
THIRTY METER TELESCOPE

# SPECIFICATION FOR PRIMARY MIRROR SEGMENT BLANKS

TMT.OPT.SPE.07.001.CCR06

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# 1. INTRODUCTION

## 1.1 PURPOSE

This document specifies the requirements for mirror Blanks that will be made into hexagonal mirror Segments for the Thirty Meter Telescope primary mirror.

## 1.2 SCOPE

This document specifies the requirements for the Blanks only. A separate document specifies the requirements for the finished mirror Segments.

## 1.3 DEFINITIONS

### 1.3.1 Average CTE

The Average CTE of a Blank is defined in Section 3.1.4.

### 1.3.2 Back Surface

The Back Surface is the convex surface of the Blank that is on the opposite side from the concave surface.

### 1.3.3 Basic Dimension

A Basic Dimension is a theoretically exact value used to describe the exact size, profile, orientation or location of a feature. Geometric Dimensioning and Tolerancing shall be interpreted per ANSI Y-14.5M-1994.

### 1.3.4 Blank

A Blank is the piece of glass or glass-ceramic from which a single hexagonal mirror Segment will be fabricated.

### 1.3.5 Blank Supplier

The Blank Supplier is the organization that will supply the Blanks.

### 1.3.6 Chip

The term Chip is defined in Section 3.6.

### 1.3.7 Critical Zone

The term Critical Zone is defined in Section 3.5.

### 1.3.8 CTE Axial Gradient

The term CTE Axial Gradient is defined in Section 3.1.5.

### 1.3.9 Generating

Generating is machining the surfaces of the Blank by fixed-abrasive grinding.

### 1.3.10 Inclusions

The term Inclusions is defined in Section 3.5.

### 1.3.11 Ion Figuring

Shaping of the Optical Surface of the Segment by bombardment from an ion source.

### 1.3.12 Mean CTE of the Primary Mirror

The Mean CTE of the Primary Mirror is defined in Section 3.1.4.

### 1.3.13 Mean CTE Axial Gradient of the Primary Mirror

The Mean CTE Axial Gradient of the Primary Mirror is defined in Section 3.1.5**.**

### 1.3.14 Observatory

The term Observatory refers to the mountaintop facility that will incorporate the Thirty Meter Telescope.

### 1.3.15 Optical Surface

The Optical Surface of the Segment is the concave surface.

### 1.3.16 Segment

A Segment is one of the hexagonal mirrors that in combination form the surface of the TMT primary mirror.

### 1.3.17 Strain Induced Birefringence

The difference (retardation) between the path length of light propagating in the direction of maximum strain and that propagating in the transverse direction, per unit length. A result of the different indices of refraction due to inherent or imposed strains in the material.

### 1.3.18 Subsurface Damage

Cracks in the glass below the surface caused by machining or grinding, whether visible or not.

## 1.4 CHANGE RECORD

| Revision | Date | Section | Modifications |
|---|---|---|---|
| REL01 | April 15, 2005 | | Original release |
| REL02 | July 26, 2006 | 1.3 | Changed definition of “Back Surface”. |
| | | 2.2 | Deleted Section 2.2<br>Modified first paragraph of 3.1.1 |
| | | 3 | Modified section 3.1.4<br>Modified section 3.1.5<br>Modified section 3.2<br>Modified section 3.3<br>Moved definition of “Critical Zone”<br>Modified section 3.5<br>Modified section 3.6 |
| | | 4 | Modified section 4 |
| | | 5 | Deleted additional Blank geometry options |
| REL03 | Jan 25, 2007 | All | Major changes were made to the specification to account for the larger segments used in the new telescope baseline design. |
| DRF04 | Mar 25, 2008 | All | Reformatted document to conform to TMT requirement template. (Section numbering has not changed from REL03) |
| | | All | Replaced all temperatures in °K with temperatures in °C |
| | | 1.3.3 | Specified interpretation of basic dimensions per ANSI Y-14.5M-1994 |
| | | 3,4 | Added requirement IDs to specific requirements |
| | | 3.1.1 | [SPE-M1.SEG.BLK-1110]: coating removal cycles was “any number” is “30 (TBC)” |
| | | 3.1.1 | [SPE-M1.SEG.BLK-1110]: removed uncertain stripping chemical concentration information |
| | | 3.1.2 | [SPE-M1.SEG.BLK-1205]: elastic temperature range was 0 to 100°C, is -40 to 105°C |

| | | | |
|---|---|---|---|
| | | 3.1.2 | [SPE-M1.SEG.BLK-1210]: Dimensional stability demonstration range was 0-10MPa, is -10 to 10MPa. Temp range was 0 to 100°C, is -40 to 105°C . Temp/stress cycles through which dimensional stability must be held was 3, is 10. Clarified that stability requirement is wavefront. |
| | | 3.1.4 | Added [SPE-M1.SEG.BLK-1460] |
| | | 3.2 | Specified positions and tolerances for residual stress measurement locations, increased number of measurements required from 7 to 13 |
| | | 3.5, 3.6 | Critical Zone was Dia. 144cm, is Dia. 145cm |
| | | 3.5 | Deleted Requirement for maximum average number of inclusions per $100cm^3$ |
| | | 3.5 | Added [SPE-M1.SEG.BLK-5020], specifying maximum total number of inclusions in the Blank |
| | | 3.5 | Revised [SPE-M1.SEG.BLK-5030]. Maximum number of inclusions per $100cm^3$ inside/outside critical zone was 20/30, is NA/10 |
| | | 3.6 | [SPE-M1.SEG.BLK-6130]: max chip diameter on convex side critical zone was 10mm, is 2mm |
| | | 3.7 | Added section 3.7: Serialization and clocking mark required |
| | | 4 | Added [SPE-M1.SEG.BLK-8000], requiring pre-delivery material compliance demonstration |
| | | 4 | Added [SPE-M1.SEG.BLK-8100], requiring periodic process stability demonstration |
| | | 4 | Specified information to be included in final data package for each Blank |
| | | 5 | Updated Blank drawing |
| CCR05 | Apr 07, 2008 | All | Changes implemented in DRF04 approved |
| CCR06 | Nov 14, 2008 | 1.5 | Added TBD, TBC, TBR to abbreviation list |
| | | 3.2 | Corrected error in [SPE-M1.SEG.BLK-2000] – corrected wording consistently requires 12 birefringence measurements at R672mm |
| | | 3.5 | Updated discussion portion of [SPE-M1.SEG.BLK-5030] to clarify expected method of inspection. |
| | | 5 | Updated segment blank drawing to show birefringence measurement locations |
| | | 5 | Updated segment blank drawing to show location of clocking mark and serial number |

## 1.5 ABBREVIATIONS

**CTE** – Coefficient of Thermal Expansion

**M1** – TMT Primary Mirror

**N/A** – Not applicable

**RMS** – Root mean square

**TBC** – To Be Confirmed

**TBD** – To Be Determined

**TBR** – To Be Reviewed

**TMT** – Thirty Meter Telescope

**FOV** – Field of View

# 2. OVERALL DESCRIPTION

## 2.1 PERSPECTIVE

The Blanks will be fabricated into hexagonal mirror Segments that make up the primary mirror of the Thirty Meter Telescope. In the primary mirror, the Segments will be separated by narrow, uniform gaps. The positions and orientations of the Segments will be controlled continuously so that the array functions as a single, highly accurate mirror.

There are 492 hexagonal Segments in the primary mirror. Because the primary mirror is curved and aspheric, the Segments are not regular hexagons and they are not identical. However, the primary mirror has six-fold symmetry, and there are six identical Segments of each of 82 types. One full set of Segments will be provided as spares, so a total of 574 Segments are required.

The finished hexagonal Segments will be approximately 1.44 meters as measured across corners. Each type of Segment has slightly different dimensions, within a range of a few millimeters, and each has a different best-fit radius of curvature of the Optical Surface. The radius of curvature specified for the concave surface of all the Blanks was chosen to minimize optical finishing effort. All Segments have the same thickness.

# 3. SPECIFIC REQUIREMENTS

*Discussion: TMT reserves the right to test the Blank material to verify that it meets these requirements.*

## 3.1 MATERIAL PROPERTIES

### 3.1.0 Segment Blank Material

[SPE-M1.SEG.BLK-1000] The material in the Blanks shall be a low-thermal-expansion glass or glass-ceramic. No other material is allowed in the Blanks, except as noted in Section 3.5.

### 3.1.1 Chemical Resistance

[SPE-M1.SEG.BLK-1100] The Optical Surface of the Segments will be subject to periodic cleaning throughout the life of the Observatory. The material in the Blanks shall show no damage or increase of surface roughness on polished surfaces after being subjected to 2000 (TBC) cleaning cycles with any combination of $CO_2$ snow, alcohol, acetone, detergents and water.

[SPE-M1.SEG.BLK-1110] The reflective coating on the Segments will be subject to periodic removal throughout the expected life of the Observatory. The material in the Blanks shall show no damage or increase of surface roughness on polished surfaces after being subjected to 30 (TBC) coating removals. Materials that may be used during coating removal include:

- Hydrochloric acid
- Cupric Sulfate
- Potassium Hydroxide
- Nitric Acid
- Ceric Ammonium Nitrate
- Calcium Carbonate
- Potassium Ferrocyanide solutions
- Sodium Thiosulfate solutions

### 3.1.2 Dimensional Stability

[SPE-M1.SEG.BLK-1200] The material in the Blanks shall be dimensionally stable over the anticipated 50-year lifetime of the Observatory.

[SPE-M1.SEG.BLK-1205] The material shall be elastic over a stress range of 0 to 10 MPa, and over a temperature range from -40°C to 105°C.

[SPE-M1.SEG.BLK-1210] The Blank shall be dimensionally stable, such that it does not cause a change in the shape of the Optical Surface of the Segment exceeding 20 nm RMS (wavefront) after being subjected to ten stress cycles from -10 to +10 MPa, and after being subjected to ten temperature cycles from -40°C to 105°C.

### 3.1.3 Polishing Compatibility

[SPE-M1.SEG.BLK-1300] The material in the Blanks shall be able to be polished using conventional optical finishing processes and materials to a surface roughness of 10 Angstroms RMS, or better.

[SPE-M1.SEG.BLK-1310] The material in the Blanks shall be compatible with Ion-Figuring processes. This compatibility shall be considered proven if samples of the material that have been polished to a surface roughness of 10 angstroms RMS can have 5 microns of material removed by Ion Figuring with no increase of the surface roughness to greater than 12 angstroms RMS.

### 3.1.4 Coefficient of Thermal Expansion

*Definition: All measurements of the CTE within a Blank shall be averaged to define the Average CTE of that Blank. The Mean CTE of the Primary Mirror is defined as the average over all Blanks of the Average CTE's of those Blanks.*

[SPE-M1.SEG.BLK-1400] The Mean CTE of the Primary Mirror shall be 0 +/- 40 x $10^{-9}$ /$^{o}$C over the temperature range -13 $^{o}$C to 27 $^{o}$C. As successive sets of Blanks are delivered, this requirement shall be met over all blanks delivered to date.

[SPE-M1.SEG.BLK-1410] The RMS spread ("Standard Deviation") of the Average CTEs of all the Blanks about the Mean CTE of the Primary Mirror shall be less than or equal to 25 x $10^{-9}$ / $^{o}$C over the temperature range -13 $^{o}$C to 27 $^{o}$C. As successive sets of Blanks are delivered, this requirement shall be met over all blanks delivered to date.

[SPE-M1.SEG.BLK-1430] The lateral spatial variation of the CTE within each Blank shall be within the range -10 x $10^{-9}$ to +10 x $10^{-9}$ / $^{o}$C relative to the Average CTE of that Blank.

[SPE-M1.SEG.BLK-1440] The maximum difference between the Average CTE in any Blank and the Mean CTE of the Primary Mirror shall be < 50 x $10^{-9}$ / $^{o}$C.

[SPE-M1.SEG.BLK-1450] The Blank Supplier shall conduct CTE measurements of sufficient accuracy in or around each blank to demonstrate that the above requirements of Section 3.1.4 have been met. All test specimens shall be delivered to TMT after the relevant testing.

[SPE-M1.SEG.BLK-1460] The Mean CTE of a blank shall not change by more than 10 x $10^{-9}$/ $^{o}$C [TBC] after being subjected to ten temperature cycles of -40°C to 105°C.

### 3.1.5 Gradient of Coefficient of Thermal Expansion

*Definition: If the measured values of the CTE in the Blank are represented by a linear least squares fit in the direction through the thickness of the Blank, the CTE Axial Gradient is defined as the slope of that straight line. The Mean CTE Axial Gradient of the Primary Mirror is defined as the average over all Blanks of the CTE Axial Gradients of all of those Blanks.*

[SPE-M1.SEG.BLK-1500] The Mean CTE Axial Gradient of the Primary Mirror shall be less than or equal to 45 x $10^{-9}$ / $^{o}$C per meter over the temperature range -13 $^{o}$C to 27 $^{o}$C, which corresponds to a difference in CTE of 2 x $10^{-9}$ / $^{o}$C over the thickness of the Blank. As successive sets of Blanks are delivered, this requirement shall be met over all blanks delivered to date.

[SPE-M1.SEG.BLK-1510] The RMS spread ("standard deviation") of the CTE Axial Gradients of all the Blanks about the Mean CTE Axial Gradient of the Primary Mirror shall be less than or equal to 45 x $10^{-9}$ / $^{o}$C per meter over the temperature range -13 $^{o}$C to 27 $^{o}$C. As successive sets

of Blanks are delivered, this requirement shall be met over all blanks delivered to date.

[SPE-M1.SEG.BLK-1530] The maximum difference between the CTE Axial Gradient in any Blank and the average of all Blanks delivered to date shall be < 90 x $10^{-9}$ / $^{o}$C per meter.

[SPE-M1.SEG.BLK-1540] While generating the meniscus, all Blanks shall be oriented so the average CTE at the concave surface is equal to or higher than the average CTE at the convex surface.

[SPE-M1.SEG.BLK-1550] The Blank Supplier shall conduct CTE measurements of sufficient accuracy in or around each Blank to demonstrate the requirements of Section 3.1.5 have been met. All test specimens shall be delivered to TMT after the relevant testing.

## 3.2 RESIDUAL STRESS

[SPE-M1.SEG.BLK-2000] The absolute value of residual stress in the Blank material shall be less than 0.2 MPa at all points in the Blank. This shall be determined by measuring the Strain-Induced Birefringence in each Blank through the thickness of the Blank at no fewer than thirteen points, with one measurement at the center and twelve measurements at a radius of 672 +/- 10mm and angular locations (relative to the clocking mark defined in Section 3.7) of 0°, 30°, 60°, 90°, 120°, 150°, 180°, 210°, 240°, 270°, 300°, and 330°, with an angular tolerance of +/- 1° at each location. The Blank shall be supported during measurement to ensure the support-induced stress is less than 0.04 MPa.

*Discussion: See segment blank drawing (Section 5) for graphical clarification of stress measurement locations.. Section 4 requires the Blank Supplier to provide documentation that validates the stress optical coefficient used in the calculation of stress.*

## 3.3 DIMENSIONS

[SPE-M1.SEG.BLK-3000] The dimensions of the Blank shall be in accordance with the Segment Blank Drawing shown in Figure 1, and incorporated as an integral part of this specification.

*Discussion: The Blanks may be made of low expansion fused silica or low expansion glass ceramic. The thickness for the Blanks depends on the choice of material, as defined in the table in Figure 1. The concave and convex surfaces of the Blanks shall be spherical. The radii of curvature shall be taken to be Basic Dimensions and the surfaces of the Blanks shall not deviate from the Basic Dimensions by more than the tolerances specified.*

*Discussion: Section 4 requires the Blank Supplier to perform an inspection of each Blank using equipment and methods adequate to ensure that all tolerances have been met, and provide an inspection report.*

## 3.4 SURFACE CONDITION

[SPE-M1.SEG.BLK-4000] All surfaces of the Blanks shall be ground to a “220 grit” finish or smoother. Subsurface Damage shall be less than 50 microns deep on all surfaces.

*Discussion: Section 4 requires the Blank Supplier to provide documentation that demonstrates that the Subsurface Damage produced by the Blank Supplier’s processes complies with this requirement.*

## 3.5 BUBBLES AND INCLUSIONS

*Definitions:*

- *Inclusions are defined as any foreign matter in the Blank that is not the low-thermal-expansion glass or glass-ceramic material from which the Blank is made.*
- *For purposes of this specification, bubbles are considered to be Inclusions.*
- *The mean diameter of an Inclusion is defined as the diameter of a sphere having the same volume as the Inclusion.*
- *The Critical Zone is defined as the volume of material that is within 5 mm of the concave surface of the Blank and within the central 145 cm diameter.*
- *Inclusions having a mean diameter smaller than 0.3 mm are not considered in this requirement.*

The inclusions in any blank shall not exceed the limitations given in Table 1 below.

*Table 1:Inclusion Limitations*

| Requirement ID | | Inside Critical Zone | Outside Critical Zone |
|---|---|---|---|
| [SPE-M1.SEG.BLK-5010] | Maximum mean diameter of any Inclusion | 1mm | 3mm |
| [SPE-M1.SEG.BLK-5020] | Maximum number of Inclusions per Blank | 5 | 100 |
| [SPE-M1.SEG.BLK-5030] | Maximum number of Inclusions per any contiguous 100 $cm^3$ volume<br>*Discussion: for the purposes of this requirement, a "contiguous" volume is defined as a cylindrical zone, whose length is the thickness of the blank. For a 4.61cm thick glass-ceramic blank, this zone would be 5.25cm in diameter. For a 5.11cm thick glass blank, the zone would be 5.00cm in diameter. The conceptual intention of the requirement is to allow the inspector to use a circular mask of the given size and look through the entire thickness of the blank.* | N/A | 10 |

## 3.6 CRACKS AND CHIPS

*Definition: A Chip is defined as a hollow depression in the surface of the Blank, usually formed where a flake has broken out of the Blank.*

[SPE-M1.SEG.BLK-6000] No visible cracks shall be allowed in the Blanks.

[SPE-M1.SEG.BLK-6010] If a Blank has a crack in its surface, that crack shall be ground out leaving a depression that is approximately spherical. The depth of any such spherical depression shall be less than half the diameter of the sphere. A ground out spherical depression shall be considered to be a Chip as defined in this specification.

[SPE-M1.SEG.BLK-6100] All surfaces of a Chip shall be ground out to remove sharp edges and cracks.

[SPE-M1.SEG.BLK-6110] No Chips are allowed on the concave surface of the Blanks within the central 145 cm diameter.

[SPE-M1.SEG.BLK-6120] No Chip shall exceed 20 mm in mean diameter after grinding and no more than three Chips are allowed on any Blank.

[SPE-M1.SEG.BLK-6130] Within the central 145 cm diameter of the convex surface of any Blank, no more than one Chip is allowed and no Chip having a mean diameter larger than 2 mm is allowed.

## 3.7 BLANK MARKING REQUIREMENTS

[SPE-M1.SEG.BLK-7010] A clocking index mark shall be permanently scribed, etched, or engraved into the cylindrical surface of the mirror blank. The mark shall be used to define the 0-degree position. While looking at the concave surface of the blank, the positive circumferential direction shall be counter-clockwise. (I.e. the positive circumferential direction is right-handed about the surface normal of the center of the concave surface.)

*Discussion: See segment blank drawing (Section 5) for graphical clarification of clocking mark and orientation.*

[SPE-M1.SEG.BLK-7020] A unique serial number shall be permanently marked on the cylindrical surface of each mirror blank. The serial number shall have a minimum of three digits: for example: 005. All inspection reports and travelers shall reference this serial number. The serial number marking shall be located within 300mm of the clocking index mark (per [SPE-M1.SEG.BLK-7010]) in either circumferential direction. The font shall be 10 to 30mm tall.

# 4. DOCUMENTATION REQUIREMENTS

[SPE-M1.SEG.BLK-8000] Prior to the delivery of the first Blank, the Blank Supplier shall submit a report demonstrating the following. The report shall be contained in a single electronic file.

- Material compliance with the requirements of Section 3.1.0 through 3.1.3.
- Material compliance with the post-thermal-cycle CTE stability requirements of Section 3.1.4
- Validity of the stress optical coefficient used in the calculation of Blank residual stress
- Subsurface damage due to Generation process is compliant with requirements of Section 3.4.

[SPE-M1.SEG.BLK-8100] At TBD intervals during the production run, Blank Supplier shall perform testing demonstrating the process stability and/or requirement compliance of the following:

- Stress optical coefficient used in the calculation of Blank residual stress

A report of the results shall be submitted.

[SPE-M1.SEG.BLK-8200] A data package shall be delivered with each Blank. A paper copy shall be packed with the Blank, and an electronic version (contained in a single data file) shall be provided to TMT. This data package shall include, at a minimum, the following information.

- Blank Identification Information
  - Blank Serial Number
  - Batch or melt identification number of the Blank material
  - Date of the melt
  - If multiple Blanks are taken from a single boule or casting, the report shall give the location within the boule or casting from which the Blank was removed.
  - A list of the serial numbers of all Blanks delivered to date
- CTE information (verification of requirements of Section 3.1.4)
  - Location and values of individual CTE measurements taken around the blank
  - Average CTE of the Blank
  - Lateral spatial variation of CTE within the Blank
  - Mean CTE of all Blanks delivered to date.
  - Standard Deviation of the Average CTEs of all blanks delivered to date
  - Difference of the Average CTE of the Blank and the Mean CTE of all Blanks delivered to date
- CTE Axial Gradient information (verification of requirements of Section 3.1.5)
  - CTE Axial Gradient of the Blank
  - Mean CTE Axial Gradient of all Blanks delivered to date.

- Standard Deviation of the CTE Axial Gradient of all blanks delivered to date
- Difference of the CTE Axial Gradient of the Blank and the Mean CTE Axial Gradient of all Blanks delivered to date

- A dimensional inspection report, including following information
  - the as-measured value for each dimension on the segment blank drawing, and the type of instrument used to make the measurement.
  - Compliance with Surface Condition requirements given in Section 3.4
  - Compliance with the inclusion limitations of Section 3.5
  - Compliance with Crack and Chip limitations given in Section 3.6
  - Location of any Chips

# 5. SEGMENT BLANK DRAWING

*Figure 1: Dimensional Requirement for Blank*