Advanced LIGO Input Test Mass Coating Specification

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Name	ITM
Applicable Documents	
Blank Specification	E080031-A
Polish Specification	E080511-v3
Polish Drawing (Fabricate From)	D080657 - v3
General to Surfaces 1 & 2	
Figure Change Before / After Coating	Over a 160 mm diameter aperture, coating uniformity & stress from the coating process shall not change the Sagitta more than 8 nanometers, and shall not add surface figure Zernike terms higher than second order with amplitude > 0.5 nanometers. Confirming measurements are to be made on both sides of the optic, by the coating vendor, and need to be demonstrated only once, on a single part, unless there has been significant reconfiguration of the coating tool. The vendor is responsible for communicating that there has been such a change to the tool, and must repeat the confirming measurements.
Optical Performance Uniformity	On both surfaces, the specified single surface reflectance or transmittances at the specified wavelengths must be maintained over a 160 mm diameter aperture.

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Coating Deposition Method	Ion Beam Sputtered
Coating Area	Coverage to 163 millimeter radius per LIGO-C0901388-v1
Witness Sample Durability Testing	Tested on one witness piece per run, coating to resist: 1. Adhesion test per MIL-C-48497A 4.5.3.1 Adhesion (snap tape). 2. MIL-C-4.5.3.2 Humidity (120F 95% RH for 24 hours), combined with before/after reflectance & transmittance spectrophotometer scans from 350 - 2500 nm in about 1 nm increments, marking the specimen ensure the same area is scanned. The scans will be provided in an Excel spreadsheet as columnar data. There should be no measureable spectral shift. 3. MIL-C-4.5.3.3 Moderate Abrasion (cheesecloth rub).
Transmission, Absorbance, Reflectance, Doublet Matching, Thermal Stability Verifications on S1 & S2	The following specifications for S1 & S2 refer to average values over the surface by collection at multiple points or the averages of maps. Vendor is to assure sampling density is sufficient to represent the coating performance over the clear aperture, and report an average value and standard deviation.
Surface 1	***ARROWS ON OPTIC SIDE POINT TO SURFACE 1***
Coating Type	Partial Transmission (High Reflection)
Angle of Incidence	Normal
Transmission at 1064 nm	0.013 - 0.015 requirement [See Transmittance Matching Explanation]

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Transmission matching between parts at 1064 nm	REQUIREMENT: All mirror transmissions fall within the above specified range (0.013 – 0.015); furthermore, it must be possible to form at least 5 sets of mirrors, each set of mirrors comprised of 2 mirrors (1 set is a doublet) such that for each doublet: $2\lvert (T_1 - T_2) / (T_1 + T_2) \rvert < 0.01$, where T_1 is the maximum and T_2 the minimum mirror transmission within that triplet. BASIC GOAL: All mirror transmissions fall within the above specified range and satisfy: $2\lvert (T_1 - T_2) / (T_1 + T_2) \rvert < 0.01$, where T_1 is the maximum and T_2 the minimum mirror transmission for the full set of all mirrors. REFINED GOAL: All mirror transmissions fall within the range 0.014 +/- 7E-5
Transmission at 532 nm	$0.005 < T < 0.02$
Thermal Stability at 532 nm	$2\lvert (T_1-T_2)/(T_1+T_2) \rvert < 0.1$ T_1 & T_2 = Transmission at 25°C & 40°C. Best effort. Verified by modeling.

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Thermal Stability at 1064 nm	$2\,\lvert(T_1-T_2)/(T_1+T_2)\rvert < 0.01$ T_1 & T_2 = Transmission at 25°C & 40°C. Best effort. Verified by modeling.
Coating Materials	The coating is comprised of silicon-dioxide layers alternating with layers tantalum pentoxide doped with 25% (by cation) titanium dioxide.
Surface Electric Field 1064 nm	E<0.25 V/m. Vendor must demonstrate through calculation using $E\,[V/m] = (27.46)\,(TP / Re\,(Y))^{1/2}$ with T=0.014 being the surface transmittance, Y the admittance in free space units, and P = 1 W/m^2 as the incident power density.

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Thermal Noise	Best effort to minimize thermal noise from coating. A full description of coating thermal noise is available in the supporting document T0900161 along with appropriate numerical input values, but a good proxy is minimization of the function $S = (z_{low} + \gamma z_{high})$, where, $z_{high\ (low)}$ = total thickness of the high (low) index coating material in units full wave optical thickness at the reference wavelength. $\gamma = abc/d$ $a = (\varphi_{high} / \varphi_{low})$ $b = (n_{low} / n_{high})$ $c = (Y_{high} / Y_{sub} + Y_{sub} / Y_{high})$ $d = (Y_{low} / Y_{sub} + Y_{sub} / Y_{low})$ $\varphi_{high(low)}$ = loss angle of the high (low) index material in radians. $n_{high(low)}$ = index of refraction of the high (low) index material at the reference wavelength. $Y_{high(low)}$ = Young's Modulus of the high (low) index material. Y_{sub} = substrate Young's Modulus.
Absorption at 1064 nm	<0.5 ppm required, goal to achieve <0.3 ppm.
Max Defect Area inside 120mm diameter of Surface 1. **Note: This is a summation of all defects of dimension greater than 50 µm**	20,000 μm^2
Max Defect Area outside 120mm diameter, to 160mm diameter of Surface 1. **Note: This is a summation of all defects of dimension greater than 50 µm**	500,000 μm^2

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Max number of Point Defects greater than 4 µm in diameter inside 120mm diameter of Surface 1	10
Max Density of Point Defects less than 4 µm in diameter inside 120mm diameter of Surface 1	1 per 4 sq. millimeter
Max Number of Point Defects on Surface 1 outside 120mm to 160 mm diameter	100
Surface 2	
Coating Type	Antireflection
Angle of Incidence	Normal
Reflection at 1064 nm	< 50 ppm requirement, goal < 20 ppm
Reflection at 532 nm	N/A
Surface Electric Field at 1064 nm	N/A
Thermal Stability at 532 nm	N/A
Thermal Stability at 1064 nm	$2\,\lvert(R_1-R_2)/(R_1+R_2)\rvert < 0.01$ R_1 & R_2 = Reflectance at 25°C & 40°C. Best effort. Verified by modeling.
Coating Materials	The coating is comprised of silicon-dioxide layers alternating with layers tantalum pentoxide doped with 25% (by cation) titanium dioxide.
Absorption at 1064 nm	< 1 ppm Measurement not required, based on coating materials and verification of S1 absorption by measurement.
Max Scratches Surface 2 inside 120mm diameter (in μm^2)	240,000 μm^2
Max Point Defects Surface 2 inside 120 mm diameter	100

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Other	
Additional Deliverables	
Witness Samples.	SURFACE 1: Two Q sample cantilevers per run required (provided by LIGO per drawing D0900659-v1) + as many 1 inch witness pieces that can be fit additionally per run (provided by vendor), with a minimum of two. SURFACE 2: As many 1 inch witness pieces that can be fit per run (provided by vendor), with a minimum of two.
Layer Thickness Information	For all layers in the design, measured thickness data from the deposition for each run, designed thicknesses, and measured indices of refraction at both 1064 nm and 532 nm for both coating materials (based on individual layers).
Surface 1 Spectral Scans	On a representative witness piece for each run, normal incidence spectrophotometer scans of reflectance and transmission of Surface 1 (HR coating) from 350-2500 nm before it is coated, between Surface 1 and Surface 2 coating, and after coating is completed. All spectrophotometer data to be provided in Excel spreadsheet format with columnar data in increments of approximately 1 nm.
Surface 2 Spectral Scans	On a representative witness piece for each run, normal incidence spectrophotometer scans of reflectance and transmission of Surface 2 (AR coating) from 350-2500 nm before it is coated, between Surface 1 and Surface 2 coating, and after coating is completed. All spectrophotometer data to be provided in Excel

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	spreadsheet format with columnar data in increments of approximately 1 nm.
Surface Defect Analysis By Three Required Methods (Alternative Methods of Analysis may be used with the prior approval of LIGO)	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. METHOD 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. Data to be supplied as a hand sketch from both Methods 1 & 2. METHOD 3. An inspection is then carried out with a dark or bright field microscope, with 5x objective at four positions at each of the following locations: a) Within 10mm of the center of the surface. b) Equally spaced along the circumference of a centered, 60 mm diameter circle.

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	c) Equally spaced along the circumference of a centered, 120 mm diameter circle. Data to be supplied as digital images.
Durability Test Data & Samples	All samples from the durability tests and data, including transmittance and reflectance spectrophotometer scans of the representative coating on each side in an Excel spreadsheet with columnar data spaced by approximately 1 nm from 350 - 2500 nm.