large	Large	
Materials									
CVD SiC	3210	465	450	470	2.2	250	670	116.24	0.21
Reaction Sintered	3030	360	850		2.5	130	680		
C/SiC	2655	249	320	150	2.5	121	800	56.97	0.17
Sintered SiC	3150	410	480		2.1	175	665	83.54	0.21
Reaction Bonded	2950	364	550	300	2.44	172	670	87.02	0.18
Converted RB SiC	2530	216.2	155	104	2.28	149	636	92.6	0.17
Corning Fused Silica	2190	73	90.00		0.5	1.4	750	0.85	0.2
Single Crystal Silicon	2330	130	65.00	120	2.5	148	640	99.25	0.24
Corning ULE	2210	67			0.015	1.3	770	0.76	0.17
6061 Aluminum	2700	68	270.00	276	23.6	175	900	72.02	0.33
Zerodur	2530	92.00	490		0.05	1.60	821	0.78	0.24
Beryllium	1850	287.00	300	237.00	11.5	216.00	1925	60.81	0.25

Trade-offs in material properties allow designers to select the optimum type of SiC for the application

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Why isn’t SiC more commonly used?

- Up until now, the answer to that question has often been **cost**.
- Material and finishing cost can be 4x more than traditional glass materials
- Only special programs having demonstrated performance value could afford SiC

- ***This is no longer true!*** AOS finishes SiC the same way we finish glass. The process time is still a little bit more, however in some cases raw material cost is the **same or less** then Zerodur or ULE.

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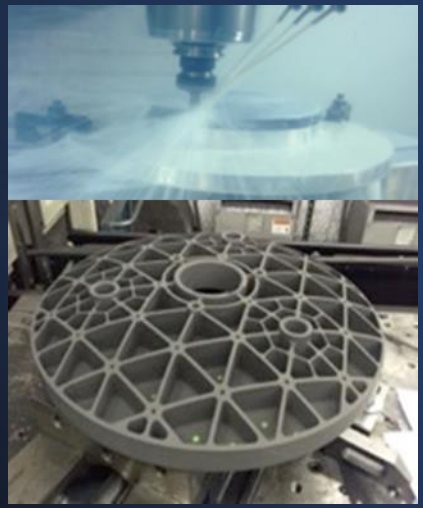
Some reasons why SiC is now more cost effective

- **Athermal mechanical designs makes systems simpler, cheaper to integrate and more effective.**
  - *Heat transfer and thermal deformation errors all become smaller and less expensive to solve when the structural and optical materials are common.*
- **Stiffer mirrors mean opto-mechanical fastening strategies can be simplified and made less expensively with easier assembly.**
  - *Errors due to fastening load, response to adhesives, impact of inserts, and deformation after coating are all reduced with stiffer mirrors made from SiC*
- **SiC is made as a near net shape material, expensive lightweighting operations are not necessary.**
  - *Expensive and risky machining and fusing operations are unnecessary when the substrate is formed to near net shape. This advantage can often make SiC the most cost-effective solution!*



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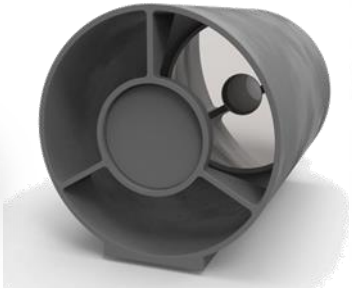
AOS offers Special SiC Products including

- All SiC integrated telescope assemblies
- Gravity insensitive mirror assemblies
- Lightweight mirrors and assemblies
- SiC mandrels for precision replication applications

Photo credit: Mersen OptoSiC



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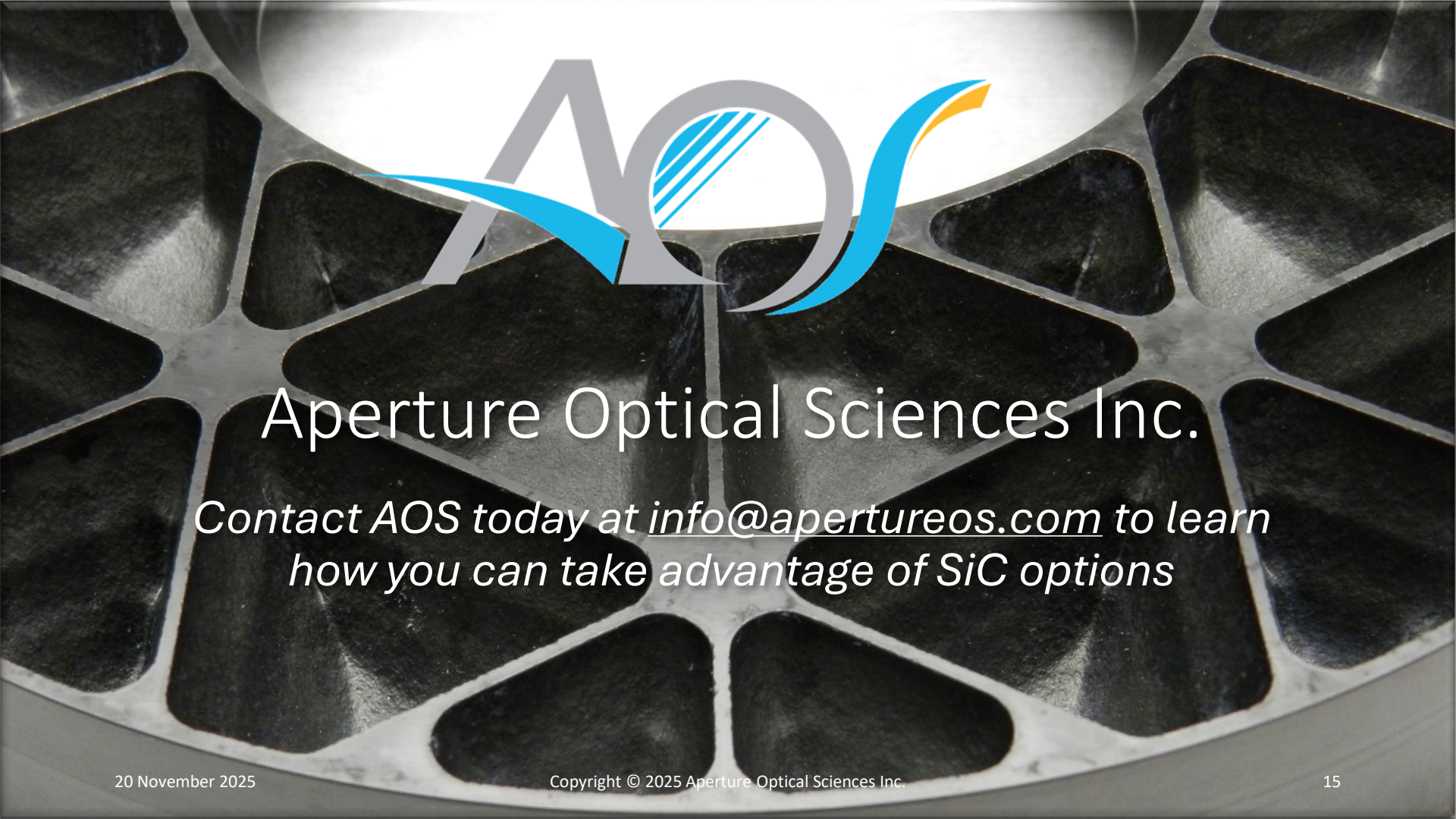
The 3 things you need to know

1) SiC has the most advantageous thermo-mechanical properties of any material that can be optically finished

2) SiC mirrors can be finished to the same or better optical performance than traditional glassy materials

3) SiC optics and systems are more cost effective today than ever



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Contact AOS today at info@apertureos.com to learn how you can take advantage of SiC options

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