Advanced LIGO End Test Mass (ETM) Re-polish

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Applicable Documents and Revisions

LIGO-D1900269-v1 End Test Mass Substrate Re-polish

Requirements

Physical Configuration

According to D1900269 End Test Mass Substrate Re-polish

Fabricate from

According to D1900269 End Test Mass Substrate Re-polish

Registration Marks

Registration marks shall be etched, ground or sandblasted and located per LIGO- D1900269

Polishing process

Ion Beam Figuring removal processes should be designed to minimize the probability of defects in the center 160 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, Sides 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. The cross hatched bonding area on S3 and S4 shall appear transparent with no grey, scuffs or scratches visible to the naked eye when viewed in normal room light against a black background.

Bevel

Bevel for safety per D1900269

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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.

Scratches and Sleeks, Surface 1

The total area of scratches and sleeks within the central 120 mm diameter shall not exceed 20×10^3 square micrometers (width times length.)

The total area of scratches and sleeks inside 300 mm and outside the central 120 mm diameter shall not exceed 500×10^3 square micrometers (width times length.)

Scratches and Sleeks, Surface 2

The total area of scratches and sleeks within the central 120 mm diameter shall not exceed 1000×10^3 square micrometers (width times length.)

Point Defects, Surface 1

There shall be no more than 10 point defects of radius greater than 2 μm within the central 120 mm diameter. There shall be no more than 100 point defects of radius greater than 2 μm on the entire surface, inspected out to 300mm diameter. Average density of defects less than 2 μm radius must be less than or equal to 1 per 4 mm^2

Point Defects, Surface 2

There shall be no more than 100 point defects of radius greater than 2 μm within the central 120 mm diameter

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 a fiber optic 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.

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Optical Surface Figure, measured over the central 160 mm diameter

Surface 1: Spherical, concave. Radius of curvature: 2245 m -5, +15 m absolute accuracy
ROC precision: R ± 3 m where 2240 m ≤ R ≤ 2260 m for all ETM optics
Astigmatism: < 1.5 nm Amplitude of the Zernike coefficient $Z_{2,2}$

Surface 2: Nominally flat. ROC > | 7000 | m

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 Zernike terms $Z_{0,0}$, $Z_{1,1}$, $Z_{2,0}$ and $Z_{2,2}$ or corresponding Seidel aberrations 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 300 mm diameter aperture: σ_{rms} < 2.5 nanometers
Measured over the central 160 mm diameter aperture: σ_{rms} < 0.3 nanometers

Surface 2 - Frequency Band: < 1 mm^{-1}
Measured over the central 300 mm diameter aperture: σ_{rms} < 40 nanometers

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

Surface 1 HSF error $\sigma_{rms} \leq$ 0.16 nanometers measured at the following locations:

1. Within 2mm of the center of the surface.
2. Four positions equally spaced along the circumference of a centered, 60 mm diameter circle.
3. Three positions equally spaced along the circumference of a centered, 120 mm diameter circle.

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

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

Mounting Flat Figure, measured over the Bond Area per D1900269, 2 places

Flatness: Peak to valley maximum deviation over the bond area, with tilt subtracted: < 60 nm
In the frequency band < 0.5 mm^{-1}: σ_{rms} < 20 nm

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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%	Surface phase maps
Errors - High Spatial Frequency	Interferometry 100%	Surface maps for 3 central locations. Numerical values included with certification
Mounting Flat figure, S3 and S4	Interferometry 100%	Surface phase map

Orientation: For the purpose of full surface phase maps the data are 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. Data sets of the phase maps are delivered in either ASCII or ZYGO.dat format.

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Inspection

The following change in E1900199 is acceptable:
1) Replace defect inspection method #2 with use of a PMM with 2.5x magnification to aid in quantifying defects.

Sleeks

Sleeks may be allocated to surface roughness 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."

LIGO-C1000393-v2
Allocating surface defects to RMS roughness on LIGO ITM surfaces Version 2

It is our (ASML) understanding that, 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 surface, excluding the area of the sleek

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

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Example 1:

RMS of 1 PMM image containing 1/20th 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