	LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY		E010127 -A- D
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<b>Homogeneity Compensation for the LIGO Pathfinder II Large Sapphire Substrate</b>			

AUTHOR:	CHECKED:	DATE	APPROVALS		
			DCN NO.	REV	DATE
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Introduction

Pathfinder II is a pilot fabrication effort undertaken by the LIGO project to determine the viability of Sapphire as a material for LIGO Test Masses. Fabrication of the Test Masses is a multi-step process that may involve up to five separate vendors. The blanks are produced by a crystal manufacturer then sent for machining, edge and bevel polish and initial surface polish. The substrates may then be sent for measurement of bulk homogeneity and compensation by polish of surface 2. This is followed by fine polish of surface 1. Finally, both surfaces are coated using ion beam sputtering.

Scope

This specification deals with compensation for bulk inhomogeneity only and does not place a requirement on polishing of surface one, edge or bevels of the substrate. The goal of this process is to compensate for optical path length differences within the material by the removal of material on surface two of the substrate. The desired result is that when taken in combination, surface two and the bulk material transmit a flat wave front when viewed exactly perpendicular to surface one.

Operations performed on the substrate should not alter the existing configuration by significantly changing the dimensional properties of the substrate or degrading the edge or bevel polish.

Applicable Documents

LIGO-D010117      Surface 2 Polish, LIGO Pathfinder II Large Sapphire Substrate

Caltech Furnished Substrate

The substrate is furnished by Caltech with all dimensions machined per drawing LIGO-D010117 and all surfaces polished. Surface 1 is polished to a residual error from flat of less than 63 nm peak to valley over 80% of the clear aperture. Surface 2 has an inspection polish.


Surface and Bevel Polish

These surfaces shall appear transparent with no gray, scuffs or scratches visible to the naked eye when viewed in normal room light against a black background.

Requirements

Physical Configuration

Fabricate from  
LIGO-D010117      Surface 2 Polish, LIGO Pathfinder II Large Sapphire Substrate

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#### Scratches, Sleeks and Point defects

Point defects of radius greater than 25 micrometers are treated like scratches for the purpose of this specification. Point defects of radius less than 2.5 micrometers are disregarded.

#### Scratches and Sleeks, Surface 2

The total area of scratches and sleeks within the central 200 mm diameter shall not exceed  $150 \times 10^3$  square micrometers (width times length.)

The total area of scratches and sleeks outside the central 200 mm diameter shall not exceed  $300 \times 10^3$  square micrometers.(width times length.)

#### Point Defects, Surface 2

There shall be no more than 30 point defects within the central 200 mm diameter  
There shall be no more than 100 point defects on the entire surface

#### Point Defect Inspection Method

1. The surface is examined visually by two observers independently. The examination is done against a dark background using a fiber optic illumination system of at least 200 W total power. A 100% inspection of the surface is carried out. Pits and scratches down to 2 micrometers in width can be detected using this method of inspection. Any scratches or sleeks that are detected will be measured using a calibrated eyepiece.
2. Further inspection will be done with a minimum 6X eyeglass using the same illumination conditions, again with two observers. Sleeks down to 0.5 micrometers wide can be detected using this method. The surface will be scanned along one or two chords from center to edge, then at ten positions around the edge, and ten to fifteen positions near the center.
3. An inspection is then carried out with a dark field microscope with a similar sampling frequency as described in section 2.

#### Homogeneity Compensating polish measured over the central 200 mm diameter

Figuring of surface 2 is intended for compensation of bulk inhomogeneity of the index of refraction of the mirror blank. There is no explicit requirement for the surface alone, only in combination with the bulk material. The optical path difference of the surface/bulk is measured in transmission through surface 2, passing through the material, reflected from surface 1, passing again through the material and again in transmission through surface 2. All requirements under this heading refer to this double pass measurement.

The real contribution of surface errors on surface 1 are removed from this measurement using an independent phase map of surface 1.

#### Compensated Figure, measured over the central 200 mm diameter


Bulk homogeneity and surface 2: Nominally flat

Amplitude of the Zernike coefficient  $Z_{2,0}$  as defined in Born and Wolf,  $0 \text{ nm} \pm 16 \text{ nm}$

Astigmatism: Amplitude of the Zernike coefficient  $Z_{2,2}$  as defined in Born and Wolf,  $< 16 \text{ nm}$

#### Compensated Error, Low Spatial Frequency

The following root mean square standard deviation ( $\sigma_{\text{rms}}$ ) values are calculated from the phase maps that are to be provided with each optic. For this calculation the amplitude for the best fit Zernike terms  $Z_{0,0}$ ,  $Z_{1,1}$ ,  $Z_{2,0}$  and  $Z_{2,2}$  is subtracted from the phase map.  $\sigma_{\text{rms}}$  for the resultant phase map is defined as the square root of the mean of the square of each pixel value. Known bad pixels may be excluded from this calculation.

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## Homogeneity Compensation for the LIGO Pathfinder II Large Sapphire Substrate

Bulk homogeneity and surface2 measured in the frequency band:  $< 4.3 \text{ cm}^{-1}$

Goal for optimum LIGO system performance  $\sigma_{\text{rms}} < 10 \text{ nanometers}$

Requirement for this procurement  $\sigma_{\text{rms}} < 20 \text{ nanometers}$

**Error, High Spatial Frequency**

Surface 2, Frequency Band:  $4.3 - 7,500 \text{ cm}^{-1}$

Goal for optimum LIGO system performance  $\sigma_{\text{rms}} < 0.5 \text{ nanometers}$

Requirement for this procurement  $\sigma_{\text{rms}} < 1 \text{ nanometer}$

- Measured at the following locations:
1. The center of the mirror substrate.
  2. Four positions equally spaced along the circumference of a centered, 80 mm diameter circle.
  3. Three positions equally spaced along the circumference of a centered, 120 mm diameter circle.

**INSPECTION**

Specification	Test Method	Data Delivered
Scratches and Point Defects	Visual Inspection	Hand sketch including scratch/defect dimensions
Compensated Figure	Interferometry	Phase Map
Compensated Errors – Low Spatial Frequency	Interferometry	Phase Map
Surface Errors – High Spatial Frequency	Interferometry	Surface maps for 3 central locations. Numerical values included with certification

Format: All Data shall be delivered according to Table 1. In addition to a hard copy, an electronic data set of the phase maps shall be delivered in either ASCII or Vision.OPD format.