

Silicon Carbide Optics for UV/EUV Applications

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SSG SiC UV/EUV Optics Activities

- High Quality, Low Scatter, SiC Optics Suitable for Space-based UV and EUV Applications-Phase 2 SBIR
 - NASA Contract #NNG04CA15C
 - COTR: Dr. Dave Content NASA-GSFC
- Superpolished Silicon Coated SiC Optics for Rapid Manufacture of Large Aperture UV and EUV Telescopes-Phase 1 SBIR
 - NASA Contract #NNG04CA64C
 - COTR: Dr. Dave Content/Dr. Peter Blake NASA-GSFC
- Single Crystal Silicon Asphere for Argonne National Labs Synchrotron Source



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High Quality, Low Scatter, SiC Optics Suitable for Space-based UV and EUV Applications

- Phase 1 Objective: Develop Computer Controlled Optical Surfacing techniques for creating CVD SiC coated RB SiC EUV quality optics
 - Two 4.5" diameter RB SiC concave spheres coated with thin layer of sputtered CVD SiC
 - 10 angstrom RMS micro-roughness achieved using CCOS process.
- Phase 2 Objective: Apply CCOS process to CVD SiC coated RB SiC lightweight mirror for coronagraphic mission
 - CCOS optimization underway
 - Goal of micro-roughness < 5 angstroms RMS using CCOS
 - Sample demonstration on CVD SiC flats
 - 3.5 angstroms RMS achieved thus far
 - Mirror design underway for SHARPI secondary
 - Baseline Material: RB SiC with thin CVD SiC coating
 - Construction: Open back, rib supported
 - Areal Density: 15.9 kg/m²
 - Optical Surface Requirements
 - Figure: 3 nm RMS
 - Mid-frequency: 1.7 nm RMS
 - Micro-roughness: 1.0 nm RMS



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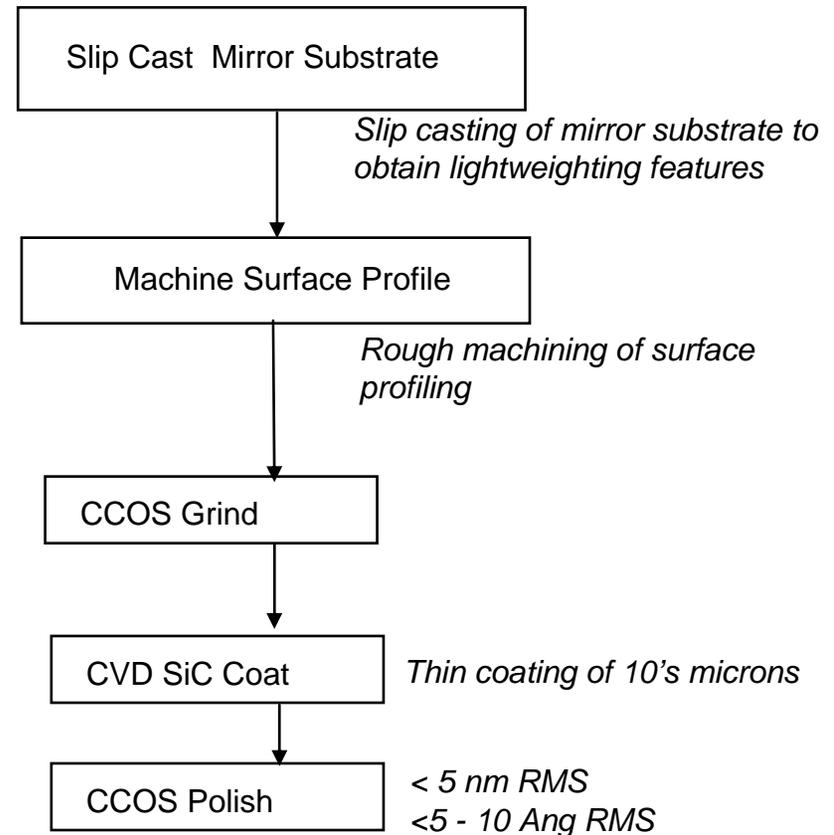
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Manufacturing Process Flow for CVD clad SiC EUV Aspheric Optics

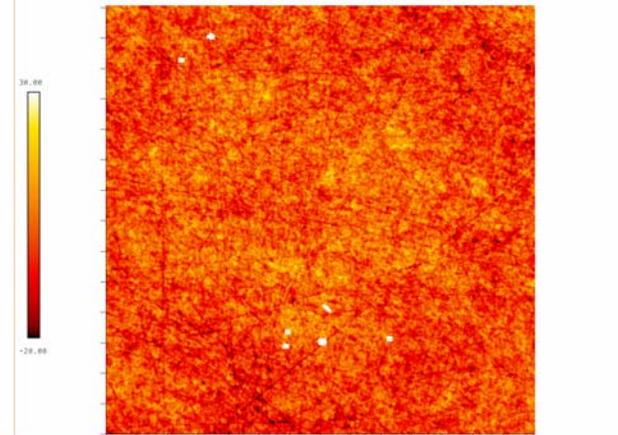
- Novel, manufacturing process for SiC optics for EUV applications
 - CVD clad RB SiC optics have been demonstrated to provide surface finishes suitable for EUV applications
 - CVD SiC materials have been demonstrated to provide excellent EUV reflectivities
 - Tinsley's CCOS process has demonstrated to provide surface figures/finishes which are consistent with stressing EUV optical requirements
 - CCOS process suitable for SiC materials



Phase 2 Process Development Results

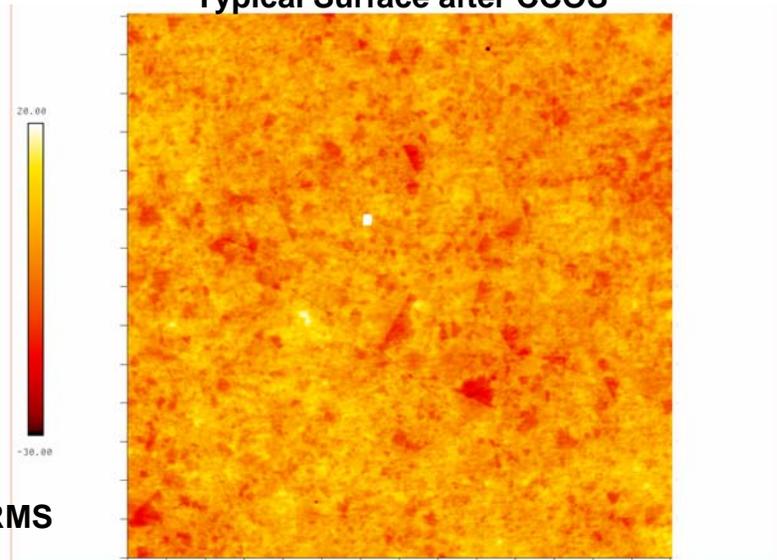
- Series of 6" x 6" CVD SiC flats processed using CCOS sub-aperture tools.
 - RMS measurements taken with Phase Measuring Microscope with 10x objective over 1.41x 1.41 mm² area.
 - Average of 5 locations on mirror, with 4 interferograms averaged at each location.
 - The aberrations from the microscope cavity were removed.
- 3.38 angstroms RMS achieved
- CCOS shown effective at removing pits and scratches

Typical Surface after conventional polish



Surface Roughness = 6.1A RMS

Typical Surface after CCOS



Surface Roughness = 4.5A RMS



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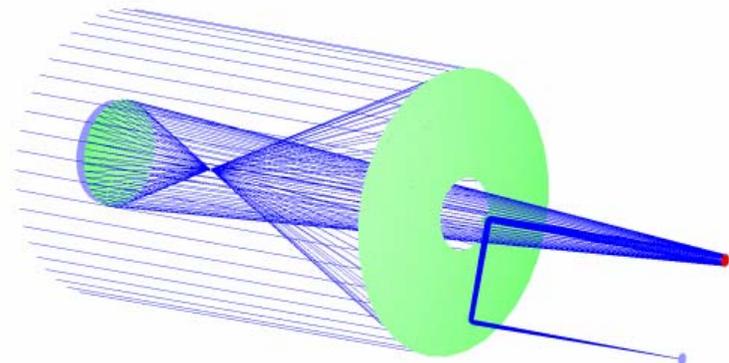
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Phase 2 Demonstration Mirror SHARPI Secondary Mirror

Material	RB SiC, thin sputtered CVD SiC coating
Construction	Rib supported lightweight design
Clear aperture	200 mm
Edge thickness	~ 20 mm
Faceplate thickness	~2.0 mm –3.0 mm
Vertex Radius	437.1959 mm
Conic Constant	-0.5445 (ellipsoid)
Global surface figure	3 nm RMS
Micro-roughness (spatial periods 1 μ m – 1mm)	1.0 nm RMS
Mid-frequency roughness (spatial periods 1 – 10 mm)	1.7 nm RMS
Areal density	10 – 20 kg m ⁻²



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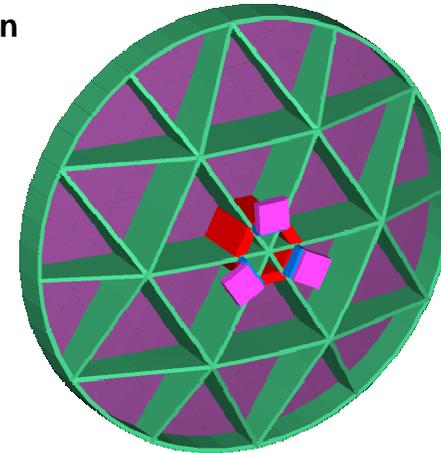


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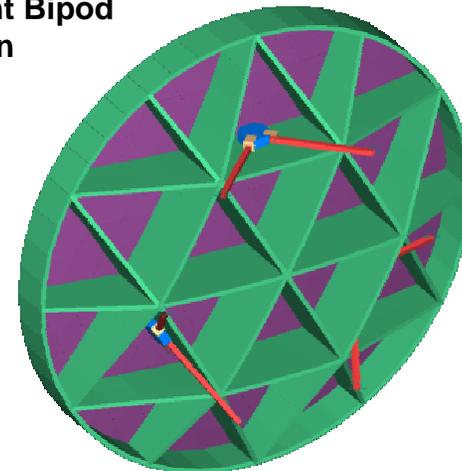
SiC Secondary Mirror Design Study

- Two Open Back Designs being investigated for UV/EUV M2 Design
 - Material: mirror: SiC, mount: Invar
 - Mirror Height = 30.48mm (center); 20.32mm (edge)
 - Face Sheet Thickness = 2.03mm
 - Rib Thickness = 2.03mm
 - Diameter of Inscribed Circle = 33.73mm
 - Bipods: 44.45mm x 2.286mm x 2.286mm; 45 deg angle
 - Areal Density: 15.9 kg/m² (segment only)

Central Post Design



3 Point Bipod Design



UV/EUV M2 Trade Study

UV/EUV M2 Surface Errors for Two Different Mirror Mount Types		
Load Case	Fit Tilt, nm rms	
	Central Post	Bipods
1G-X, Lateral	1.3	0.7
1G-Y, Lateral	1.3	0.7
1G-Z, Vertical	4.2	1.2
One Bipod Leg 0.001" Up	0.06	2.6
One Bipod Leg 0.001" Outward	144.8	1.5

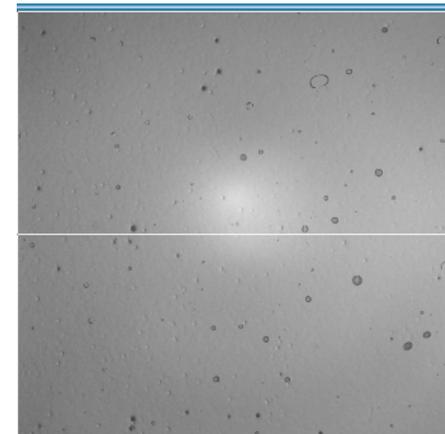
Significant Surface Error from movement of Central Post.

Bipod Mounting appears to be the best design solution



Superpolishing Silicon Coated SiC Optics for Rapid manufacture of Large Aperture UV and EUV Telescopes

- Objective: Develop CCOS superpolishing techniques for Si coated SiC UV and EUV Optics with a micro-roughness goal of <5 Angstroms RMS.
- Status
 - Series of SiC samples were generated and coated with a thin layer of amorphous Si (nominal thickness 50 microns).
 - 10 cm On-axis parabola
 - Various 2" and 3" flat samples
 - 5.9" diameter flat samples (pre-coat surface grind/polish and coated, but not polished)
 - Best local results between 5 and 7 angstroms RMS
 - Results were limited by defects in the Si layer
 - Improved uniformity in coating and substrate prep will be explored to address defects
 - Phase 2 submitted 7/19/04



Typical Defects Observed in Si layer



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Single Crystal Silicon Asphere for Argonne National Labs Synchrotron Source



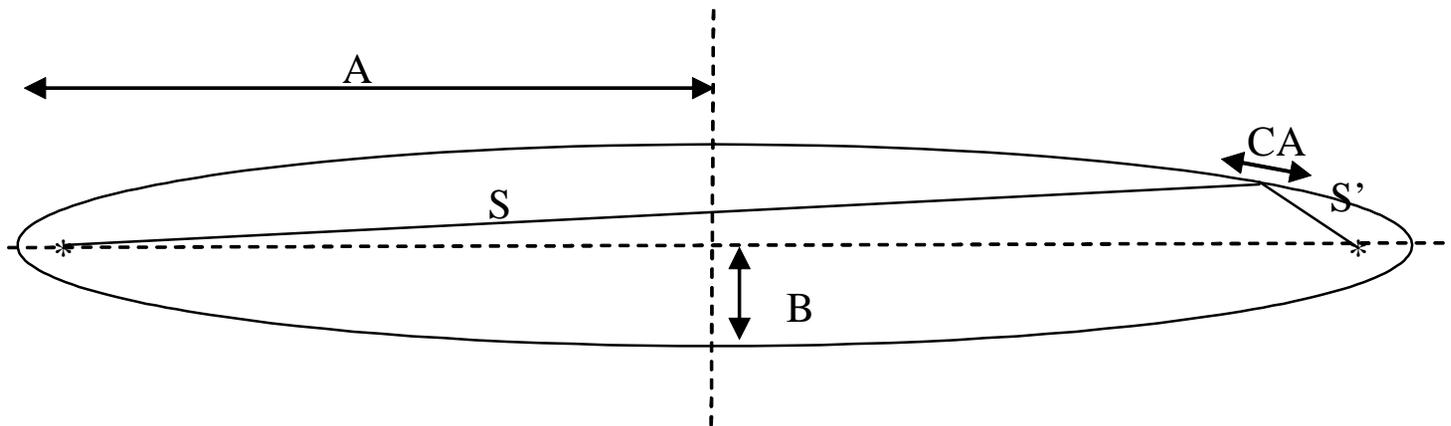
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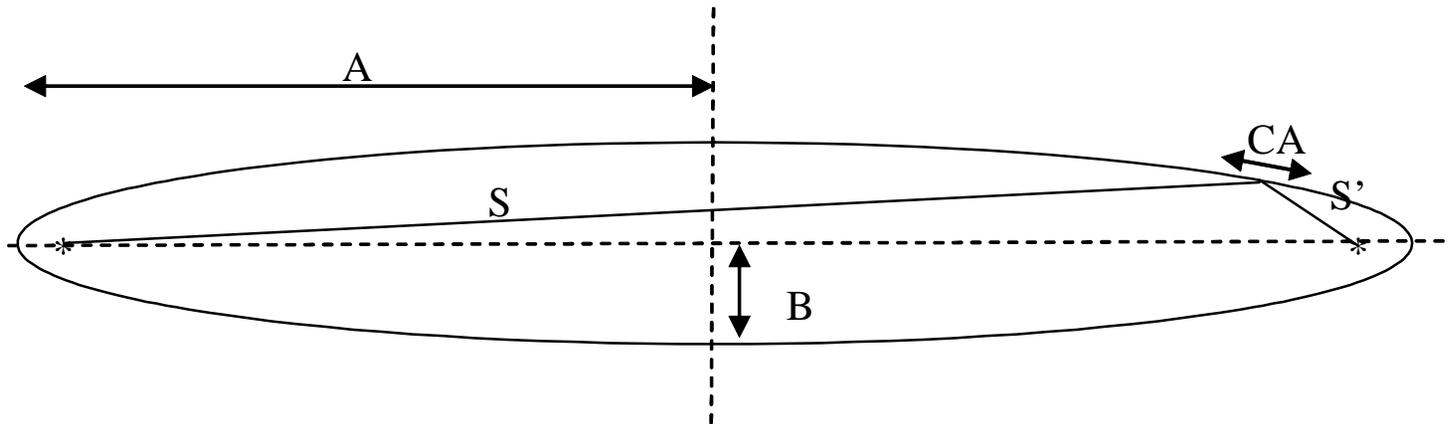
Argonne Test Method Description

- Test component as high quality spherical map
 - Use rotational shearing and high quality reference optic at same nominal radius as part to obtain very high accuracy in the test
- Remove S/W null map from spherical data
- Clip out sub-apertures (line scan of data at four heights)
- Optimize asphere to best value of “B” (A isn’t floated)
 - B changes by 0-15 um from nominal 5.692 mm



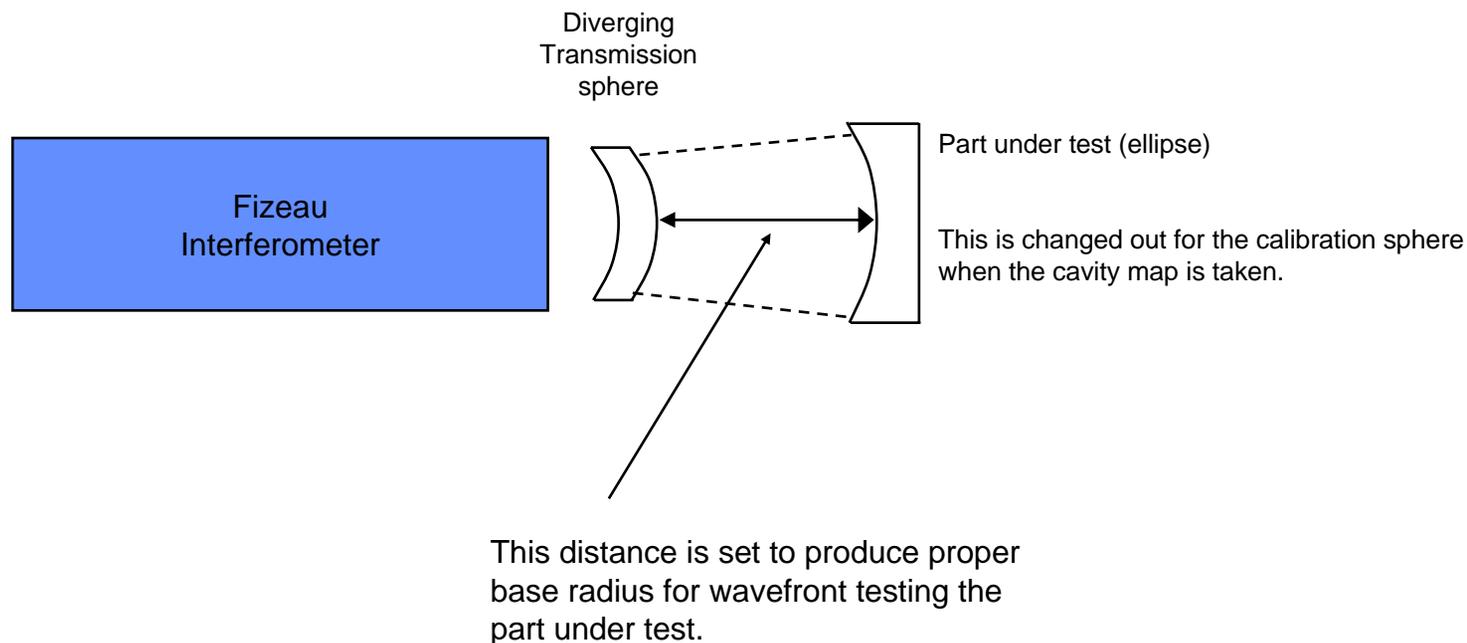
Ellipse Constraints

- Ellipse is polished as a sphere in the cross axis direction and as an ellipse in the long axis direction
- Aspect ratio of the ellipse must be long enough that aspheric departure is kept relatively low (few μm)



Test Setup

- A reference sphere is used to map the transmission sphere cavity
- The ellipse is spaced relative to the transmission sphere to produce the proper base radius for the asphere



Data Results: Clear Aperture 1

- Tilt and focus are removed from this map
- Aperture is 16x38mm

```
file : 315cal.gnt
units: x = mm
      y = mm
      z = nm
xspac: 0.2921
yspac: 0.2921
ngx   : 131
ngy   : 55
gxcen: 0
gycen: 37.97

z ptv: 4.119
z rms: 0.5916

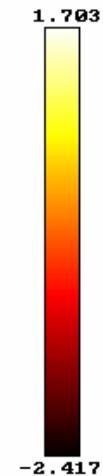
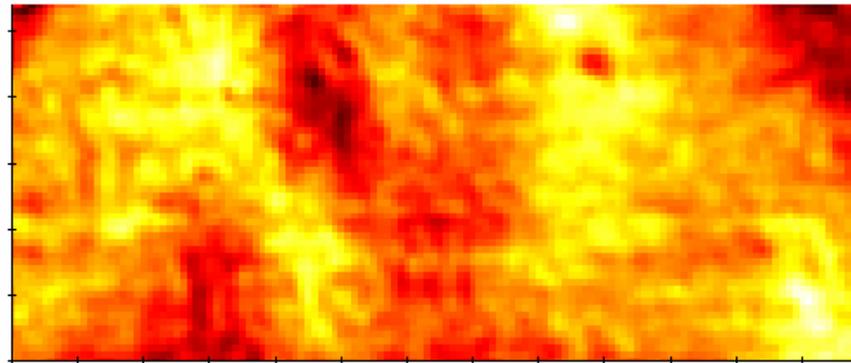
x-apr: 37.97
y-apr: 15.77

z min:-2.417
@ (131, 43)
z max: 1.703
@ (122, 10)
z avg:-2.311e-005

ndata: 7205

ix   : 66
iy   : 28
xpos : 0.0000
ypos : 37.9730
r     : 37.9730
theta: 90.0000
zval  : -0.429

color: hot
```



Surface accuracy: 0.59 nm RMS



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Data Results: Clear Aperture 2

- Tilt and focus are removed from this map
- Aperture is 16x38mm

```
file : 315ca2.gnt  
units: x = mm  
       y = mm  
       z = nm  
xspac: 0.2921  
yspac: 0.2921  
ngx   : 131  
ngy   : 55  
gxcen : 0  
gycen : 14.02
```

```
z ptv: 5.532  
z rms: 0.7058
```

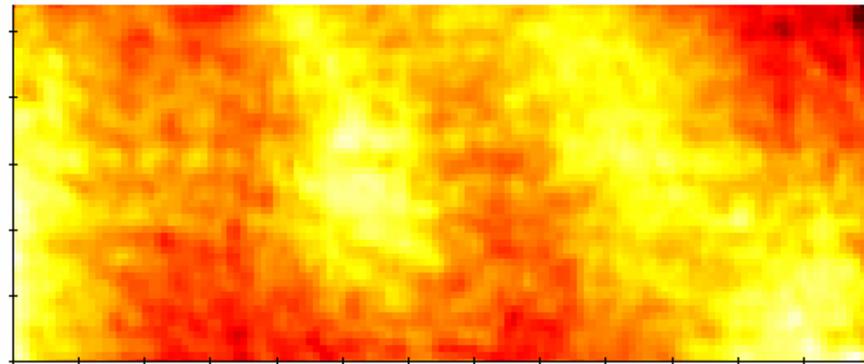
```
x-apr: 37.97  
y-apr: 15.77
```

```
z min: -3.537  
      @ (131, 55)  
z max: 1.995  
      @ (1, 17)  
z avg: 2.382e-005
```

```
ndata: 7205
```

```
ix   : 66  
iy   : 28  
xpos : 0.0000  
ypos : 14.0208  
r     : 14.0208  
theta: 90.0000  
zval : 0.0649
```

```
color: hot
```



Surface accuracy: 0.7 nm RMS



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Data Results: Typical Surface Roughness Single Crystal Silicon

```
file : 310dr.gnt
units: x = MM
      y = MM
      z = nm
xspac: 0.001381
yspac: 0.001381
ngx   : 1020
ngy   : 1022
gxcen: 0
gycen: 0

z ptv: 5.775
z rms: 0.2879

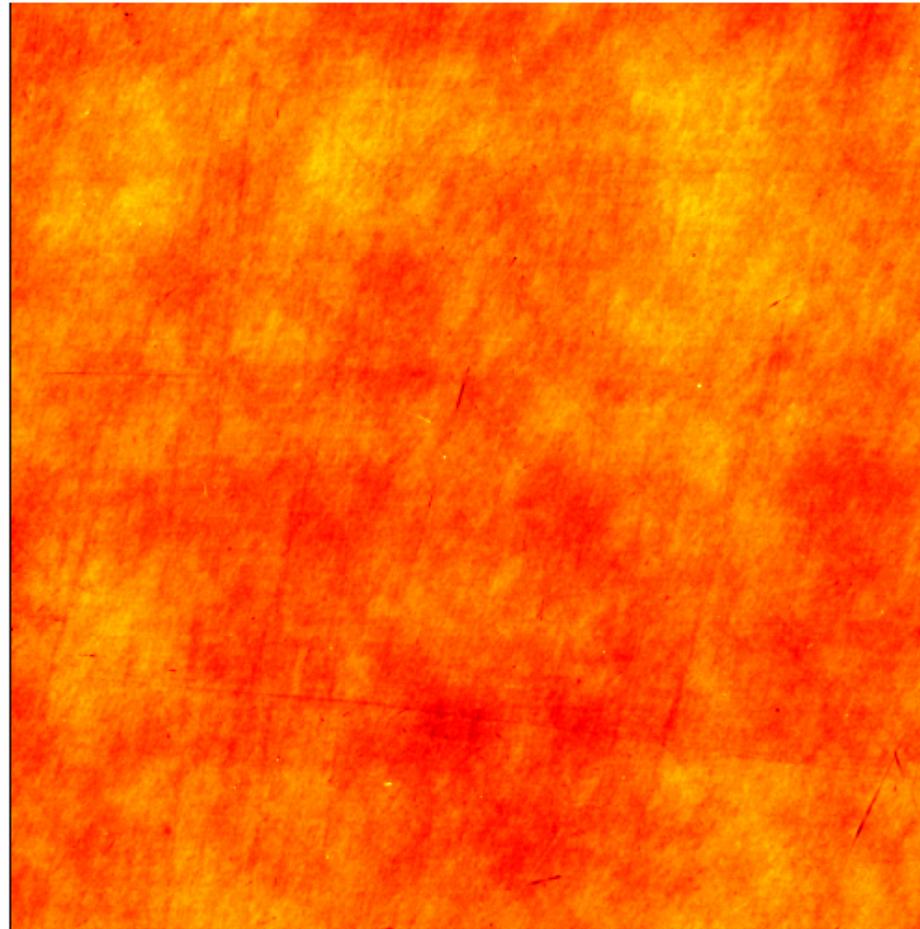
x-apr: 1.41
y-apr: 1.41

z min:-3.016
      @ (3, 334)
z max: 2.759
      @ (761, 601)
z avg: 0.0003548

ndata: 1041416

ix   : 511
iy   : 512
xpos : 0.0007
ypos : 0.0007
r     : 0.0010
theta: 44.9995
zval  : -0.0342

color: hot
```



Micro-roughness: 2.88 angstroms RMS



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Summary

- Combination of SiC bulk material properties, and near net shape forming techniques make SSG's SiC an excellent optical material for lightweight, stiff space-based optical systems
- Application of Tinsley's CCOS process to SiC and single crystal Silicon optics enables EUV level aspheric optics
- CCOS results have been demonstrated in a number of different forms
 - CVD SiC (3.38 angstroms RMS micro-roughness)
 - Use of CVD SiC thin coating on SSG SiC demonstrated on flat with 1.5 nm RMS surface error
 - Si coated SiC (5 to 7 angstroms RMS demonstrated in Phase 1 SBIR)
 - Results limited by coating defects
 - Improved coating uniformity and surface prep avenues to <5 angstroms
 - Single crystal Silicon
 - <0.7 nm RMS surface error
 - 2.88 angstroms RMS micro-roughness
- Successful completion of SBIR efforts will lead to demonstration of lightweight (~16 kg/m²) SiC aspheres for space-based EUV telescopes