LIGO Laboratory / LIGO Scientific Collaboration

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LASTI Test Mass – Coating Characterization

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LIGO Science Collaboration

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1. Scatter

The scatter of the LASTI LEM-1 HR side was measured on the RTS bench at Caltech by using a focused beam and an integrating sphere. The beam waist is about 125 microns and adjusted to be at the surface of the optic. The integrated polar angle range is from 1.5º to 78º, corresponding to a spatial bandwidth of 250 – 9200 cm^{-1}. Four scans of 10 mm × 10 mm were carried out at the center part with a scan step of 0.1 mm, so the total scanned area is 20 mm × 20 mm. Fig. 1 shows the maps of the four scans and fig. 2 summarizes their statistics. In addition to a uniform background, which is decided by the micro roughness scattering, there are some non uniform high scattering points. Because the optic was cleaned by using the First-Contact before the scan, these points are thus believed to be more or less 'permanent', caused by some sort of defects in the coating or bulk.

Figs. 3 and 4 are color map and histogram comparisons of the best one of scatter scans of the LASTI LEM-1 optic with that of other LIGO-I optics, respectively. In addition, also included is a REO 1" (dia.) mirror as reference, which is super polished and HR coated. Looking at the scatter averages in fig. 4, the LEM-1 shows a better scatter average than most of the LIGO-I mirrors. But if we take into account all the four scatter measurements, the LEM-1 is in the same class of the LIGO-1 good mirrors, like 2ITM04 and ETM04. One may also want to compare the distribution edges at low scatter side, which is supposed to be decided by the micro roughness property. The LEM-1 doesn't show a lower distribution edge like that of the two super polished mirrors, SPETM02-A and SPETM04-A, though its substrate is super polished. About this point, we are not confident and need more works to further confirm it because the optical noise background is at about 10 ppm level for the moment and may introduce an unknown systematic error, though it is deliberately subtracted.

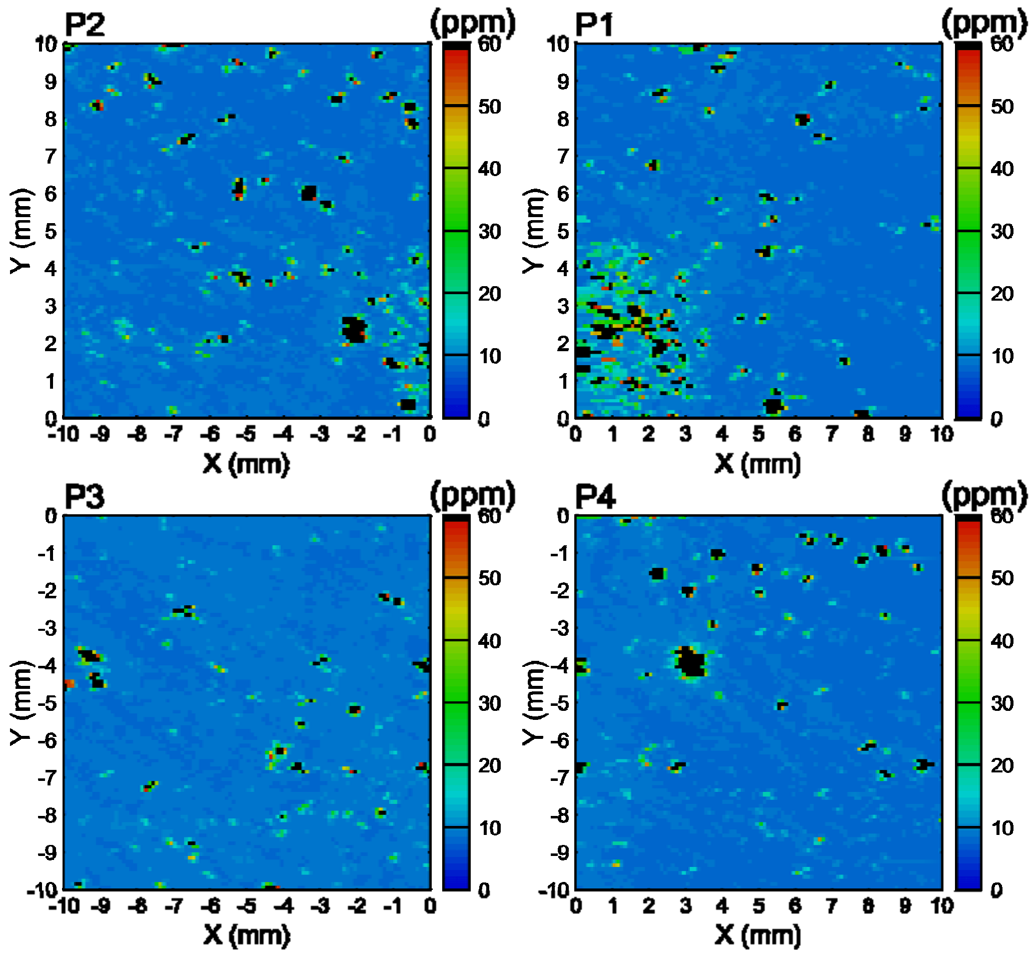


Fig. 1. Four scatter measurements on the HR coating of the LASTI LEM-1 optic.

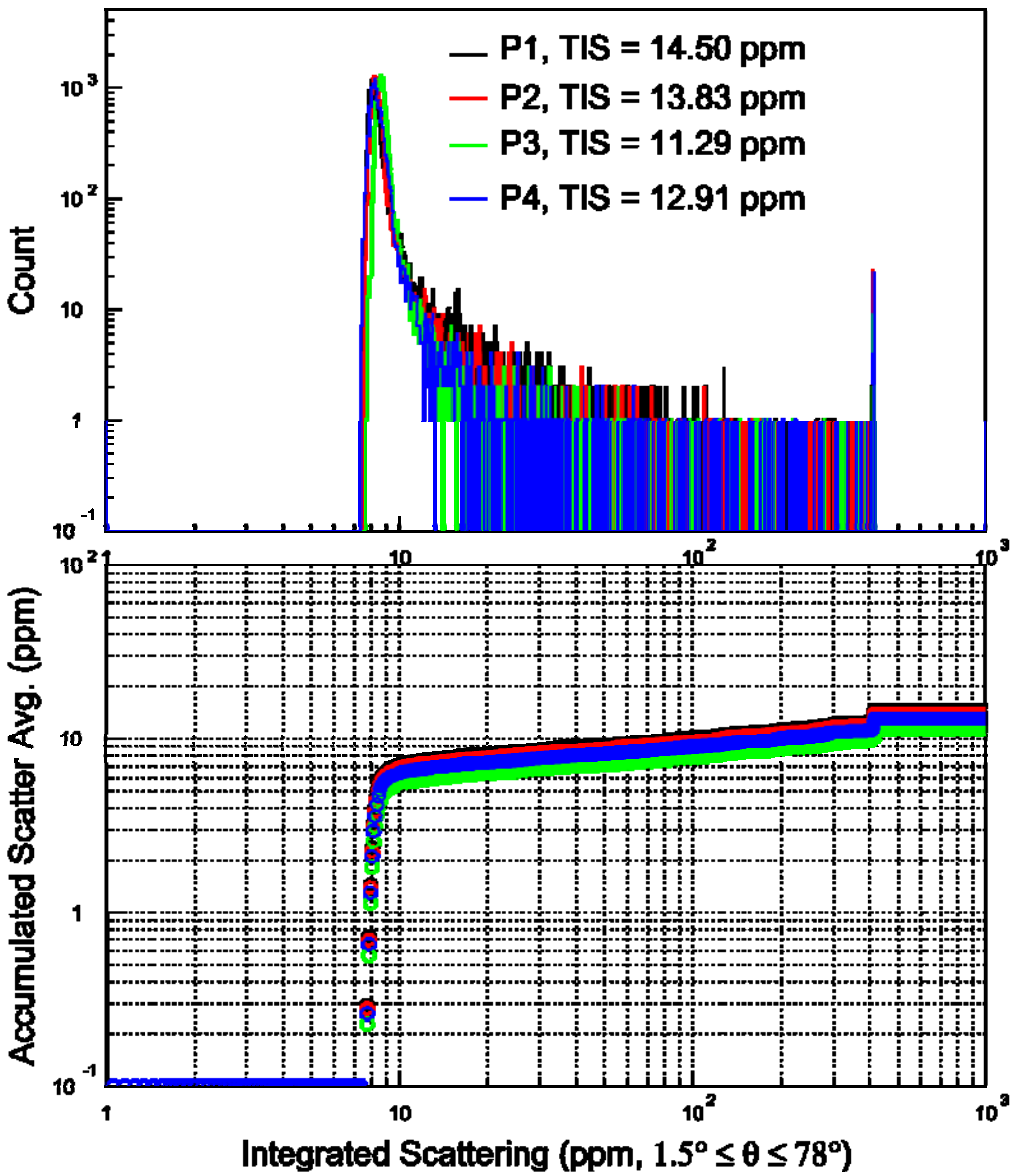


Fig. 2 Statistics of the four scatter measurements, upper: the histograms, and lower: accumulated scatter average.

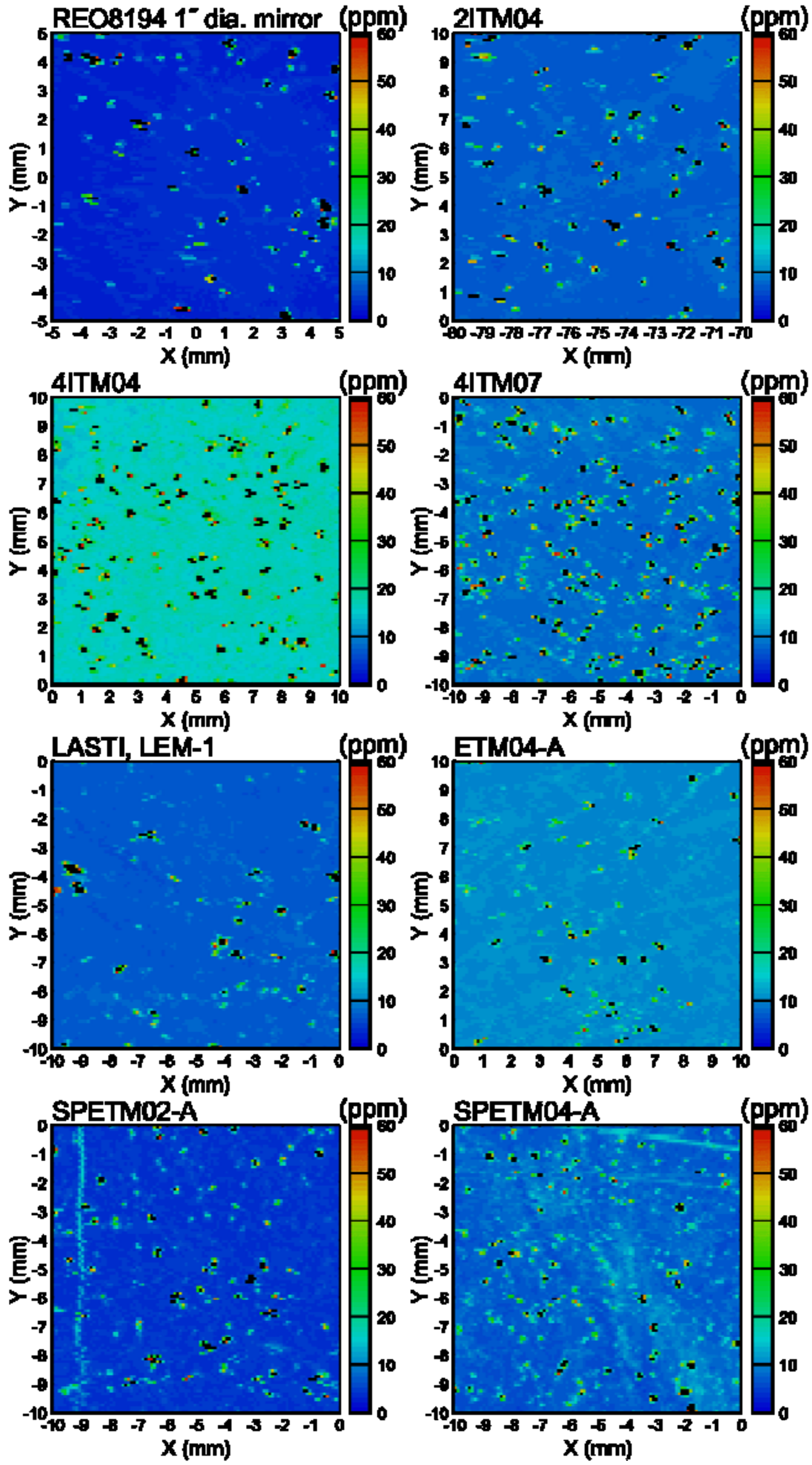


Fig. 3. Comparison of the scatter measurement of LASTI LEM-1 optic with that of other LIGO-I optics.

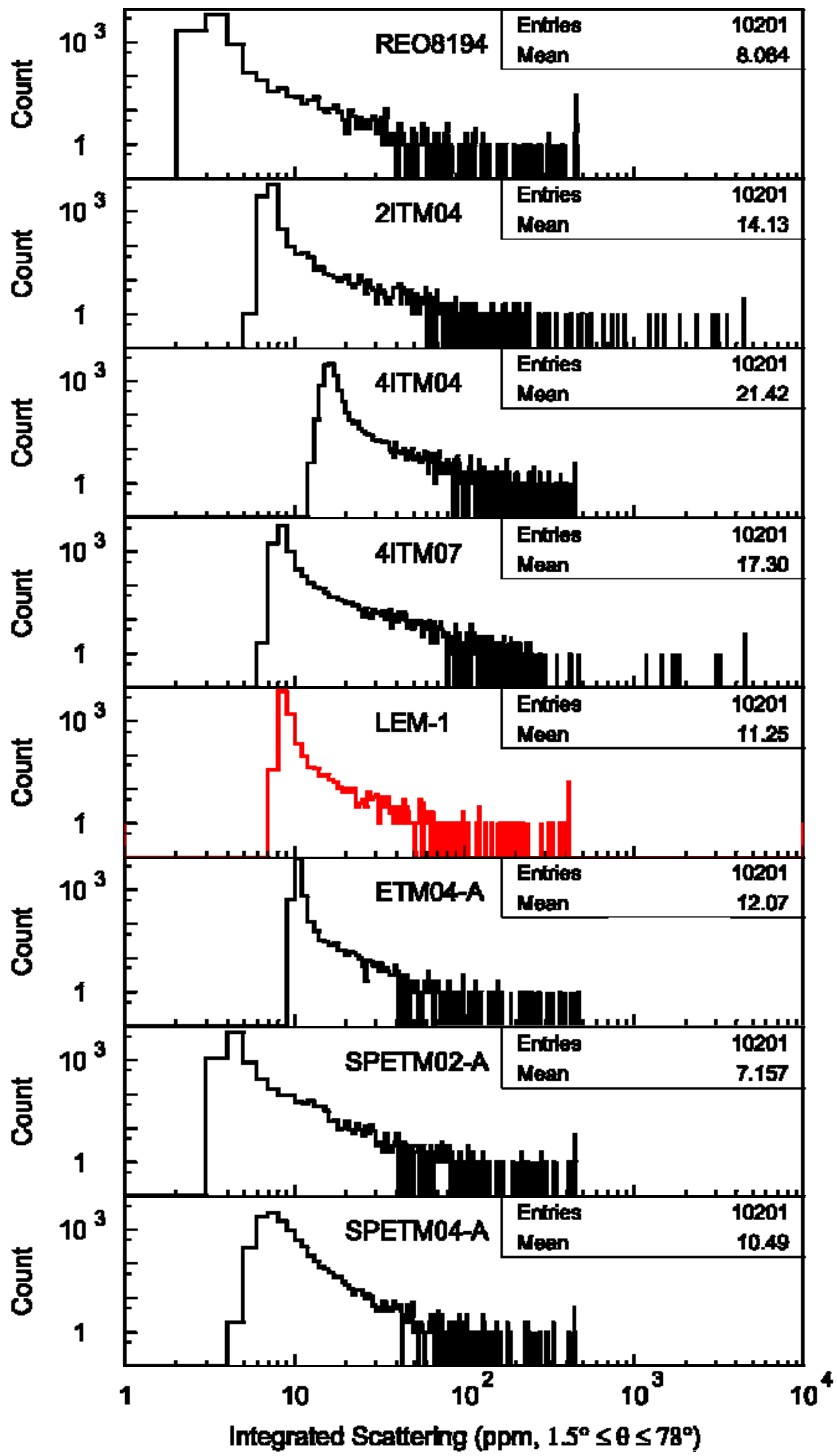


Fig. 4. Histogram comparison of the scatter measurement of LASTI LEM-1 optic with that of other LIGO-I optics.

2. Absorption

The HR coating absorption was measured on the RTS bench by using the photo-thermal common–path interferometer (PCI) method. The heating source is a 30 W CW Nd:YAG laser, and the probe beam from a He-Ne laser. Because our environment is not clean enough to assure that there will be no dust burned on the surface by the high power YAG beam, the event which may downgrade the HR coating, we just measured two lines of 30 mm along X (wedge at Y) with a scan step of 0.1 mm at outside of the center part of 100 mm in diameter. Fig. 5 shows the result and its histogram. While most of the points are around 0.2 ppm, the mean is 0.29 ppm due to several high absorption points spreading from several ppm to 22 ppm. Since the FWHM of the distribution peak, dominated by the noise, is about 0.2 ppm, our result is thus 0.3±0.1 ppm.

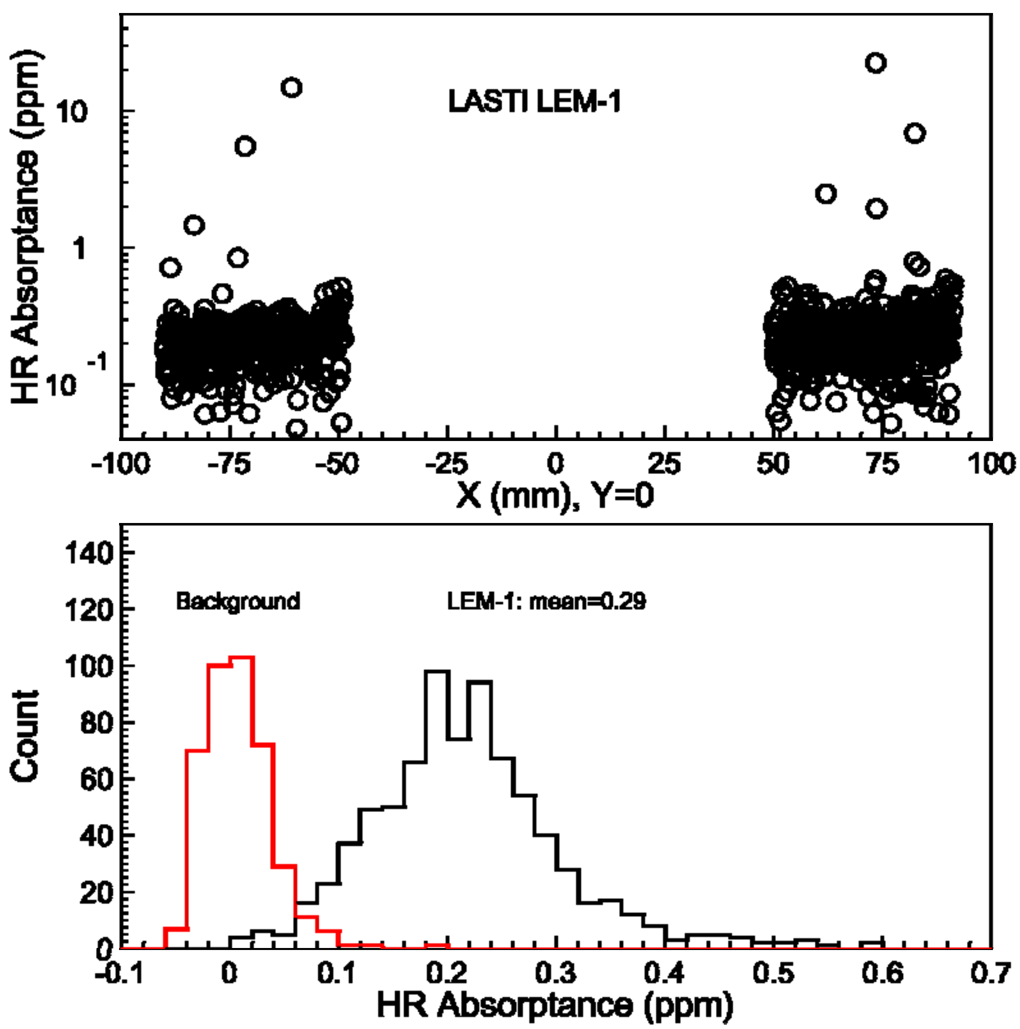


Fig. 5. HR coating absorption of the LASTI LEM-1 optic (upper), and its statistics (lower).

3. Transmission

The transmission was measured by using a collimated beam of 1 mm in diameter and an 1 mm scan step at the center part of 160 × 160 mm^2. While most of points were within 9-10 ppm, indicating a very good uniformity, nine very high transmission points were found, as shown in figs. 6, in which seven of them were saturated in the lock-in amplifier. To get an overall average, each of these 9 points or 'holes' was individually calibrated and put in the histogram, as shown in fig. 7. One can see that the contribution of the points is about 1/3 of the overall average of transmission and is non-negligible. Then all of the 9 'holes' were marked by the First-Contact and observed under a dark field microscope, more information and discussion will be given in later part.

Following the LASTI LEM-1 optic, we checked transmission of the 4 TNI mirrors which were coated after the LEM-1 at LMA. The effective measured area is a round of 40 mm in diameter at each of the four mirrors due to their curvature of surface. We found only three defects on one mirror, of which the transmission peaks are much less than those of 'holes' at LEM-1. Besides, we scanned four LIGO-I ETMs in an area of 100 × 100 mm^2. While one (ETM04-A) looks good, three of them (ETM03-A, SPETM02-A and SPETM04-A) show one or two transmission defects. Like on the TNI mirror, the transmission peaks of defects on these LIGO mirrors are much less than that of the 'holes' on the LEM-1. Table I gives a summary. One can see that the transmission peaks of holes of the LASTI LEM-1 optic are about one order of magnitude larger than those of the TNI mirror and LIGO-I mirrors, and the estimated density of 'holes' is less on the LIGO mirrors than on the LASTI and TNI mirrors.

Table I: Summary of the transmission 'holes' measured with the 1 mm beam.

Mirror ID	Area	Number of defects	Transmission peak (ppm)	Density (# per cm^2)
LASTI LEM-1	16 × 16 cm^2	9	7000~20000	0.04
TNI C070522	2 cm (dia.)	0		0.24
TNI C070523	2 cm (dia.)	3	500, 800, 1800	
TNI C070532	2 cm (dia.)	0		
TNI C070533	2 cm (dia.)	0		
SPETM02-A	10 × 10 cm^2	1	~300	0.01
SPETM04-A	10 × 10 cm^2	2	~500, 1200	
ETM03-A	10 × 10 cm^2	1	~100	
ETM04-A	10 × 10 cm^2	0		

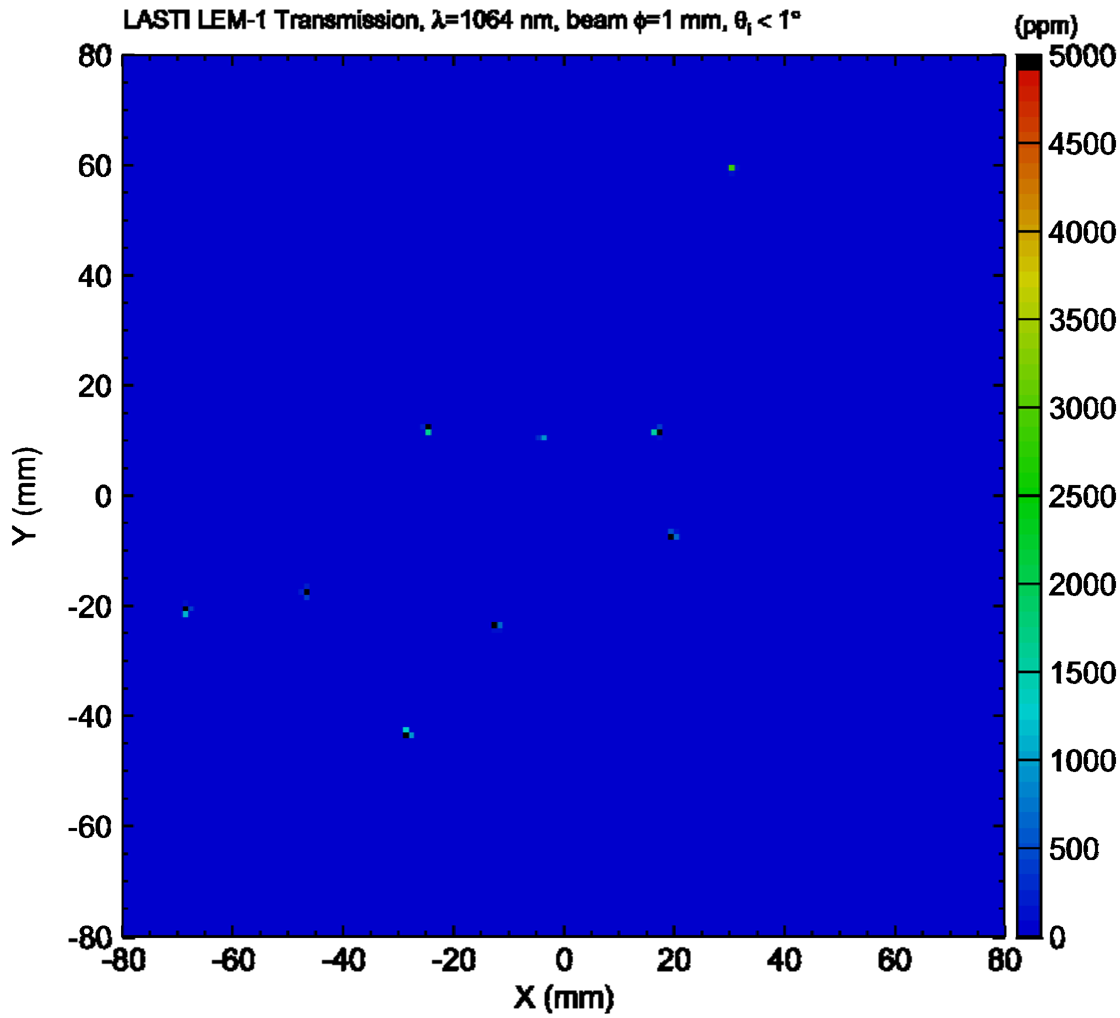


Fig. 6. Transmission map of the LASTI LEM-1 optic.

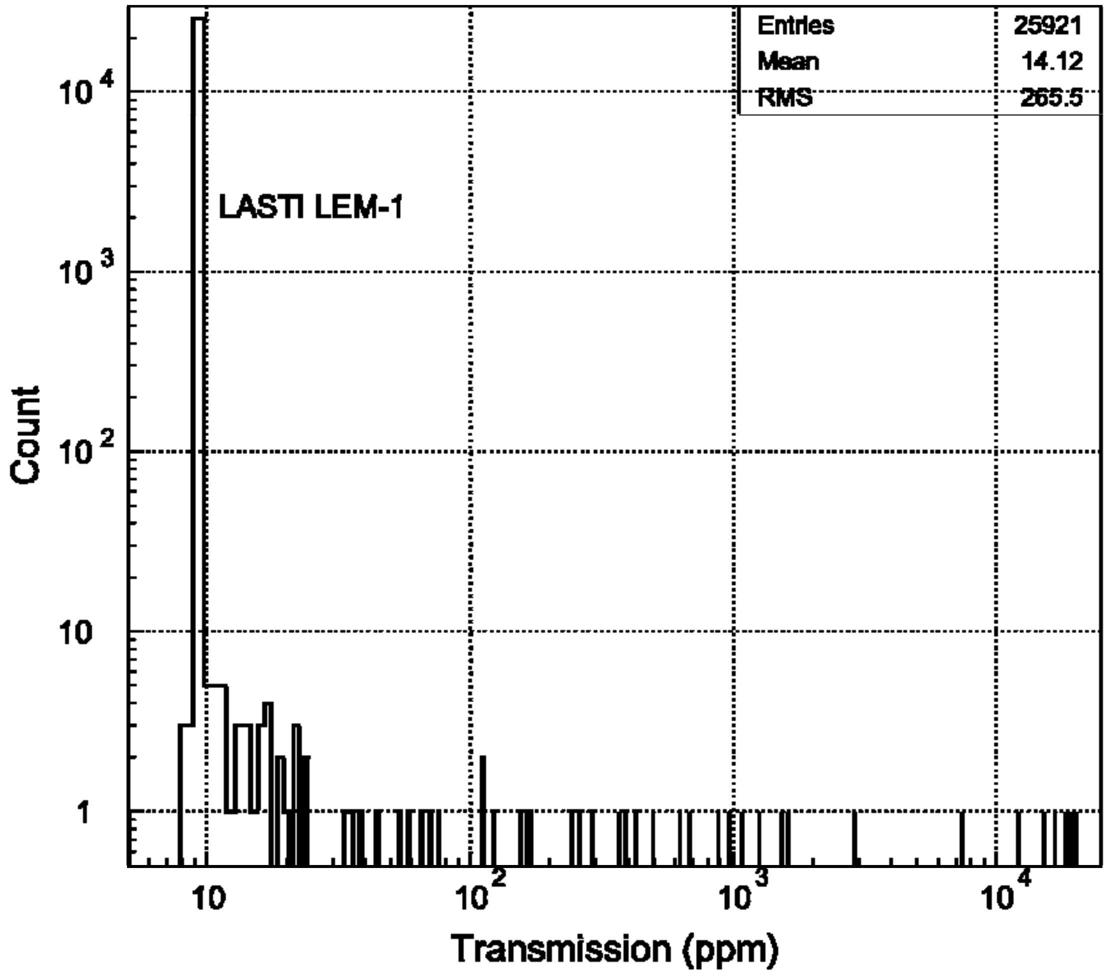


Fig. 7. Histogram of the measured transmission of the LASTI LEM-1 optic.

4. Reflection of the AR coating

The reflection of the AR coating was also measured with the collimated beam of 1 mm in diameter at the central part of 160 mm × 160 mm. The AR coating doesn't show the good uniformity as that of HR coating, with about 230 ppm at center, 160 ppm at edge and an average of 180 ppm. Fig. 8 shows the map, and fig. 9 the histogram of all measured points and the variation along the X axis. One can also note that, in addition to this spherical distribution, there are some high refection points, among which about 20 are saturated at 550 ppm limited by the scale setting of lock-in amplifier in the readout. Unfortunately, we had no time to further investigate these points before delivering the optic.

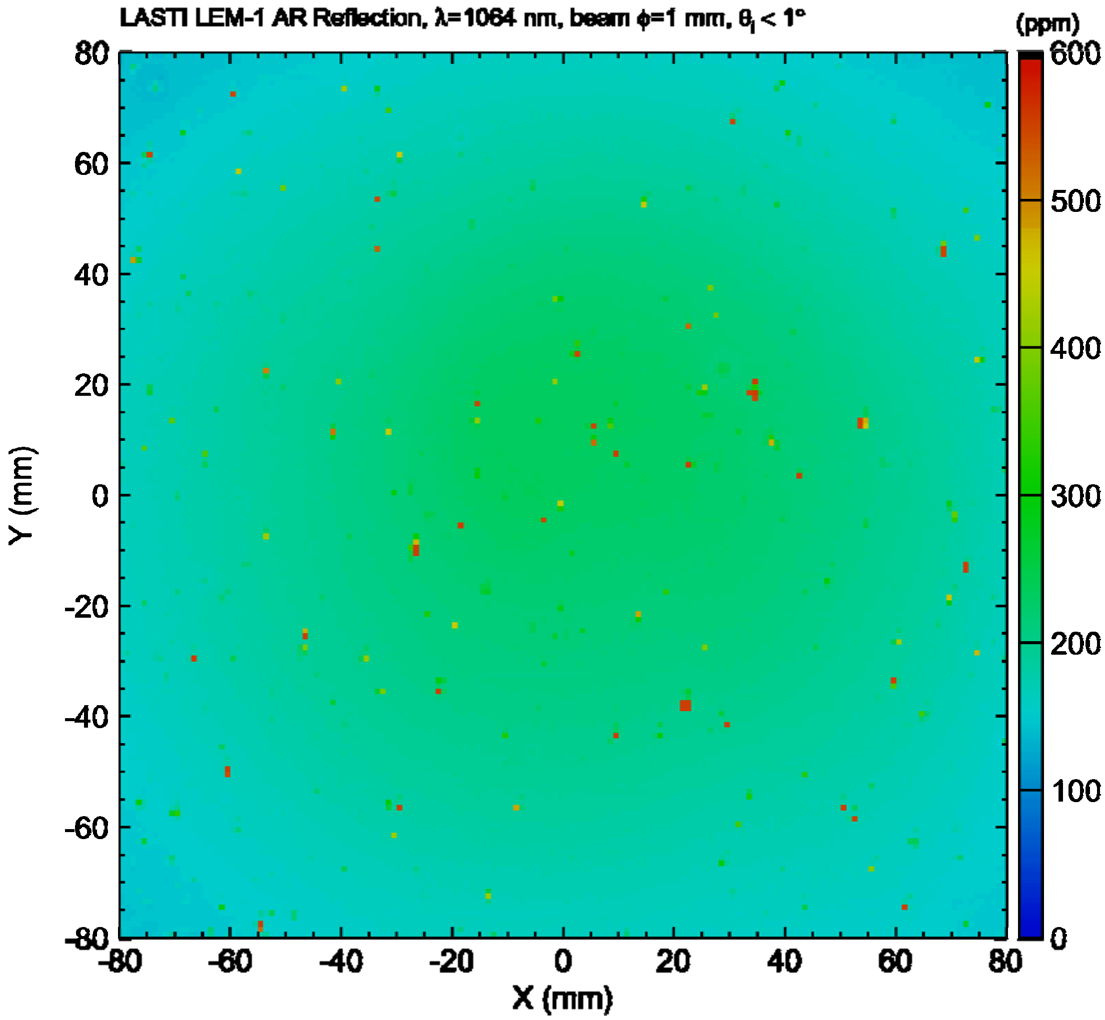


Fig. 8 AR reflection map of the LASTI LEM-1 optic.

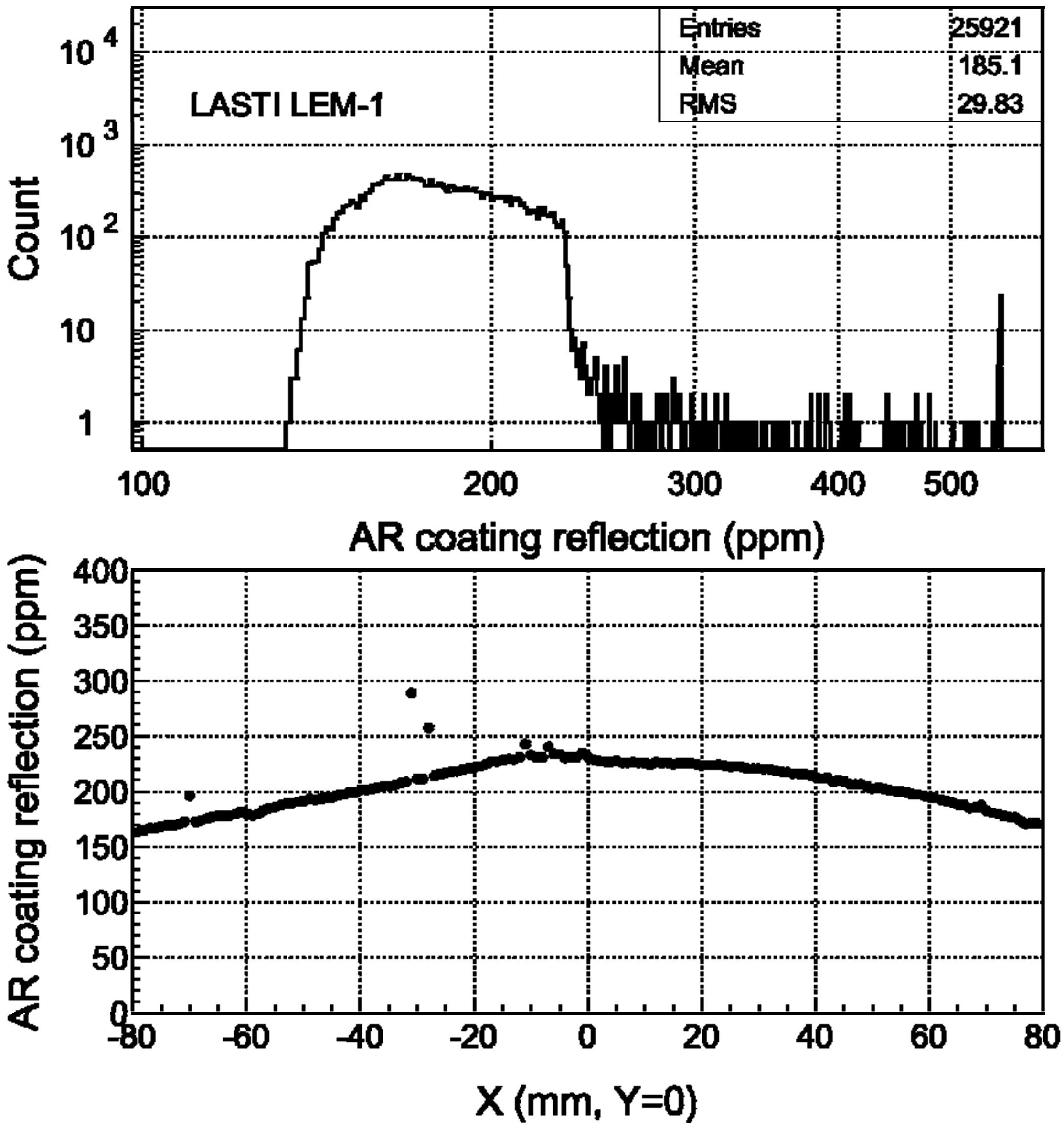


Fig. 9. Upper: histogram of all the measured points of the AR reflection; Lower: variation of the AR reflection along the X axis.

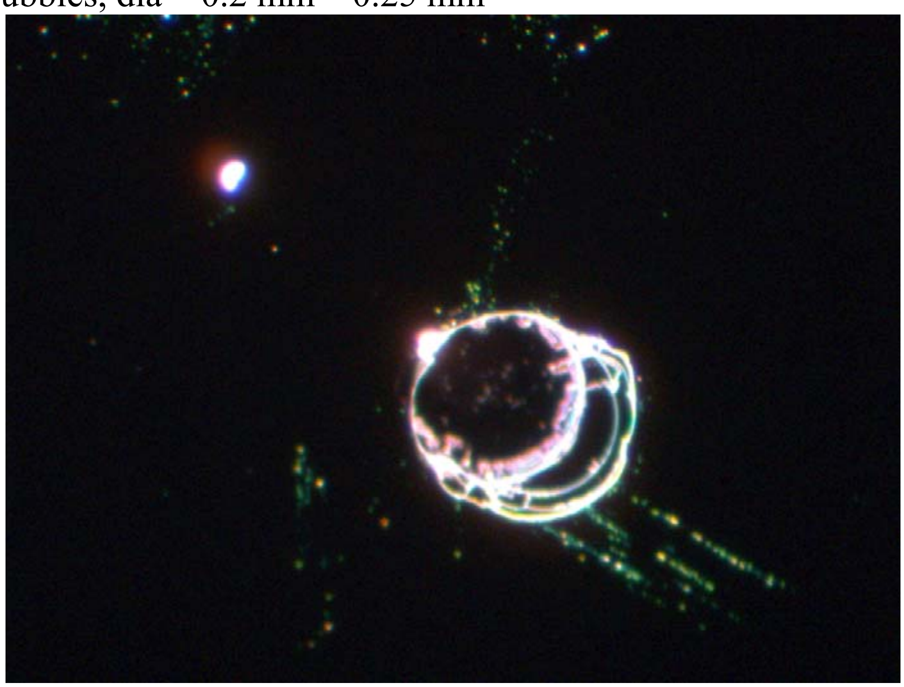
5. Dark field microscope inspection

The HR surface of the LASTI mirror was inspected under the dark field microscope to look at the amount of point defects in an effort to correlate them with scatter.
Twenty eight fields of view were analyzed at 5x magnification in the "x" direction and 28 in the "y" direction.
Counted the defects in each field of view, most of them were under one micron, except for a scratch and a bubble.

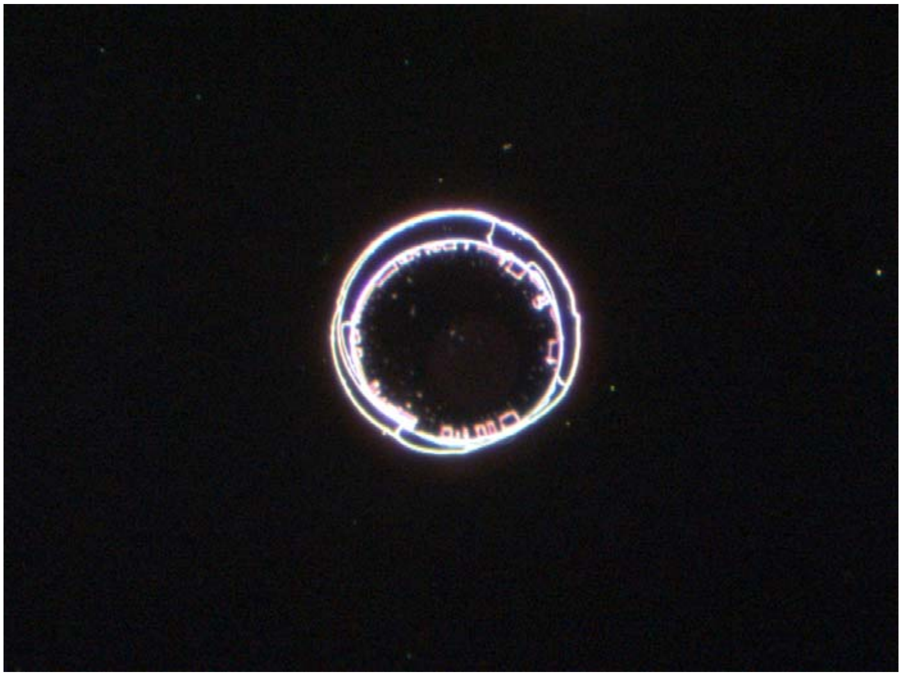
Field of view is a circle of 4 mm dia., so, the area inspected = 12,57 mm^2 x 56 = 703.7 mm^2
There were 193 point defects of about 2 micron (dia.) size (average).
Then:
Occluded area = $193\times(\pi\times10^{-6})$ mm^2=606.3×10^{-6} mm^2
Scatter =606.3×10^{-6} / 703.7= **0.86 ppm.**

6. Coating Bubbles

As stated in section 3, while measuring transmission, nine very high transmission points were found. These points were identified and pictures of some of them were taken under a dark field microscope at 10x.
Field of view = 0.85mm
All bubbles, dia ~ 0.2 mm – 0.25 mm

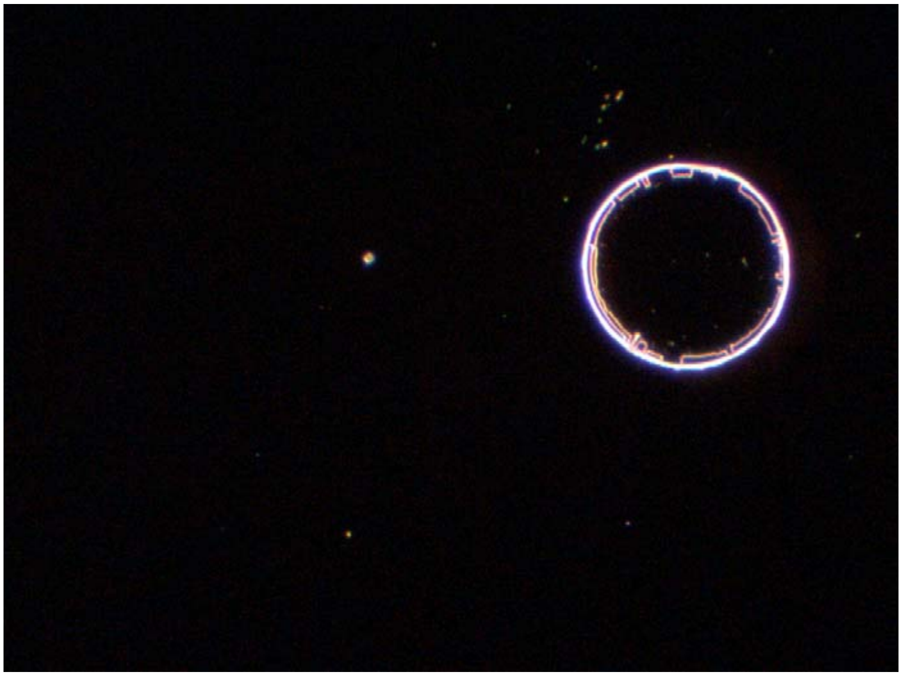


Bubble 1



Bubble 2

Bubble 3



Bubble 4