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FINAL REPORT

NOAO PRODUCTION AND FEASIBILITY STUDY

Production Report

SSG Precision Optronics

1 October 2004

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Executive Summary

SSG Precision Optronics, Inc. has completed a feasibility study for production of meter class Silicon Carbide mirror substrates for the Thirty Meter Telescope. The study investigated: (1) the design and performance predictions of lightweight SiC segments under expected ground-based operational conditions, and (2) the feasibility of scaling SSGs slip forming process and manufacturing process flow to large numbers of meter class segments.

The results of the study indicate that a SiC solution provides superior stiffness, enabling a simplified mounting scheme in comparison to Zerodur meniscus mirrors, reduced weight, comparable thermal performance and rapid, cost effective production inherent in the near-net-shape forming techniques.

Design and performance predictions considered gravity sag, weight density, mounting configuration, segment curvature, temperature, wind and seismic conditions. A surface error budget that included material properties and fabrication tolerances was used to predict performance to the first order. Our baseline design (see figure 1) uses a 6-point bipod mounting scheme. In comparison to multi-point mount designs required for glass meniscus mirrors (18-point or greater whiffle tree configuration typical), the six-point mount significantly reduces the complexity and cost associated with supporting the substrate adequately to meet gravity sag requirements. By increasing the depth of the lightweighted substrate, it is possible to utilize a 3-point design for the SiC substrate while still meeting expected surface requirements. This option increases the weight of the substrate, but the weight density is still significantly less than the Zerodur counterpart. The silicon carbide optic exhibits 1/10 the error of a solid Zerodur meniscus at one-half the weight for a given mount scheme, which allows for less complex mount design for a meter class optic.

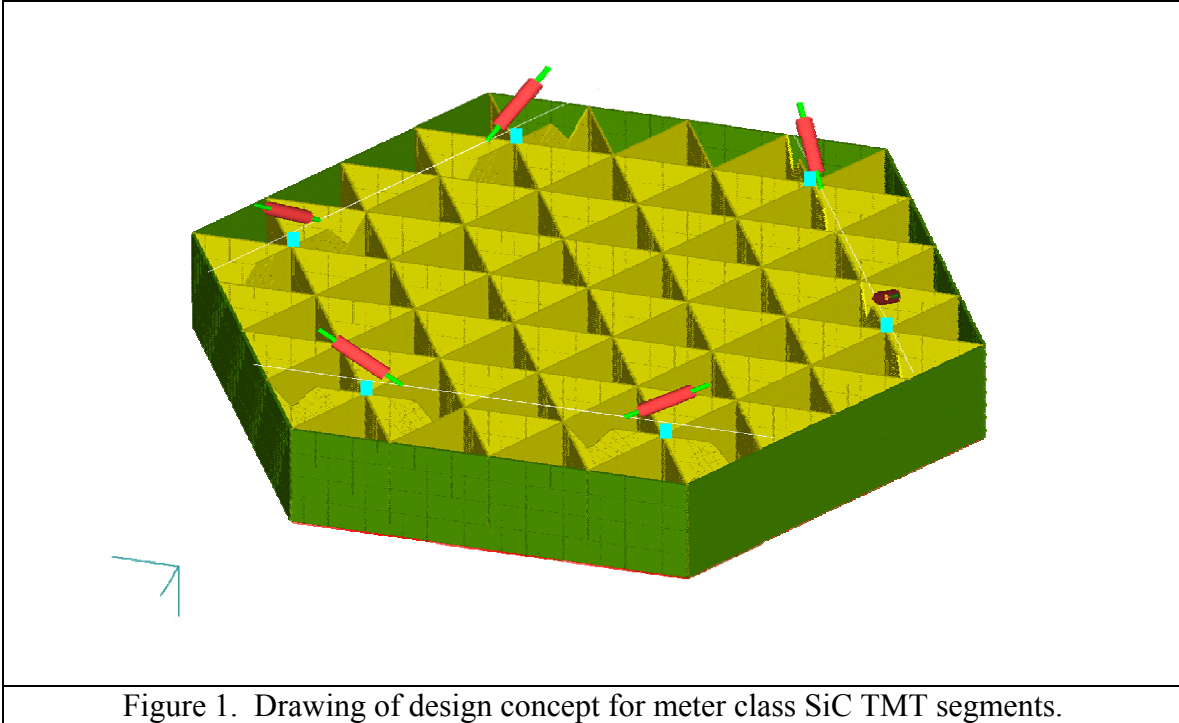


Figure 1. Drawing of design concept for meter class SiC TMT segments.

The material properties of SSG's SiC are shown in figure 2. SiC has a high stiffness to weight ratio (4x that of Zerodur) which makes it possible to manufacture lightweight, stiff mirrors. The thermal stability parameter of thermal conductivity to CTE ratio is typically used to compare optical materials. In addition, it is important to understand how these properties vary from part to part and within a part. If we consider CTE variation or homogeneity as well as coating and temperature gradient induced errors, the thermal performance of SiC compares very well with Zerodur even though Zerodur has a lower value of CTE and homogeneity compared with SiC. Control of CTE random homogeneity on the order of 40 ppb/°C is more than sufficient in the absence of preferential linear variations.

Parameter	Symbol	Units	SSG RB SiC
Density	ρ	g/cm ³ (lb/in ³)	2.9 -0.105
Young's Modulus	E	MPa (ksi)	331 -48
4-Point Bend Strength	σ 4-pt	MPa (ksi)	249 -36.2
4-Point Bend Weibull	m		9.7
Poisson's Ratio	ν		0.14
CTE T=100K T=150K T=200K T=250K T=300K	α	10 ⁻⁶ /K	-0.09 0.58 1.24 1.89 2.52
Thermal Conductivity T=138 K T=208 K T=263 K T=298 K	K	W/m-K	 256 217 182 165
Specific Heat T=138K T=208K T=263K T=295K	cp	J/kg-K	 285 474 615 680
Electrical Resistivity		$\mu\Omega$ -cm	3148

Figure 2. Material properties of SSG's 55A SiC.

SSG utilizes a slip forming, near-net-shape manufacturing process for generating lightweight mirror substrates. Using a reusable negative mold, the near net shaped

substrate is cast, then processed at high temperatures. The fully densified end product requires a minimum level of machining to be brought to final tolerances. The dimensions of lightweighting ribs and facesheet of the design developed in this study are well within the capabilities of our manufacturing process. The combination of low cost raw materials, reusable tooling and minimal machining results in low-cost, rapid manufacture. With facility upgrades in place to handle the volume of parts required for the TMT, a cycle time per part is on the order of 5 to 7 weeks including machining of an aspheric facesheet profile.

SSG has been designing and producing SiC substrates, mirrors and optical telescopes including structures for more than 12 years. Table 1 summarizes SSG's experience with SiC materials and optical instruments.

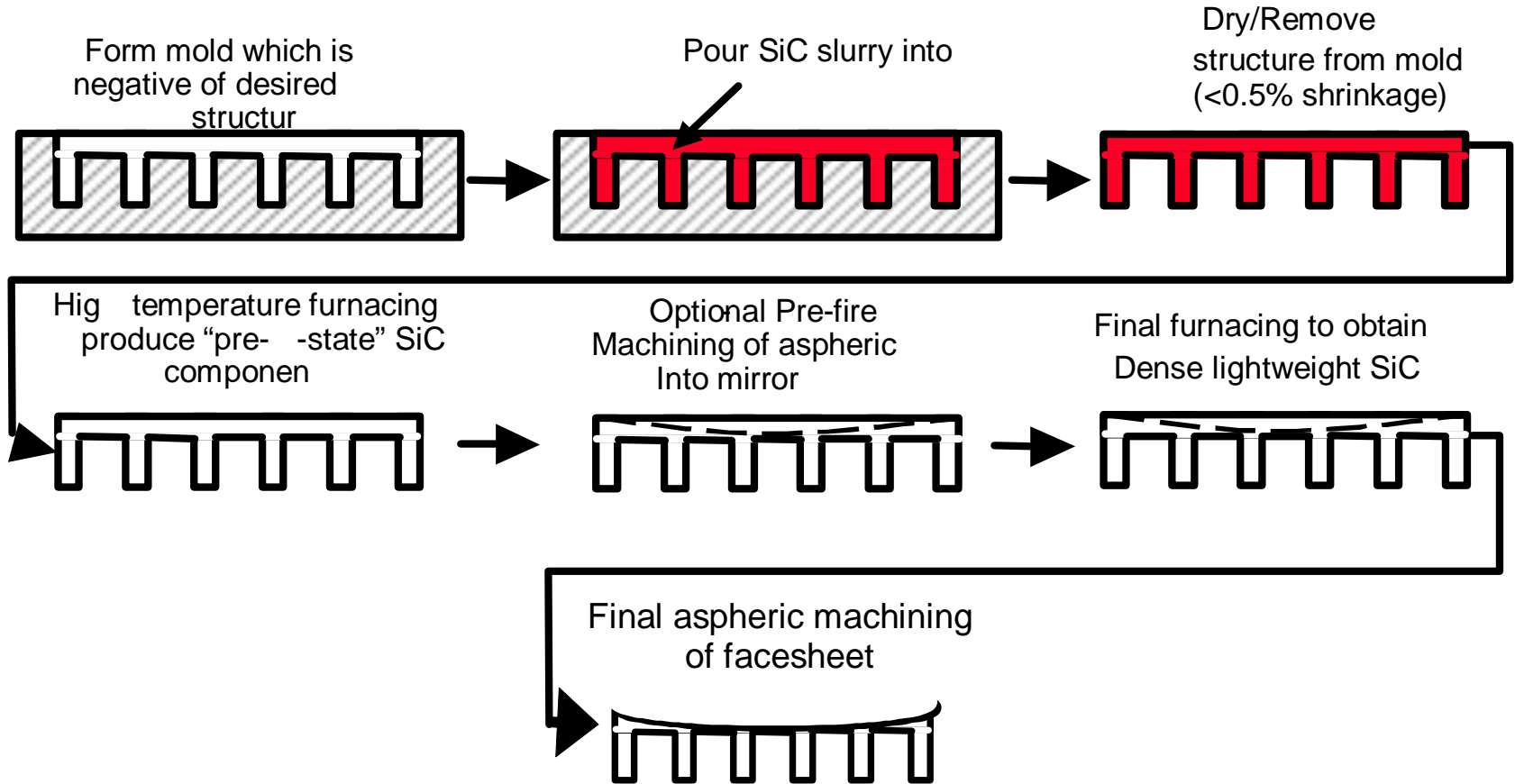
- **\$25 Million, 12 Years in SiC Programs & Development**
 - *R&D, SBIRs, DoD, & NASA contract support*
 - *Over 25 development programs and ground demonstrations completed*
 - *5 space flight programs, plus airborne flight programs*
 - *~10 SiC programs currently in-progress*
- **Full In-House SiC Facilities & Processing**
 - *Reaction bonded mirror & structure production*
 - *Polishing*
 - *Composite structure lay-up and pre-forming*
 - *Machining and grinding*
 - *Strength testing*
- **System Level SiC Engineering & Test Experience**
 - *SiC mirror & system design*
 - *Weibull test data, proof loading data*
 - *System fabrication, assembly, alignment*
 - *Full environmental testing (vibration, thermal vac)*
 - *Full optical testing: wavefront, surface roughness, BRDF*

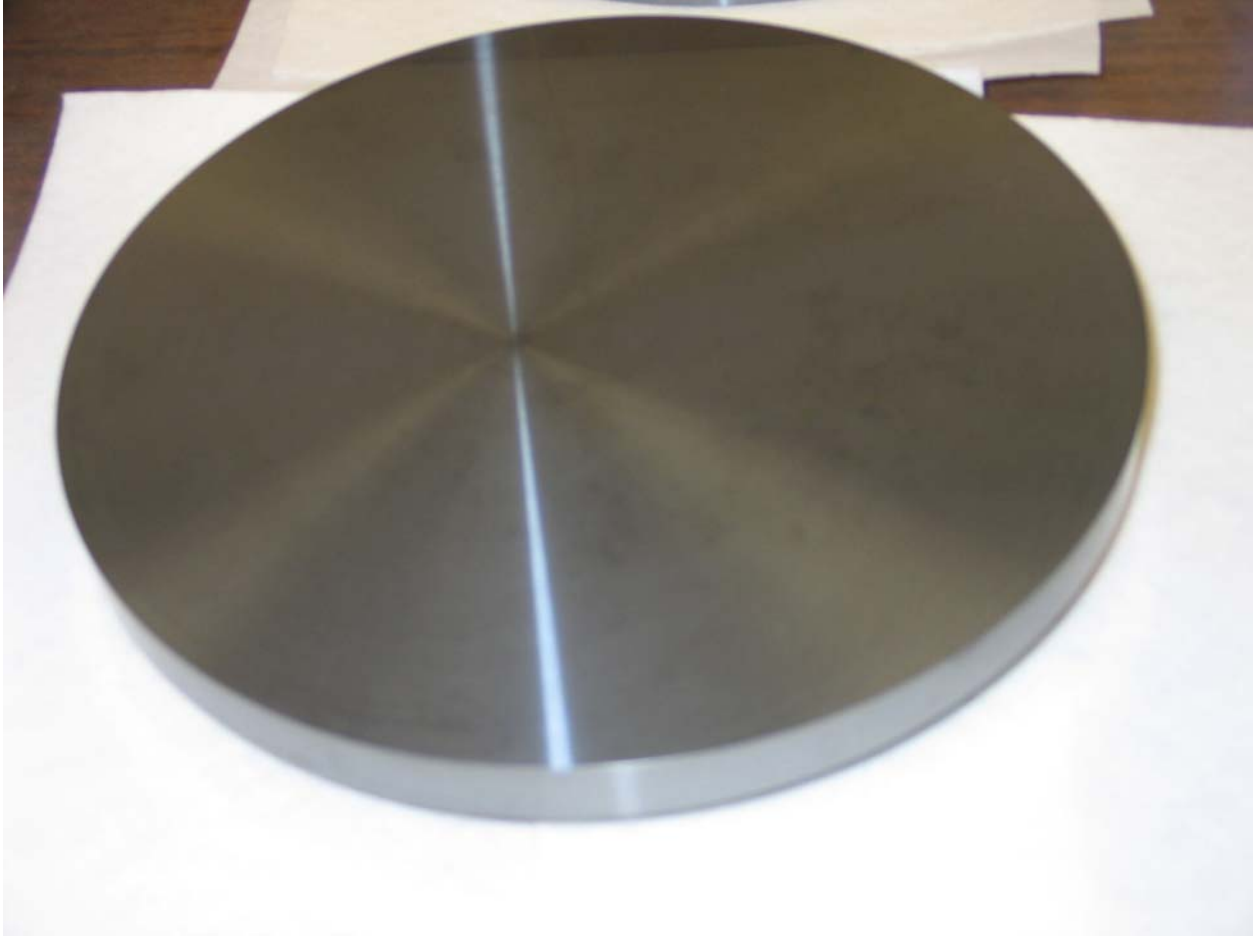
Table 1. Summary of SSG's SiC Experience

In addition to our ability to generate SiC substrates, SSG's Tinsley Laboratories subsidiary has extensive experience with precision optical surfacing of large aperture meter class optics. Tinsley's Computer Controlled Optical Surfacing (CCOS) process has been applied to a large array of optical materials including Zerodur, ULE and SiC and is being utilized for the surfacing of Be optics for JWST. Tinsley implemented a stressed mirror polishing process for the manufacture of 18 ULE segments for the Keck telescope.

SSG (Wilmington, MA)

Outline of SSG's SiC Manufacturing Process





Front surface of a SiC blank manufactured by SSG



Back surface of a SiC blank manufactured by SSG