The LBT Adaptive Secondary Thin Shells

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ABSTRACT

The most critical component of an adaptive secondary mirror (ASM) is its thin shell; this is the deformable part of the ASM and therefore the component actually providing the adaptive correction. Moreover, because of its intrinsic nature, this component is also the most delicate and difficult to maintain, requiring special attention every time it is handled. LBT has three thin shells, one for each 'eye' of the telescope and one spare. These shells were produced and put in operation between 2006 and 2011 and since then have become the 'heart' of the LBT adaptive optics system. In this paper we report on the maintenance and repair activities that have been carried out during the operation of the LBT adaptive secondary mirrors during the past 5-6 years. In particular we discuss regular maintenance operations such as optical-side surface re-coating and magnet re-gluing as well as extraordinary maintenance such as the re-coating of the magnet-side surface. In addition to techniques and tools used for these activities we will also discuss the strategies put in place for the handling of our thin shell in order to protect and preserve these unique assets.

Keywords: adaptive optics, deformable mirrors, adaptive secondary mirrors

1. INTRODUCTION

The LBT Observatory makes use of several advanced AO systems which all share the same correctors[1] (one per telescope 'eye'), located at the secondary mirror location of the telescope, called Adaptive Secondary Mirror (ASM)[2]. The critical component of each ASM is its thin shell of which LBTO has three (one per unit plus one spare). These shells started production in 2006 and were fully integrated with their units at the telescope by 2011 (with the exception of the spare shell, which was completed in 2013) and have been in operation since. Each thin shell[3] is a thin meniscus, 1.6 mm thick with a diameter of 911 mm. On its convex side 672 magnets are glued. These magnets are used to apply a local force, allowing the shape necessary for the adaptive correction to be achieved. These thin shells are extremely fragile and for this reason their handling is performed in a very controlled environment and following very strictly well defined procedures.

2. HANDLING PROCEDURES

Two main regular maintenance activities require handling of the thin shells, these are:

- Removal of the thin shell from its unit
- Coating of front (optical) side of the thin shell

The removal of the thin shell from its unit (see Fig. 1) is performed on the mountain while the handling activity for coating (see Fig. 2) is performed off the mountain, in a specially equipped clean room. Each activity is carried out following detailed procedures that were developed over the course of the past several years and are now well established. Here we should stress the fact that most operations still carry a significant risk to the integrity of the thin shells and therefore the decision whether to proceed is always balanced considering the benefits. In general we only proceed when it has been shown that the operation is strictly necessary to guarantee the functionality of the AO system while regular maintenance operation are carried out in combination with other repairs or troubleshooting activities. Most procedures require a minimum of three highly skilled operators plus one supervisor during execution; any departure from the expected result triggers a stop in the procedure execution and assessment of the situation.

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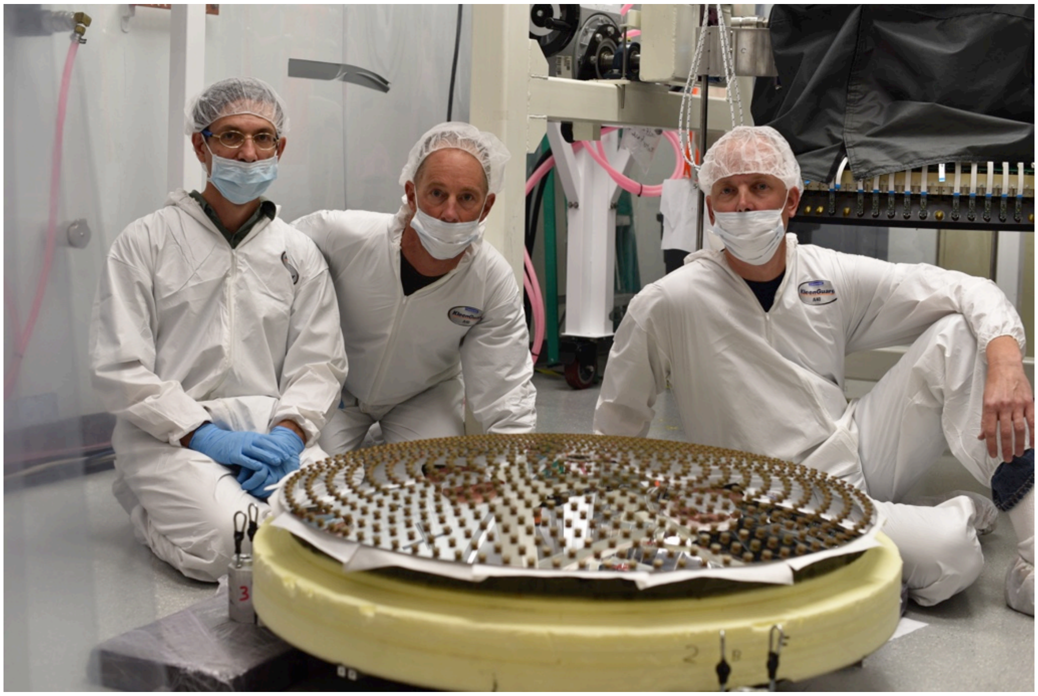

Figure 1 - This photo shows a moment of rest after handling of one of the thin shells in the lab at the mountain. The so-called magnet or 'electrical' side of the thin shell is shown. From left to right: G. Brusa, M.J. Lefebvre and J.C. Vogel.

Figure 2 - Handling of one of the thin shells for coating. At this stage the the thin shell is clamped between two supports. From left to right: M. Wagner, M.J. Lefebvre and R. Sosa.

The personnel involved undergoes a long period of training which start with just observing the operation and then slowly assuming more and more important role. Good mental and physical skills are required. The procedures are constantly checked and when modifications improving the process or reducing the risk are considered they are first tested using a dummy shell and then after full qualification they are introduced in the procedure. Sometimes hardware modifications are implemented which require even more strict criteria of acceptance like FEA analysis to determine if these modifications could potentially increase the mechanical stress applied to the thin shells being handled.

3. OPTICAL SIDE COATING

The coating of the optical side of the thin shell is obtained by physical vapor deposition of evaporated Al; during the testing of the ASM units that occurred in Italy the thin shell were coated with Ag using the silvering process developed by Peacock Labs.
The sequence of operations for coating can be divided into the following steps (with associated time):

1. Removal from the Unit of the Thin Shell and Packing (1 week)
2. Transportation from Mountain to Tucson (1 day)
3. Unpacking, Stripping, Cleaning, Coating, Protective Coating, Re-packing (5-6 weeks)
4. Transportation from Tucson to Mountain (1 day)
5. Un-packing, Re-integration of the Thin shell in Unit (1-2 weeks)

As far as step 3, which is the bulk of the activity, it requires a minimum of six flips of the shell from concave up to convex up or vice versa, each one of these flips requiring a very critical effort; the installation of the thin shell in the chamber and removal being probably the second most critical activity. In Table 1 we provide a summary of the operation and time required.

Un-packing and installation on flipping stand	1 d
Flipping on cleaning tray	1 d
Sealing of OD and ID	1 w
Stripping and cleaning of optical surface	1 d
Flipping on handling tray	1 d
Flipping on cleaning tray	1 d
Final alcohol cleaning	1 d
Flipping on handling tray	1 d
Installation in coating chamber and coating	2 d
Removal from coating chamber	1 d
Flipping on cleaning tray	1 d
Inspection	1 d
Protective coating	1 w
Flipping on shipping tray	1 d
Packing for shipping	1 d

Table 1 - Sequence of activities and respective duration to complete the optical side coating of a thin shell.

As far as coating frequency the LBT Observatory is still in the process of deciding how often the re-coating should occur, trying to balance the risk associated with handling of the thin shell vs. the benefit of an improved reflectivity and reduced scattering.
The re-coating process is essentially identical to the coating requiring therefore the some amount of time (see Tab. 1) and requires transportation to and from the telescope site.

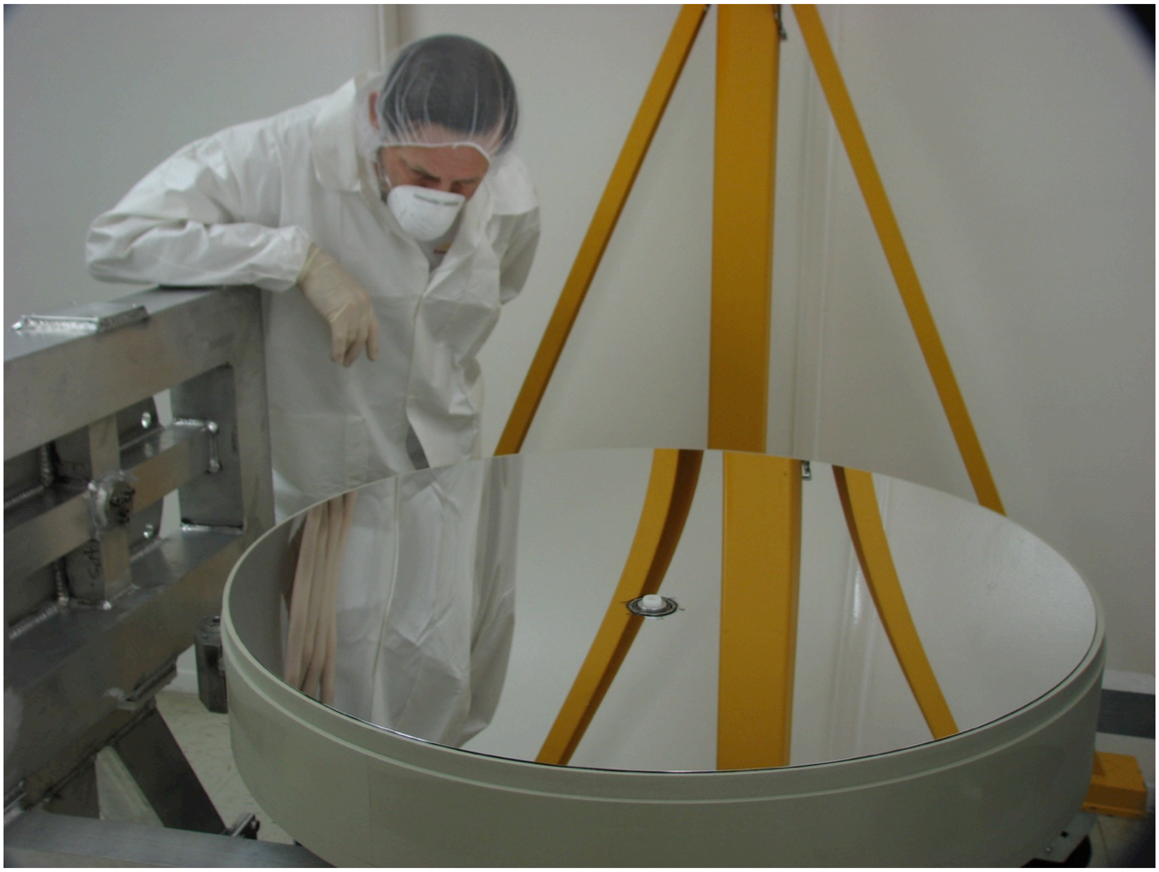

Figure 3. G. Rosenbaum inspecting a freshly coated thin shell. Then thin shell is installed on the cleaning tray.

4. MAGNET RE-GLUYING

Since early on, during operation, we have experienced detachment of the thin shell magnets from the thin shell. These special magnets are glued to the rear surface of the shells and are used to impart the necessary out-of-plane deformations in order to apply the AO correction. We have established that the primary cause of this detachment is a rotation along the shell's axis caused by the interaction between the thin shell magnets and both the driving coils and the so-called 'bias-magnets'[4]. Without entering in the details of this interaction we will say that the combined forces applied to the shell's surface (here gravity is one of them) do not have a zero torque about the shell's axis. This non-zero torque causes a significant rotation because of the relative compliance of the interface responsible for constraining the degrees of freedom of translation and rotation located at the shell's central hole.

We are currently evaluating a solution to this problem including modifying some of the hardware but, in the meantime, we have to deal with the fact that the rotation imparted to the thin shell is large and fast enough that it causes the magnets impacting with the sides of the holes of the reference body and ultimately their detachment. The detachment usually occurs at the interface between the magnet and the glue layer so that the glue joint remains attached to the thin shell (see Fig. 4, left). To restore the magnets we first remove the residual glue layer and then proceed with re-gluing the magnets following the standard magnet integration procedure.

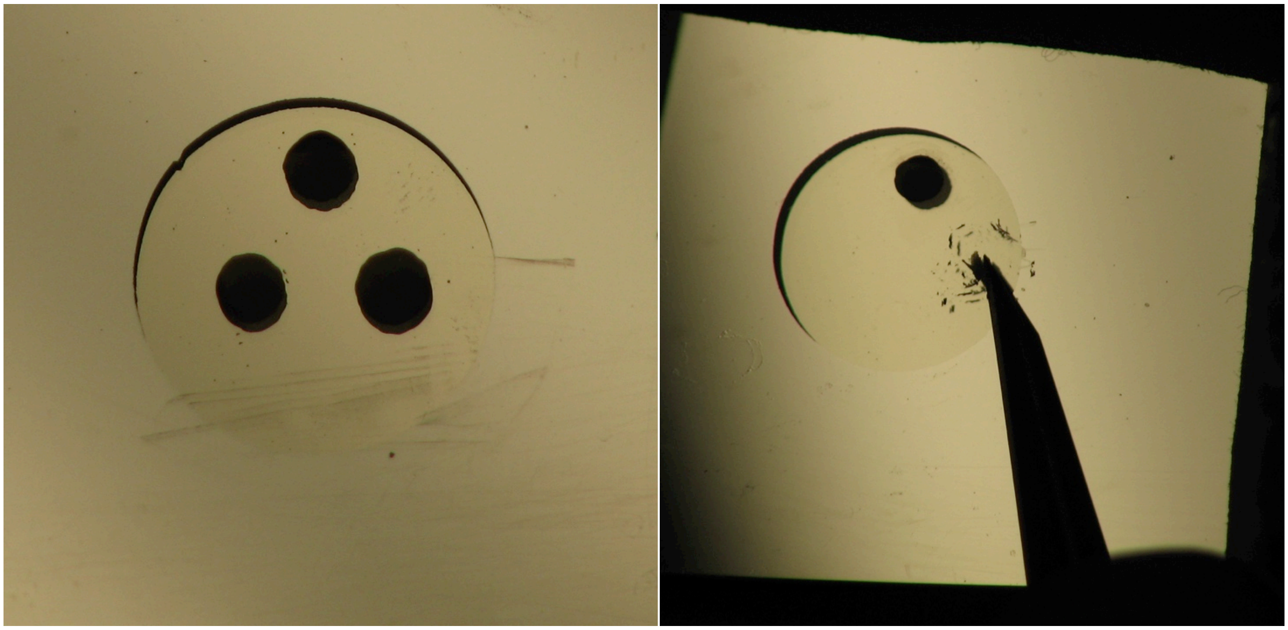

Figure 4 - Glue pads on the shell's surface (left), each pads has an approximate diameter of 2 mm and 50um height above the shell's surface. Right - removal of the glue pads using a surgical scalpel.

To remove the glue pads (see Fig. 4 left) the glue pads are first wetted using alcohol and then carefully scraped using a very sharp surgical scalpel until all the residues have been removed (see Fig. 4 right).

5. MAGNET SIDE RE-COATING

The magnet (or 'electrical') side of the thin shells is coated with Al at the very beginning of the shell integration process, before the magnet integration. This is done to provide a conductive layer used for the capacitive sensing method implementation that allows for closed loop control of the front (optical) surface. This side was never planned to be re-coated however after water contamination of the thin shell gap (first reported in[5]) caused extensive damage to one of our thin shells it was decided to attempt the re-coating of the damaged side without removing the magnets. After the accident (that occurred in 2013 and involved Thin Shell #3) a plan was put together that called for the following sequence of operations:

- Strip and Clean the Optical Side
- Strip and Clean the Magnet Side
- Coat the Magnet Side
- Coat the Optical Side

In other words we decided that we would strip and recoat both sides. A procedure was developed and two main issues were addressed:

- How to protect the magnets during the stripping of the old Al coating
- How to support the shell in the coating chamber with magnets installed

These are discussed in the following sections.

5.1 Magnet protection during stripping and cleaning of magnet side surface

The thin shell surface to be re-coated needs to be stripped of the old coating and prepared for new coating by performing a thorough cleaning. This process requires using aggressive chemical agents that would damage (if not destroy) the permanent magnets attached to the surface; we designed a sealed cover that is installed one each of the 672 magnets and is pre-loaded against the shell's surface using a magnetic pull force provided by the magnets themselves (see Fig. 5).

Figure 5 – Design of the magnet cover (left), the magnet used as counter-magnet to the magnet on the shell as well as the O-ring used to seal the cavity in which the shell's magnet is housed are shown. (Right) Thin shell #3 ready to have the magnet side stripped and cleaned, 672 magnet covers have been installed on its surface.

5.2 Shell support in the coating chamber

Before integration with magnets the thin shells are supported in the coating chamber using a magnetic clamping method (see Fig. 6, left) that allows supporting them above the chamber 'illuminators'. After integration with magnets this method can no longer be used and we designed a support that uses twenty-four small 'fingers' supporting the shell at its outer edge (see Fig. 6, right).

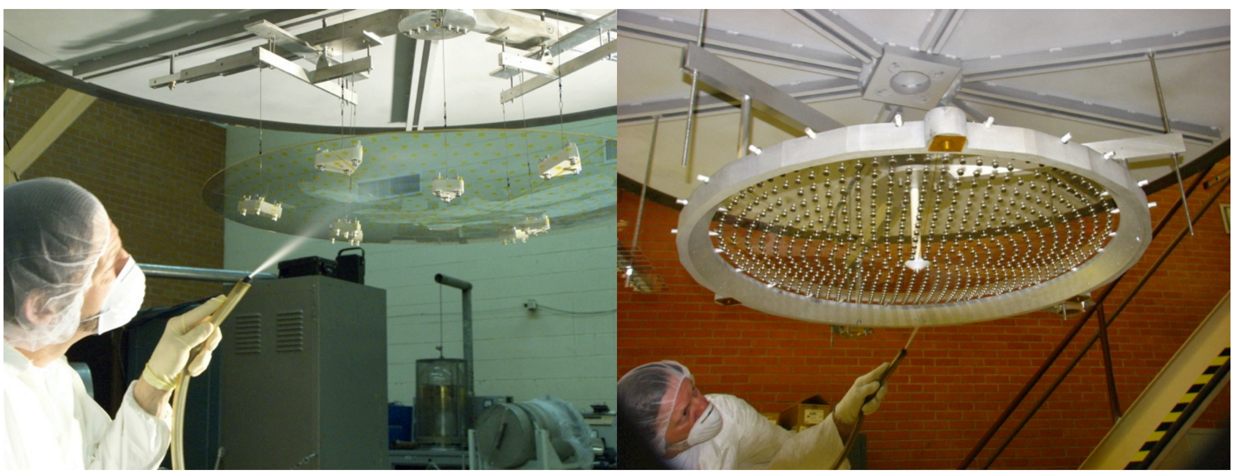
Figure 6 – (Left) supporting the thin shell for magnet-side coating before magnet integration. As the shell is coated 'from below' it needs to be suspended against gravity, this is achieved using an inverted 'whiffle tree' and clamping the shell between several pairs of permanent magnets. (Right) After the thin shell has been integrated with magnets we had to use twenty-four 'fingers' supporting the shell at its outer diameter, since the space for the clamping magnets was no longer available.

5.3 Magnet side re-coating of Thin Shell #3

After extensive tests and a dry run using our test shell we were able to complete the re-coating of the magnet side of Thin Shell #3 in March this year. The entire process was quite involved and took almost nine months to be completed. The coating passed our standard tape test. The final test, of course, will happen when the shell will be re-installed in the unit and the ASM unit tested, this is planned for 2018.

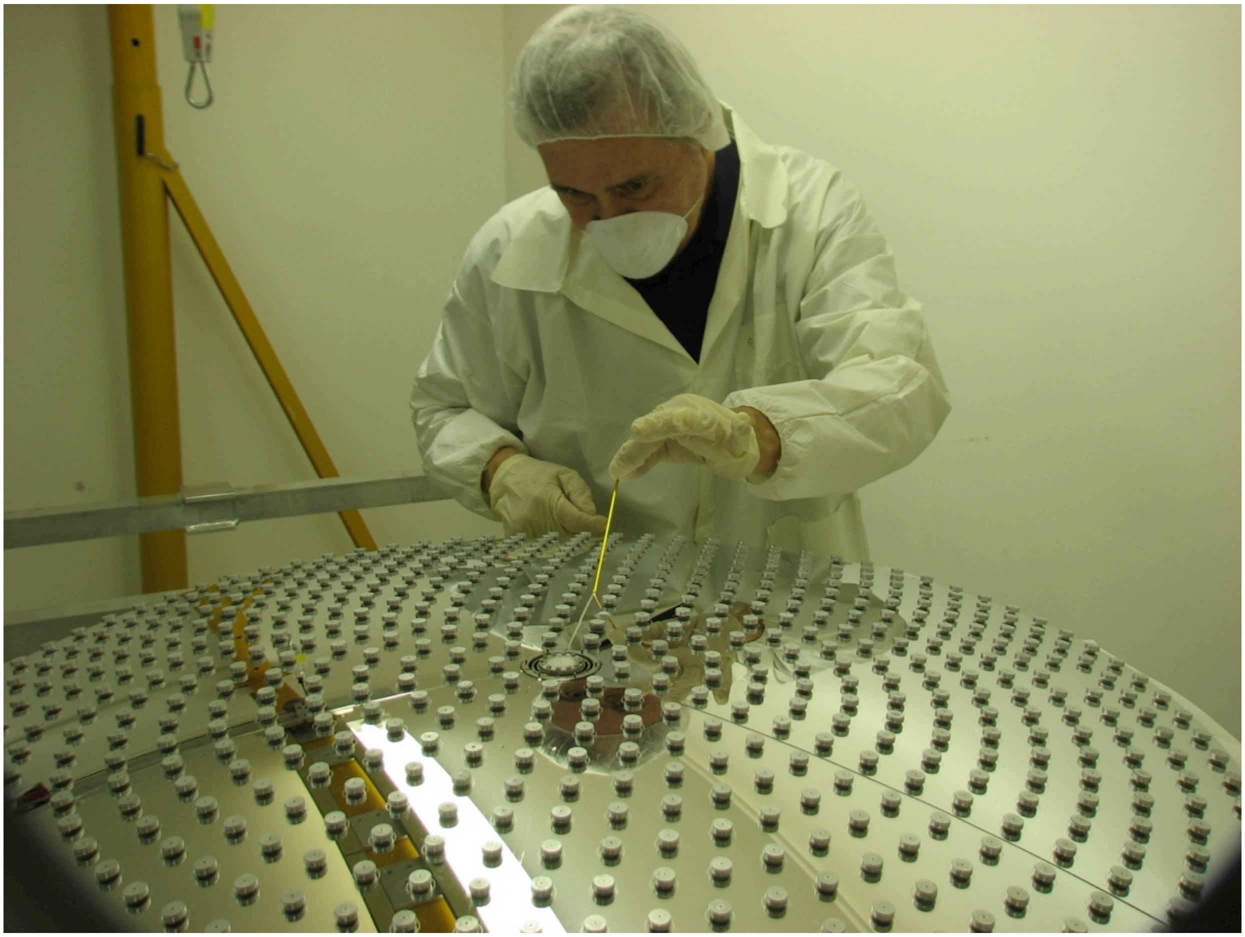
Figure 8 Thin Shell #3 after re-coating of its magnet-side. R. Sosa is removing some Kapton tape strips used to locally mask the coating and produce the necessary division lines in the coating layer.

6. CONCLUSIONS

We have described the procedures currently used for handling the three thin shells used by the two ASMs in operation at the LBT Observatory. As we have indicated we believe we have developed and tested all the procedures necessary to carryout all the ordinary and extra-ordinary maintenance activities for these shells. After many years of operation our conclusion is that for a successful activity not only a well-developed set of hardware handling tools and procedures must be established but also that of primary importance is the team carrying out these activities. As the risk associated with these operations is significant a well-trained and dedicated team is paramount.

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