Mirror coatings for the Large Synoptic Survey Telescope: requirements and solutions

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Abstract

The coating of large ground-based astronomical telescope mirrors is always a challenge and the Large Synoptic Survey Telescope (LSST) contains some of the largest monolithic mirrors ever made for astronomy: a 3.4m diameter convex secondary mirror and an 8.4m diameter concave primary mirror. Bare aluminum coating deposited by evaporation is the most common type of coating deposited on such large mirrors. However, following the success of the Gemini Telescope coatings, LSST has chosen to develop a similar process based on magnetron sputtering deposition. We present the specific requirements for coating the large LSST mirrors and describe the solutions developed to meet these specifications, describing the design features and the major performance requirements.

1. INTRODUCTION

Magnetron sputtering deposition is a technique that is used commonly in industry and that has been applied to small and medium size astronomical mirrors. However, for large monolithic astronomical mirrors (diameter of 4m or above) the evaporation process is the most commonly developed and used technique in the astronomical community where aluminum is the metal the most commonly deposited. Unlike the conventional evaporation method, magnetron sputtering deposition of coatings on large astronomical telescope mirrors has so far been solely implemented on the Twin Gemini Telescopes [1,2] and the European Southern Observatory Very Large Telescope (VLT) [3]. Both of these observatories were designed with 8m diameter monolithic meniscus mirrors.

Large telescopes are usually located on remote elevated sites that are inherently dusty and windy. Because of these conditions, the coatings can age rapidly and their reflectivity will degrade with time. Protecting the coating with a protective layer or layers increases its durability. In addition, the coating lifetime can be extended by allowing regular washes to maintain a high reflectivity level and therefore increasing the period between successive coatings. Although bare coatings have also been cleaned in-situ, the protective layer allows for a better cleaning of the mirror surface for example using wash mops with reduced risk of coating removal in case of adhesion issue.

Extending the coating lifetime reduces the downtime in terms of science operations, as a shutdown for coating a large mirror is generally a major disruptive activity that requires a long preparation. It is a potentially hazardous period for the glass as many activities are happening in its close proximity. It is also important to note that the coating recipe shall minimize the number of layers
deposited on such large mirrors as the stripping operation may become more and more difficult to remove completely the thin films within a reasonable time duration.

2. Large Synoptic Survey Telescope

The Large Synoptic Survey Telescope (LSST) is a large, ground-based, wide-field survey telescope, which is currently in construction on the summit of Cerro Pachón in Chile [4]. The project is designed to image at a fast cadence the available southern sky during a ten years survey, analyze the data to produce alerts and object catalogs, archive the raw and processed data, and serve the data.

This achievement is accomplished via a three-mirror telescope design consisting of an 8.4-meter Primary Mirror (M1), 3.5-meter Secondary Mirror (M2), and a 5.0-meter Tertiary Mirror (M3). This optical design accommodates a 3.5-degree field of view, feeding a large three-lens refractive Camera sampled by a 3.2 gigapixel focal plane array. The survey will yield contiguous overlapping imaging of 20,000 square degrees of sky in six photometric bands [ugrizY] (320–1060 nm to magnitudes 26.5-27 AB).

The LSST has a very unique, compact, optical arrangement, figure 1. The tertiary mirror (M3) resides within the 5-m diameter central hole of the primary mirror (M1). The two mirrors are a monolith called the M1M3 mirror, sharing the same single substrate [5]. The camera is positioned directly inside the secondary mirror (M2) center hole with its optics located between the M1M3 mirror and the M2 mirror. The M1M3 mirror substrate is made of Ohara E6 borosilicate glass and was spinned-cast over a honeycomb mold and polished at the University of Arizona Steward Observatory Mirror Lab (SOML). Temperature and strain measurements were performed to demonstrate that it would be safe to use a magnetron sputtering process for coating this type of mirrors [6]. The M2 mirror, fabricated from ultra-low expansion (ULE) glass at Corning, did not require a similar demonstration. It is currently being polished at Harris in Rochester, New York.

3. LSST Mirrors Coatings

The required minimum throughput of the combined three mirrors is provided in table 1 as the averaged reflectivity over each of the six LSST photometric bands.

Table 1: Required minimum averaged throughput per filter.

<table>
<thead>
<tr>
<th></th>
<th>u-band</th>
<th>g-band</th>
<th>r-band</th>
<th>i-band</th>
<th>z-band</th>
<th>Y-band</th>
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<tbody>
<tr>
<td>Value</td>
<td>0.676</td>
<td>0.683</td>
<td>0.659</td>
<td>0.592</td>
<td>0.590</td>
<td>0.686</td>
</tr>
</tbody>
</table>
The current baseline is to use protective aluminum for all mirrors but a combination of protective aluminum and silver coating is expected to give the best performances relative to the throughput requirements, cleaning requirements and extended lifetime. Figure 2 show the possible final throughput using a combination of different recipes of coatings, M1M3 coated with bare aluminum and M2 with protected silver (and vice-versa) from measurements obtained from coatings deposited with the Gemini coating chamber for the Gemini and SOAR telescopes. Gemini has developed a successful multilayer protected silver recipe that can be implemented for LSST given the similarities of the environment conditions and the size of the mirrors. This protected silver recipe has a high performance at visible and near IR regions that has been maintained for duration of at least 5 years with an appropriate cleaning/washing cycle. Its main drawback is the lack of reflectivity in the u-band. These combinations of coatings per mirror were shown to be the best solution for LSST until a new recipe of material on a single mirror can be probed [7]. The protected aluminum facing up will allow to maintain, to clean and to wash the M1M3 mirror. A protected silver facing down with the M2 mirror may allow extending the lifetime of the coating for years, since at Gemini South the same M2 protected silver has had a lifetime of more than 12 years with the same original protected silver coating. Regular/weekly CO2 cleaning of the mirrors is required in order to reach such results and yearly or biannual in-situ washes will need to be implemented [8]. These operations will be performed during the day improving the overall operational efficiency.

4. LSST Coating Plant Requirements

4.1. Coating Facility General Description

The coating plant will be located at the service floor of the LSST summit facility building, sharing this level with the camera maintenance rooms, the platform lift and the shipping and receiving area (figure 3). The facility building overhead crane was designed to be available during the installation of the coating chamber on the summit.

The Coating Plant area will be capable of receiving the M1M3 and M2 mirror assemblies after removal from the telescope via a platform lift that will run vertically to the service floor where the Coating Plant is located. The size of the cleaning and stripping area and the coating chamber are driven by the size of the 8.4m diameter M1M3 mirror, which cannot be removed, from its cell during stripping, cleaning and coating. Handling procedures and the risk of overstressing the glass during removal of the M1M3 mirror from its cell require that the mirror be supported in its cell during the stripping and coating process. The mirror and cell assembly mass is approx. 55 metric tons and will be transported on a powered cart on rails that run through the facility and under the coating chamber.

The Coating Plant level will also hold all support equipment to coat and strip the M1M3 and M2 mirrors, like vacuum pumps, cryogenics systems, transport rails, coating office, magnetrons
maintenance room, electronic and electrical system, chemical treatment plant, de-water and regular water system, handling cranes, refrigeration system and a clean room environment.

4.2. Coating Plant Main Requirements

During the lifetime of the observatory, the M1M3 and M2 mirrors will require periodic recoating. The main purpose of the Coating Plant is to provide the equipment and logistics to coat the M1M3 and M2 mirrors, and to include the equipment for mirror cleaning and stripping in preparation for coating.

During washing, stripping and coating, the M1M3 mirror must remained inside its mirror cell, and this cell will constitute the lower vacuum vessel of the coating chamber during this operation. Consequently, the coating chamber lower vessel will be moved from under the upper vessel and replaced with the M1M3 mirror cell.

In comparison, the M2 mirror will be removed from its mirror cell, transferred onto a wash stand for washing/stripping, and then placed on a dedicated M2 support system inside the coating chamber lower vessel for coating. The M2 mirror cell will not be used during coating.

Because of its large diameter, the M1M3 mirror stripping, washing and drying process will be complex. Procedures already developed and practiced by other telescopes with such large mirrors will be adapted and implemented for LSST with the safety measures to keep personnel and equipment safe. The coating plant is required to include safety interlocks and equipment during these activities.

The M2 mirror washing, stripping and drying process will be simpler and will be mostly manual as its surface is smaller than the M1M3 mirror surface and is easily accessible from the inside and outside diameters due to its large inside diameter dimension.

Because the M1M3 mirror must remain in its cell, it is not possible to rotate the mirror alone during coating deposition. It would require rotating the whole mirror with the mirror cell if the magnetrons are to be kept fixed. Instead, the requirement is to design a magnetron rotation system attached to the upper vessel to keep the mirror fixed.

To provide the combination of coatings required for LSST, the Coating Chamber must be capable of depositing aluminum, silver, silicone and nickel-chrome. In addition, the M1 and M3 mirrors being in one glass substrate are required to be coated during the same cycle. The specification is to have four linear magnetrons located above the M1 surface and four linear magnetrons located above the M3 surface because the magnetrons are already required to rotate. In addition, the position angle of the M3 magnetrons is specified to be adjustable to coat a concave surface and a convex surface to be used for the M2 mirror coating.
During the M1M3 mirror coating, heating of the mirror substrate by the deposition system shall not produce a temperature gradient across the mirror diameter surface and through the mirror faceplate thickness greater than 5 degrees Celsius. Because the mirror is made of spin-cast borosilicate glass, the working stress of the mirror non-polished surfaces is 100 psi (0.69 MPa), resulting in a local temperature difference limit of 5 °C. Temperature and strain measurements were conducted [6] to verify this requirement.

The roughing pumps alone shall be able to maintain a pressure of at least 2.7 x10^{-2} mbar in ~1h time duration. With the deposition equipment installed and with the M2 support system and/or sample holders installed in the coating chamber, a high vacuum pressure better than 10^{-6} mbar (goal of 3x10^{-7} mbar) shall be attained in the vacuum vessel starting from ambient air conditions within ~8 hours.

4.3. Coating Plant Design Solutions

The LSST baseline design is shown in figures 4, 5 and 6. The upper vessel is a stainless steel vessel that can be lower or raised in the vertical direction using four screw jacks. The upper vessel is first raised high enough in order to move the M1M3 cell or the lower vessel with the M2 mirror under it, then lowered down until its flange contacts the M1M3 cell flange or the lower vessel flange. The four screw jacks are supported by a frame designed with enough reinforcements to resist the seismic requirements. The upper vessel is composed of an intermediate ring attached to the top section of the upper vessel to support an inflatable seal that contacts the M1M3 mirror outside diameter (OD) to separate the vacuum between the M1M3 cell and the upper vessel. This intermediate ring is detachable from the top section to allow inspection of the contact between the seal and the mirror. The upper vessel has curtains all around its perimeter to provide a clean environment under the vessel for maintenance. A filtered air blowing system provides a slightly positive air pressure inside that space to keep the dust out.

The magnetrons are suspended on the upper vessel through a rotation bearing. A cable chain located above the rotation bearing provides enough angular range for all the utility lines to rotate with the magnetrons. A ferro-fluidic rotating seal located around the main rotating axis of the support frame is used to seal the vacuum in the upper vessel. The utilities are routed down through the rotating axis to a vacuum feedthrough. From there, the utilities are connected to each magnetron using flexible stainless steel lines.

The position of the M1 magnetrons is always kept fixed but the M2/M3 magnetrons are adjusted manually to match the M2 or M3 mirror surface shape. To change their slope, the end of the magnetron assembly located toward the OD of the mirror has a fixed pivot point while the other end of the magnetron is simply changed and locked manually in height. Once the magnetron is locked in that position, no other adjustment is possible afterwards. Position switches will be installed to report the magnetron position to the control system.
The lower vessel is a separate vessel supported by a trolley to move in both the front and back directions. It includes a nine point whiffle tree mount that supports the M2 mirror with a lateral restraint system. The lower vessel drive system is attached to the trolley support frame. To produce a uniform loading of the lower vessel, a compliant mount is used between the frame and the vessel to compensate for tip/tilt misalignment when lowering the upper vessel on top of the lower vessel. The support frame is designed to allow storage of the M1M3 mirror cart under the lower vessel when not in use.

The vacuum pumping system for the coating chamber is composed of a rotary vane pump system with isolation valves for rough pumping. After pumping with the rotary vane pumps, the roots pumps are used. When the pumping system reaches a vacuum pressure of at least $2.7 \times 10^{-2}$ mbar, the main valve is closed and the cryopumps gate valves are fully opened to start pumping the coating chamber with the cryopumps. Four cryopumps are used to ensure a uniform pumping over the whole volume of the chamber.

The Coating plant includes not only the coating chamber and all its utility equipment, but also the cleaning and stripping equipment used to prepare the mirrors before they are coated. The stripping equipment includes an M2 Wash Stand, a Platform system around the perimeter of the M1M3 mirror, a Rolling Bridge for access over the top of the M1M3 mirror, a rotating Rinse Boom and Air Knife Assembly and an effluent collection system for both the M1M3 mirror and the M2 mirror.

The M2 Wash Stand will safely support the mirror during the stripping and cleaning process as well as collect effluent draining off the mirrors optical surface. The stand will allow access to the OD and ID for cleaning, stripping and drying of the optical surface.

The mirror optical surface will be ~3 meters high and access to the surface is made possible by a deployable platform system. The platform system will be constructed around the OD of the mirror after it arrives in the cleaning and stripping area. The platform allows complete 360-degree access around the OD of the M1 surface with handrails around the outer perimeter.

The perimeter platform will allow good access to the OD of the M1 surface but it will not allow enough access to the M3 surface and the center hole of the mirror. The M1M3 rolling bridge assembly will remedy this issue by moving over the top of the mirror to give access to the mirrors surface that is not accessible from the perimeter platform.

The M1M3 rinse and dry boom assembly rotates above the center of the mirror. The design uses a pivoting jib attached to the facility column on the side of the cleaning and stripping area. A rotating boom with an air knife and rinse boom are suspended from the end of the jib beam by means of a motorized rotary union. A wired control pendant is used to control the deployment of jib. A rotating rinse wand with spray nozzles will be installed to apply tap water or DI water to the optical surface of the M1M3 mirror. The rinse wand is attached to a rotating boom assembly suspended from a motorized rotary union at the end of the pivoting jib. A series of adjustable nozzles are spaced
along the length of the rinse wand. Since the air knife assembly is located directly adjacent to the rinse wand, a plastic barrier is placed between the wand and air knife to prevent overspray and splash water from the mirror surface to reach the air knife.

The concave surfaces of the M1M3 mirror create a large funnel toward the center hole of the mirror where the effluent are collected in a drain placed in the center hole. This central drain is sealed to the inside edge of the M3 using tape. A support post placed inside the M1M3 cell supports the bottom of the drain and allows a person from the rolling bridge assembly to stand in the center of the drain.

5. Conclusion

The LSST multi-layer coating plant will provide a deposition system for high reflective optical coating and a cleaning and stripping station for the primary/tertiary mirror (M1M3) and the secondary mirror (M2). The deposition unit will be designed to operate in the summit facility building on Cerro Pachón, Chile. Sputtering technology will be utilized to deposit the thin films. The cleaning and stripping station design will include all the equipment required for a safe and efficient process to prepare the mirrors before they are coated.

The current plan is to deliver the fully installed and tested coating plant on the summit towards the beginning of fall 2018. The coating over the M2 mirror surface is planned right after delivery during the second semester of 2018 to be followed soon after by the coating of the M1M3 mirror.

6. Acknowledgements

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References

2. T. Vucina, M. Boccas, C. Araya, C. Ahee, “Gemini Protected Silver Coatings: first two years in operation”, SPIE Vol. 6273, 2006
4. W. Gressler; J. DeVries; E. Hileman; D. R. Neill; J. Sebag; O. Wiecha; J. Andrew; P. Lotz; W. Schoening, “LSST Telescope and Site Status”, SPIE Vol. 9145, 2014

5. H. M. Martin; R. G. Allen; J. H. Burge; B. Cuerden; W. Gressler; W. Hubler; D. Ketelsen; D. W. Kim; J. S. Kingsley; K. Law; P. A. Strittmatter; M. T. Tuell; S. C. West; C. Zhao; P. Zhou, “Manufacture of the combined primary and tertiary mirrors of the large synoptic survey telescope”, SPIE Vol. 9151, 2014


8. T. Vucina, M. Boccas; C. Araya; C. Ah Hee; C. Cavedoni, “Gemini Primary Mirror In-Situ Wash”, SPIE Vol. 7012, 2008
Figure 1.- LSST Optical Diagram.

Figure 2.- Throughput comparison of Al/Ag/Al and Ag/Al/Ag combinations with LSST 6 filter bands
Figure 3.- Summit Facility Layout
Figure 4.- LSST Coating Chamber Baseline Design

Figure 5.- LSST Baseline Design of the M1M3 Mirror Coating Configuration.

Figure 6.- LSST Baseline Design of the M1M3 Cleaning and Stripping Configuration.