A+ LIGO Beam Splitter (BBS)

AUTHOR:	DATE	APPROVALS		
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Applicable Documents

LIGO-D1900151-v2	Mirror Substrate Drawing, A+ Beam Splitter
LIGO-D1900150-v2	Mirror Blank Drawing, A+ Beam Splitter
LIGO-E1900150-v1	Mirror Blank Specification, A+ Beam Splitter

Requirements

Physical Configuration

According to LIGO-D1900151 Mirror Substrate Drawing, A+ Beam Splitter

Fabricate from

LIGO-D1900150	Mirror Blank Drawing, A+ Beam Splitter
LIGO-E1900150	Mirror Blank Specification, A+ Beam Splitter

Registration Marks

Registration marks shall be etched, ground or sandblasted and located per LIGO-D1900151

Polishing process

Ion Beam Figuring removal processes should be designed to minimize the probability of defects in the center 250 mm diameter. All Surfaces, Sides and Bevels shall be polished using a progression of smaller grit sizes. The last step before final polish shall be equal to or less than a five µm grit finish.

Surfaces, Side and Bevel Polish

All surfaces shall appear transparent with no grey, checks or fractures visible to the naked eye when viewed in normal room light against a black background. Scuffs are limited to a total sum area of less than 8 square millimeters. Scratches are limited to a total sum area of less than 4 square millimeters.

Bevel

Bevel for safety per LIGO-D1900151

Serial Number

Serial Number “BBSXX” shall be shall be etched, ground or sandblasted on the barrel of the optic per LIGO-D1900151, where XX is incremental and the starting number is supplied with the contract.

Scratches, Sleeks and Point defects

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

Scratches and Sleeks, Surfaces 1 and 2

The total area of scratches and sleeks within the central 250 mm diameter shall not exceed 500×10^3 square micrometers (width times length.)

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Point Defects, Surfaces 1 and 2

There shall be no more than 100 point defects of radius greater than 2 μm within the central 250 mm diameter on each surface. Density of defects less than 2 μm radius must be less than or equal to $1/mm^2$

Scratch and Point Defect Inspection Method

1. The surface is examined visually by two observers independently. The examination is done in a dark room, against a dark background using an illumination system of at least 150 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 centre to edge, then at ten positions around the edge, and ten to fifteen positions near the centre.

Surface Figure, measured over the central 250 mm diameter

Surface 1: Nominally Flat. Radius of curvature: Flat > 300 Km concave, >1000 Km convex

Surface 2, measured in transmission, reflected back from Surface 1: Nominally flat. Surface two should be polished such that the Radius of curvature of Surface 1 as measured through Surface 2 and the material is > | 300 | Km

Surface Error, Low Spatial Frequency: measurement aperture to 1 mm^{-1}

The following root mean square standard deviation (σ_{rms}) values are calculated from the phase maps which are to be provided with each optic. For this calculation the amplitudes for the best fit piston, tilt and power, or the corresponding Zernike coefficients, are subtracted from the phase map. Known bad pixels may be excluded from this calculation.

Surface 1, Frequency Band: < 1 mm^{-1}
Measured over the central 360 mm diameter aperture: σ_{rms} < 3 nanometers
Measured over the central 250 mm diameter aperture: σ_{rms} < 2 nanometers

Single Pass Transmitted wavefront error - Frequency Band: < 0.166 mm^{-1}
In the central 360 mm diameter aperture: σ_{rms} < 4.0 nanometers
In the central 250 mm diameter aperture: σ_{rms} < 2.0 nanometers

Error, High Spatial Frequency: 1– 750 mm^{-1}

Surface 1 HSF error $\sigma_{rms} \leq 0.3$ nanometers measured at the following locations:

1. Within 2 mm of the center of the surface.
2. Four positions equally spaced along the circumference of a centered, 125 mm diameter circle.
3. Three positions equally spaced along the circumference of a centered, 250 mm diameter circle.

Surface 2 HSF error $\sigma_{rms} \leq 0.5$ nanometer measured at the following location:

1. Within 2 mm of the center of the surface.

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Inspection

Table 1: Inspections

Specification	Test Method and frequency	Data Delivered
Dimensions	Measurement 100%	Measurement Results
Scratches and Point defects methods 1 and 2	Visual Inspection 100%	Hand sketch including scratch/pit dimensions
Figure	Interferometry 100%	Surface phase maps
Errors - Low Spatial Frequency	Interferometry 100%	Phase maps
Errors - High Spatial Frequency	Interferometry 100%	Surface maps for 3 central locations. Numerical values included with certification

Orientation: For the purpose of full surface phase maps the data shall be oriented such that the substrate registration mark is at the top center of the data.

Format: All Data are delivered according to Table 1 in electronic form. In addition to the report, an electronic data set of the phase maps are delivered in either ASCII or Metropro.dat format.

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Inspection

The following change in E1900151 is acceptable:
1) Replace defect inspection method #2 with use of a Phase Measuring Microscope (PMM) with 2.5x magnification to aid in quantifying defects.

Sleeks

Sleeks may be allocated to the HIGH SPATIAL FREQUENCY ERROR requirement rather than the "Scratches, Sleeks and Point Defects" requirement per LIGO-C1000393 "ASML proposal on allocating surface defects to RMS roughness on LIGO ITM surfaces" as follows.

Allocating surface defects to RMS roughness on LIGO Test Mass surfaces

In order for a defect to be counted as part of the surface roughness specification allocation, it must be measurable by PMM, have an amplitude of less than 100nm, and its contribution to the local surface RMS roughness be quantifiable. It is expected that sleeks may qualify for this but not scratches. Scratches will be counted as part of the area exclusion allocation.

To properly add the contribution of a single defect to the total accumulated RMS surface roughness the RMS of local defect area must be statistically added to the total surface area roughness.

The following equation is believed to accurately make this calculation. The RMS is assumed to be the RMS deviation, relative to a best fit plane.

$$RMS_{Total} = \sqrt{\frac{AREA_{Full} * RMS_{Full}^2 + AREA_{Local} * RMS_{Local}^2}{AREA_{Full} + AREA_{Local}}}$$

RMS_{Local} = RMS of local area containing the sleek
$AREA_{Local}$ = Area of local RMS

RMS_{Full} = RMS surface roughness of total area, excluding the effect of the defect
$AREA_{Full}$ = Total Area of 250 mm diameter circle, excluding the area of the sleek

RMS_{Total} = RMS surface roughness of total area, including the effect of the defect

Example 1:
RMS of 1 PMM image containing $1/20^{th}$ of the defect = 3nm. The defect is 5mm, and extends over 20 PMM images
Size of PMM image = 0.25mm x 0.25mm

RMS_{Local} = 3.0nm
$AREA_{Local}$ = 0.25 x 0.25 x 20 = 1.25mm^2. This is the total estimated area of the affected zone, represented by the 3.0nm RMS.

RMS_{Full} = 0.12nm
$AREA_{Full}$ = 11309.7mm^2 - 1.25mm^2

RMS_{Total} , RMS surface roughness of total area plus defect = 0.124nm

Example 2:

The system also works using only the 3D diminutions of only the defect itself. Sleek 20mm long, 1micron wide, 10 nm deep

In center 120mm Aperture of ITM R1

RMS_{Local} = 10nm
$AREA_{Local}$ = 0.02mm^2

RMS_{Full} = 0.12nm
$AREA_{Full}$ = 11309.7mm^2 - 0.02mm^2

RMS_{Total} , RMS surface roughness of total area plus defect = 0.121nm