HET HRS M1 and M2 Mirrors Reflectivity and Scattering Measurements

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1. Introduction

The HET primary mirror segments and spherical aberration corrector mirrors are not the only surfaces coated with Denton's FSS-99 silver coating. Many of the LRS (Low Resolution Spectrograph), MRS (Medium Resolution Spectrograph), HRS (High Resolution Spectrograph), and UFOE (Upgraded Fiber Optic Echelle) instrument mirrors are FSS-99 coated as well. In particular, both HRS M1 and M2 collimator mirrors have the same coating.

In April 1999, it was noticed that HRS M1 showed noticeable tarnishing. This was cause for great concerns as this mirror had been left crated in Dr. Tull's office for one year. Original reports were that HRS M1 had suffered the same kind of tarnishing degradation as the primary mirror segments do. Upon arrival at the HET, Dr. Tull and I carefully inspected both HRS M1 and the more recently coated M2 mirrors with a flashlight. It became quickly evident that HRS M1 tarnishing DOES NOT have the same origin as the primary mirror segments degradation does. In fact, the surface of HRS M1 shows the same dotted/bubbled structure as had been noticed on SAC M2 in February 1999. On a brand new surface, before tarnishing has started hurting the coating, this kind of coating structure can only be seen with a meticulous inspection of the surface with a light source. A good illustration of that came with the inspection of HRS M2. At first sight, HRS M2's surface looks fine, but upon closer inspection, the same dotted/bubbled coating defect is readily apparent over approximately 25% of the coated surface.

It was therefore decided to measure reflectivity and surface roughness of both HRS M1 and M2 for quantification of coating performance. Results are presented in this document.

2. Procedure

The TMA μScan™ portable scatterometer was used to obtain some of the measurements. The light source is a 670 nm laser diode. Reflectivity is measured at an incidence angle of 25 degrees. Scattering measurements are taken at 25 degree angle from specular reflection, at two diametrically opposite directions. An absolute reflectometer, constructed by Dr. Tull was used for the remaining measurements. The light source is a 660 nm laser diode. No independent calibration is required for this instrument. The detector is placed in front of the laser diode and that is taken as 100% reflectivity. Mirror reflectivity is measured by placing the detector such that it is measuring specular reflection of the laser diode beam from the measured mirror. Instrument accuracy is estimated to be approximately ±0.5 % and is limited by the laser diode power stability and possible contamination from ambient light source. Dr. Tull reflectometer has a ~6 mm beam diameter, while the μScan™ scatterometer is more around 3 mm diameter. Consequently, the later is more sensitive to localized coating degradation than the former.

The regular (i.e. ODA calibrated) aluminum and FSS-99 coated samples were not available for calibration. But a large FSS-99 plate was available and used for reference under the safe assumption that this plate glass reflectivity is the same as that of the smaller FSS-99 reference plates being calibrated by ODA. There were no aluminum coated mirror measured for calibration of the μScan™ reflectometer response non-linearity. Since all measured reflectivities are within a few percent of 98.6%, the reflectivity of the fresh FSS-99 coating, non-linearity is not affecting the calculated reflectivities significantly.

3. Results

Reflectivity measurements of HRS' collimator mirrors are presented in Sheets 1 and 2 for Dr. Tull's and the μScan™ reflectometer respectively. Scattering measurements are shown on Sheet 3. The first section of Sheet 1 gives the 100% reflectivity readings. The second section gives measurements obtained from the large FSS-99 plate. These were obtained for consistency check only and to ascertain the influence of taking measurements with the room lights on and off. Room light contamination leads to an artificial increase of 0.3 to 0.4% in calculated reflectivity. The next two sections give results for HRS M1 and M2 respectively. Measurements were taken with room lights off. The location of the instrument is shown to the right. Two sets of measurements were taken using the same measurement pattern, although not necessarily the exact same locations. Sheet 2 gives the results obtained with the μScan™ reflectometer. The FSS-99 plate was measured both before and after measuring the HRS collimator mirrors. Both measurement sets agree very well with each other. The measured reflectivity of both HRS M1 and M2 is given in the lower portion of the spreadsheet.

HRS M2's reflectivity is lower than the expected value of 98.6% by about 2% and both reflectometers give consistent results. HRS M1's reflectivity is measured at between 94.5% and 95.5%, with Dr. Tull reflectometer giving values higher by about 0.75% on average. In short, tarnishing of HRS M1's coating has lead to about 2% reflectivity degradation, as compared to HRS M2. As expected, the scatter in HRS M1's reflectivity measurements is higher with the μScan™ reflectometer than with Dr. Tull's reflectometer. This is due to the localized distribution of silver tarnishing and the smaller beam size of the μScan™ reflectometer.

Sheet 3 gives the scattering measurement results. The first column gives surface roughness in angstroms; the second and third column gives measurements of the bidirectional scattering distribution function for forward and backward scattering in percent. The deterioration of HRS M1's coating is clearly evident in the factor of 6 increase in surface roughness, and factor of ~30 increase in scattered energy, from HRS M2, which is showing numbers typical of a pristine FSS-99 sliver coating. On the other hand, when measurements are restricted to the "messed up" portion of HRS M2's surface, a clear increase in surface roughness is detected, confirming the less than satisfactory quality of the silver coating.

4. Conclusions

Both HRS M1 and M2 collimator mirrors suffer from the same coating failure that is affecting SAC M2. HRS M1 has suffered tarnishing in the fifteen months since it was delivered to us as a by product of the coating defect. HRS M2's reflectivity has not been significantly affected by coating failure yet, but the defect is readily apparent in surface roughness measurements, and the coating is expected to tarnish in the future as a result.

Since HRS is situated in an enclosed environment, it is conceivable that FSS-99 UV has the durability to survive such an atmosphere without significant tarnishing for at least a decade. That would let us keep the higher reflectivity performance of the FSS-99 UV coating between 350 – 400 nm. Furthermore, as these mirrors are of limited size, it is conceivable to implement a regular CO_2 snow cleaning schedule with a more gentle set-up than the primary cleaning wand.

5. Acknowledgment

Thanks to Dr. Tull for his assistance with his absolute reflectometer and the historical perspective about the HRS M1 and M2 coating.

6. Addendum

At the July 7th meeting, Ian Stevenson inspected both HRS M1 and M2. It was Ian's contention that this is the same kind of coating tarnishing that occurs on all other mirrors, but that it looks like the packaging paper provided catalyst sites for the tarnishing chemical reaction to occur faster than usual. As a result Denton has agreed to recoat HRS M1 with FSS99-500 at no cost to us, and suggests not keeping the mirrors under wrap for extended period of time. They are currently performing humidity and salt fog tests on samples kept under wrap for extended period of time to see how they perform.

Sheet 1. June 17th, Dr. Tull's HRS M1 & M2 Reflectivity Measurement

Performed with Dr. Tull's absolute reflectometer and the FSS-99 large plate as calibration check.

Calibration Check

	Before #1	Before #2	After
Straight through LED	181.8	181.6	178.2
Unaffected by room light	181.6	181.7	178.3
	181.8	181.3	178.1
	181.5	181.5	178.2
	181.5	181.4	178.4
average =	181.6	181.5	178.2
stdev =	0.2	0.2	0.1

Adopted value is 179.9. Uncertainty due to drift is +/- 1.5% peak to peak.

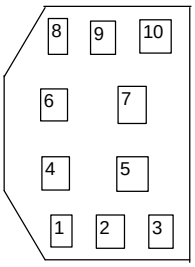
		Before Light on	Before Light Out	After Light Out	
FSS 99 silver coating:		178.6	177.4	176.2	
		178.1	177.3	176.1	
		178.0	177.4	176.1	
		178.0	177.0	175.9	
		178.0	177.2	175.9	
98.5% nominal*	average =	178.1	177.3	176.0	176.6 single light on measurement
	stdev =	0.3	0.2	0.1	
	reflectivity =	0.981	0.977	0.988	0.991

Room lights on gives results about 0.3 to 0.4% higher than light off.
* The 98.5% comes from the June 99 ODA measurements of small plates.

HRS M1 Done with lights out

Location	Data Set #1	Reflectivity Set #1	Data Set #2	Reflectivity Set #2
1	169.5	0.942	167.1	0.929
2	174.1	0.968	169.6	0.943
3	172.8	0.961	169.2	0.941
4	170.4	0.947	171.3	0.952
5	173.7	0.966	173.5	0.964
6	173.1	0.962	172.2	0.957
7	172.9	0.961	171.8	0.955
8	169.2	0.941	168.5	0.937
9	172.5	0.959	171.6	0.954
10	172.1	0.957	172.2	0.957
average =	172.0	0.956	170.7	0.949
stdev =	1.7	0.010	2.0	0.011

Measurement Pattern

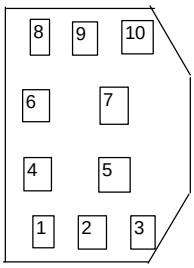


0.75% higher calculated reflectivity than with the µSCAN reflectometer

HRS M2 Done with lights out

Location	Data Set #1	Reflectivity Set #1	Data Set #2	Reflectivity Set #2
1	174.4	0.969	174.0	0.967
2	174.2	0.968	173.8	0.966
3	174.1	0.968	173.7	0.966
4	174.0	0.967	173.7	0.966
5	174.1	0.968	174.0	0.967
6	173.9	0.967	173.9	0.967
7	173.9	0.967	174.0	0.967
8	174.4	0.969	174.2	0.968
9	174.3	0.969	174.3	0.969
10	174.0	0.967	174.1	0.968
average =	174.1	0.968	174.0	0.967
stdev =	0.2	0.001	0.2	0.001

Measurement Pattern



Exactly the same as with the µSCAN reflectometer

HRS M1 has lost 1.5% due to tarnishing

Sheet 2. June 17th, HRS M1 & M2 µSCAN Reflectivity Measurement

Performed with µSCAN reflectometer with FSS-99 large plate as sole calibrator.

Calibration

	Before			After		
FSS 99 silver coating:	98.7			99.0		
	98.7			98.8		
	98.6			99.0		
	98.7			98.8		
	98.7			99.0		
98.6% nominal*	average = 98.7	Scale Factor =	0.999	average = 98.9	Scale Factor =	0.997
	stdev = 0.0			stdev = 0.1		

Scale factor adopted = 0.997

* The 98.6% comes from the June 99 ODA measurements of small plates.

HRS M1

	Data Set #1	Data Set #2
	92.1	97.0
	92.3	91.4
	97.0	90.4
	94.1	96.5
	96.7	94.9
	96.1	90.9
	96.4	96.5
	95.3	95.8
	94.7	95.4
	96.1	96.2
average =	95.1	94.5
stdev =	1.8	2.6
scaled =	94.8	94.2
scatter =	1.8	2.6

HRS M2

	Data Set #1	Data Set #2
	97.4	96.9
	97.1	97.1
	97.2	97.1
	96.9	96.9
	97.1	97.2
	96.9	96.7
	97.1	97.1
	97.0	97.1
	97.0	97.1
	97.1	97.2
average =	97.1	97.0
stdev =	0.1	0.2
scaled =	96.8	96.7
scatter =	0.1	0.2

Measurement pattern as with Dr. Tull reflectometer's measurements.

HRS M1 has lost 2.25% due to tarnishing.

Sheet 3. June 17th, HRS M1 & M2 Scattering Measurement

Performed with μSCAN scatterometer with FSS-99 large plate as reference.

Calibration

FSS 99 silver coating:

	σ (RMS) Å	scattering forward (0,0)	scattering backward (-50,180)
	6.8	1.05E-04	6.41E-05
	8.1	3.26E-05	2.36E-06
	10.5	1.92E-05	8.90E-07
	6.1	7.61E-05	2.58E-05
	11.1	2.42E-04	7.07E-05
average =	8.5	9.50E-05	3.28E-05
stdev =	2.2	8.90E-05	3.32E-05

Repeatability better than 0.1 angstrom.

HRS M1

	σ (RMS) Å	scattering forward (0,0)	scattering backward (-50,180)
	99.4	1.79E-02	5.00E-03
	97.7	1.97E-02	9.50E-03
	38.6	2.59E-03	5.73E-04
	20.0	8.54E-04	3.93E-04
	40.7	2.47E-03	4.26E-04
	87.6	1.54E-02	6.65E-03
	45.6	4.47E-03	2.43E-03
	61.9	6.90E-03	1.73E-03
	41.8	3.76E-03	1.95E-03
	25.5	1.35E-03	5.10E-04
average =	55.9	7.54E-03	2.92E-03
stdev =	29.3	7.26E-03	3.13E-03

HRS M2

	σ (RMS) Å	scattering forward (0,0)	scattering backward (-50,180)
	11.7	3.04E-04	2.10E-04
	8.2	1.26E-04	3.37E-05
	16.7	2.50E-04	2.61E-04
	5.5	5.34E-05	1.22E-05
	3.9	2.87E-04	8.11E-06
	11.8	1.85E-04	2.79E-05
	4.1	2.65E-05	4.95E-06
	22.2	1.08E-03	6.60E-04
	5.5	5.53E-05	1.40E-05
	4.3	3.61E-05	1.06E-05
average =	9.4	2.40E-04	1.24E-04
stdev =	6.2	3.13E-04	2.10E-04

Over the bad section of HRS M2

Conclusions:

HRS M1 has an increased surface roughness by a factor of about 6 relative to HRS M2.

The bad section of HRS M2 has an increased surface roughness by a factor of 2.

	σ (RMS) Å	scattering forward (0,0)	scattering backward (-50,180)
	11.2	2.04E-04	4.00E-05
	22.2	1.06E-03	5.36E-04
	39.8	5.68E-04	3.57E-05
	15.7	3.20E-04	4.65E-05
	17.6	4.36E-04	6.99E-05
average =	21.3	5.18E-04	1.46E-04
stdev =	11.1	3.32E-04	2.19E-04