Design, development and manufacturing of highly advanced and cost effective aluminum sputtering plant for large area telescopic mirrors.

Rajeev R Pillai*[a], Sanjth K K[a], K Mohanchandran[a], Nagarjun Sakhamuri[a],
Vishal Shukla[b], Alok Gupta[b]
[a]Hind High Vacuum Co. Pvt. Ltd., Bangalore, India-560058; [b]Aryabhatta Research Institute of Observational Sciences, Nainital, India-263129

ABSTRACT

The design, development and manufacturing of a fully automated and cost effective aluminum sputtering unit for the deposition of aluminum on large area telescopic mirrors (maximum diameter of 3600mm) is presented here. The unit employs DC planar magnetron sputtering for the deposition process. A large area glow discharge unit is also designed for the pre-cleaning of the mirrors prior to aluminum coating. A special kinematic support structure with rotation is designed to support heavy mirrors of large area to minimize the deflection of the mirrors during deposition process. A custom designed 'mask' is employed in the magnetron system to improve the thickness uniformity within <±3%. The adhesion, thickness uniformity and reflectivity properties are studied in detail to validate the sputtering plant. Special fixtures have been designed for the system to accommodate smaller mirrors and studies have been conducted for the coatings and reported in the paper. The unit was successfully tested at HHV facility in Bangalore and will be installed at the ARIES Facility, Nainital.

Keywords: Telescopic mirror, magnetron sputtering, sputtering mask, glow discharge,whiffletree, reflectivity.

1. INTRODUCTION

The modern day very large telescope (VLT) mirrors are a marvel of engineering and glassmaking, having a very precise curved shape and surfaces polished to within a few wavelengths of light. These large mirror surfaces are covered with a thin layer of highly reflecting material (normally aluminum or silver), ensures approximately 90% of the photons from stars impinging on the mirror to be registered by the sensitive telescope instruments. The optical telescope mirror coatings used in observatories get damaged and tarnished over time due to oxidation, humidity, dust, impact of charged particles from space etc. In order to maintain the accuracy of observations these mirrors must be re-coated frequently. It is preferable to have the coating unit near the telescope as the mirrors are heavy, have large diameters and have to be handled delicately. The recoating process is usually carried out under precisely controlled high vacuum conditions using either magnetron sputtering or thermal evaporation technique. The films deposited using this technique should be spotlessly clean, and extremely uniform. In addition to that, in the case of large telescopes, the re-coating equipment needs to employ specially designed, whiffletree support system which distributes the weight of the mirrors across a series of points to minimize deformation.

HHV is a pioneering high vacuum equipment manufacturer in India, established in 1965 and is one of the leading players in designing and developing VLT mirror coating units. HHV has demonstrated its technological strength by commissioning telescope re-coating equipments in various parts of India. They include the 2.1diameter telescope mirror coating unit, which uses thermal evaporation technique, installed at the Hanle observatory located in the Ladakh region of the Himalayas, at a height of 4570 meters. In 2006, a re-coater is commissioned with sputtering process for a telescope mirror of 2.2 metre diameter at Girawali near Mumbai at an altitude of 1000 metres above sea level.

The present paper discusses the design, manufacturing and testing of re-coating equipment for the 3.6m mirror for the telescope, which is to be installed at 'The Aryabhatta Research Institute of Observational Sciences (ARIES) facility, Nainital, India at an altitude of 2500 meters above sea level.

*rajeevpillai@hhv.in; phone +91-080-22633740; fax +91-080-28394874; www.hhv.in

Ground-based and Airborne Telescopes IV, edited by Larry M. Stepp, Roberto Gilmozzi, Helen J. Hall,
Proc. of SPIE Vol. 8444, 844428 · © 2012 SPIE · CCC code: 0277-786/12/$18 · doi: 10.1117/12.925833

2. THE COATING UNIT

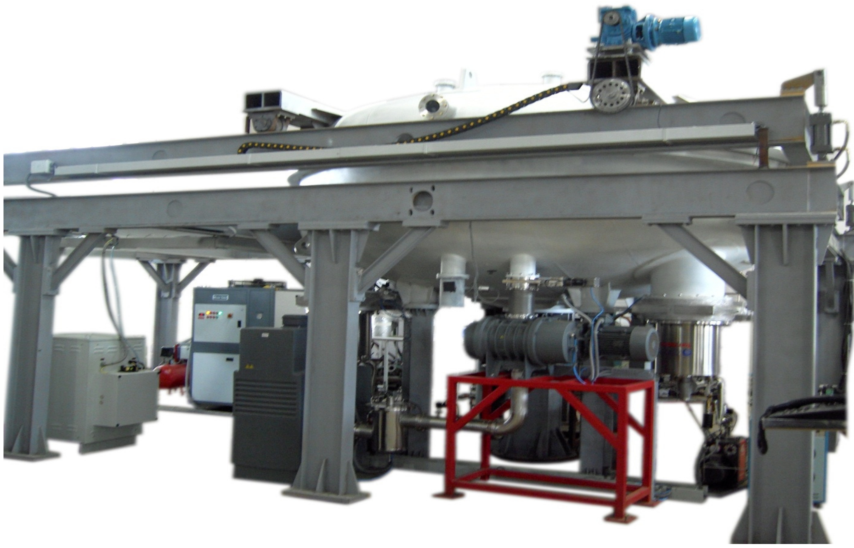

Figure 1.ARIES telescopic mirror coating unit.

The coating unit consists of a vacuum chamber fabricated out of stainless steel, with 2 halves, torrispherical dished ends welded with flanges and clamped together. The chamber has an overall dimension of 4000mm dia x 1700mm (ht.) (i.e. from centre of the bottom dish to the centre of the top dish). The bottom chamber is supported on a 4 -tubular support structure in order to support of the total weight of the chamber. A separate support structure made of mild steel tubes are provided for bearing housing of the rotary drive mechanism to transfer the total load to the ground.

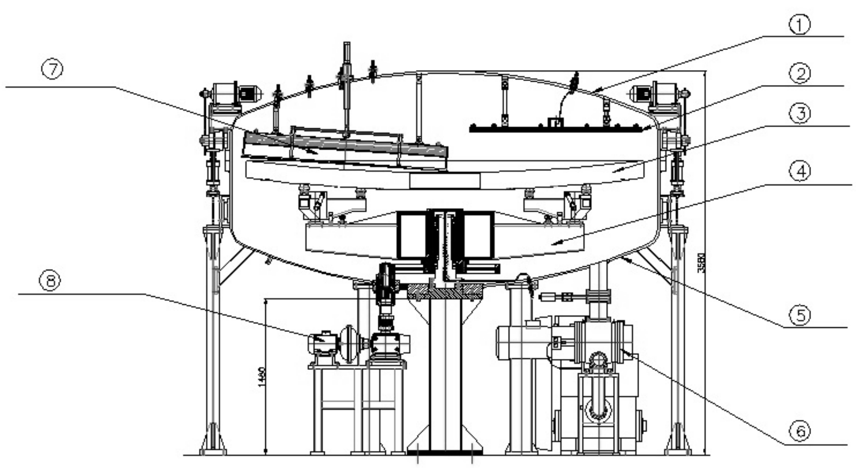

Figure 2. Main components of ARIES telescopic mirror coating unit.(1)Top chamber,(2)Glow discharge gadget,(3)Primary mirror,(4)Mirror support system,(5)Bottom chamber,(6)Roots-rotary combination ,(7)magnetron, shield ,shutter,(8)work holder rotary mechanism.

It has a custom built mechanism for opening and closing the chamber's top lid. During opening of the chamber, the top lid is lifted up by a pair of hydraulic cylinders, and then it is moved horizontally on the channels with wheels provided to the lid located on the railings, by means of a drive mechanism. The vacuum pumping systems consists of a combination of rough pumping system with (EDWARDS 412J) direct drive mechanical booster pump (EDWARDS EH 2600) and high vacuum pumping system consisting of two cryo-pumps (CVI TM 450) regenerated with rotary pump (EDWARDS E2M40).

Rotary work holder for 3.6m diameter mirror is designed to hold the large thin mirrors within the deflection threshold. The mirror stability is evaluated using finite element analysis. The work holder consists of a whiffletree structure comprising of a central hub attached to a thick hollow tube. This hub on its periphery is welded with three stainless steel arms 120^o apart. Each arm is provided with a three point kinematic support with soft pads on the top. The entire assembly is supported on thrust bearings and roller bearings enclosed in a bearing housing to take care of the total load of the mirror which is 4.5 tons. This hollow shaft will pass through a specially designed vacuum shaft seal using Viton lip seal for vacuum tightness during substrate rotation.

Figure 3. Rotatable Whiffle tree.

The drive mechanism for the entire assembly is achieved by means of reduction gear box with an AC motor and AC drive mechanism attached to the drive shaft through gear arrangement. The rotary mechanism is kept between 0-1 rpm. Sensors are used for sensing and counting of the work holder rotation, enabling precise timing of start and stop of deposition process. It helps in the starting and stopping of the work holder rotation at the same point. The whole work holder structure is designed and evaluated by finite element analysis method prior to manufacturing. The manufactured structure has proven the evaluation correct by its functionality and reliability.

The coating unit is capable of accommodating individual separate substrate holders for smaller mirrors of size 1.313m, 0.980m and 0.610m in diameter. These substrate holders were designed taking into consideration the radius of curvature of the mirrors. These substrate holders are located on the arms of the main rotary work holder. At any given point of time, one substrate can be used depending upon the mirror on which aluminum deposition is carried out.

The present system employs DC magnetron sputtering technology for depositing the aluminum film on the mirror. Water cooled rectangular Magnetron Source (HHV), with split shutters, is used to sputter aluminum target (99.999%) of size 180mm (W) x 2000mm (L) x 6mm (T). The magnetron is mounted on the inner side of the top lid with suitable supports and adjusting mechanisms to vary the distance and angle for downward sputtering of aluminum on to the telescope mirrors. A glow discharge gadget, powered with an HT power supply is provided inside the chamber for the ion bombardment cleaning of the mirror, prior to sputtering deposition.

A specially designed stainless steel mask (trim shield) is provided below the magnetron source to trim the deposition of the sputtered aluminum and to achieve a uniform thickness of aluminum on the mirror. The mask is custom designed so that the same mask can be used for the uniform deposition of mirrors of sizes 1.313m, 0.980m and 0.610m in diameter respectively. This attractive feature of the mask helps the user in avoiding the hustles of mask changing during the coating of each type of mirrors and also reduces the cost of designing and developing individual masks for each mirror, in-turn reducing the cost of the coating unit as a whole.

3. EXPERIMENTAL PROCEDURE

The system can be operated both in auto and manual mode. In auto mode the recipe for the whole process of pumping, glow discharge cleaning and deposition can be programmed. In order to optimize the deposition process, coating trials were conducted by fabricating a special dummy work holder (test platform) with specified radius of curvature, which exactly replicates the surface of the mirrors. The glass test coupons (50x50 mm, 1 mm thick) were then mounted onto the dummy work holder surface at intervals of 50 mm along the mirror radius. The position of the slides is recorded on the back of the slides, together with the coating run number. Once the sample loading is completed, the chamber is sealed and is pumped down to achieve the base vacuum level of 1 x 10^{-6}mbar.

The glow discharge cleaning of the mirror glass surface is done by introducing argon gas (99.999%) to the chamber and a process pressure of 1x 10^{-2}mbar is maintained by throttling. During the glow discharge cleaning process, mirror is rotated at a speed of 1rpm and the glow discharge is carried out at 3 kV, 500mA for 45 minutes. On the completion of the glow discharge cleaning process, the pumping is throttled to attain a process pressure of 1x 10^{-3}mbar. Then the magnetron is switched on and the aluminum target (99.99%) was pre sputtered with a DC power (Huttinger) of 7kW, until the target surface is clean. During pre-sputtering the shutters of the magnetron is closed in order to prevent any coating of the mirror surface. Once the pre-sputtering is completed the split shutter is opened and the coating is carried out for a predetermined time, after which the magnetron is switched off in such a way that a joint free film is deposited on the mirror. Once the coating is over the chamber is opened. The test coupons are unloaded and are taken for various measurements. The thickness of the test coupons are measured by stylus profiler (Veeco-Dektak 6M), the reflectance study is performed using spectrophotometer (Ocean Optics UV-VIS-NIR DH 2000) and adhesion test is carried out by scotch tape pull test.

4. RESULTS & DISCUSSION

Finite element (FE) analysis of the mirror was performed using the parameters of glass i.e. Young's modulus and density. Using this technique, maximum stress, maximum sag and points of minimal strain have been identified. Considering several parameters, the design has been finalized to a nine point load distribution mechanism as shown in figure 3.

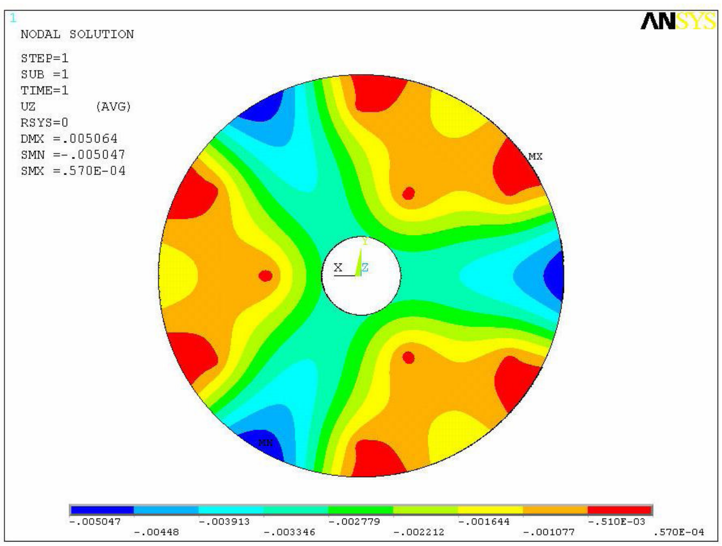

Figure 4. Displacement contours by FE analysis.

Figure 4 shows the displacement contours due to gravitational deformation of the 3.6m mirror with nine point support. The maximum sag of the glass is found to be only 0.005047 mm. The load distribution of the 3.6m mirror over the nine point contact is measured using load cell and the data is tabulated in table 1.

Table 1. Load distribution studies.

Load distribution study of the mirror using load cell	
Load cell position	load (kg)
A1	304.5
A2	304.9
A3	325.7
B1	305.4
B2	304.6
B3	323.3
C1	303.5
C2	303.1
C3	321.3

During the magnetron sputtering process the temperature of the substrate is found to increase to a maximum of 15^{o}C. For the optimized conditions, a typical aluminum sputter rate of 15Å/min is obtained. The deposited aluminum films deposited is found to be uniform and shows good adhesion. The film thickness of the sputtered aluminum is investigated using a stylus profiler by selectively removing coating from the test coupons. The optimization goal was obtain a film thickness of 1000 Å±50Å. For a given test coupon, thickness is measured at least three places, in order to confirm the accuracy. The thickness uniformity was calculated from standard deviation of the thickness measurements and a graph between thickness and radial distance is shown in figure 5 and fig 6.

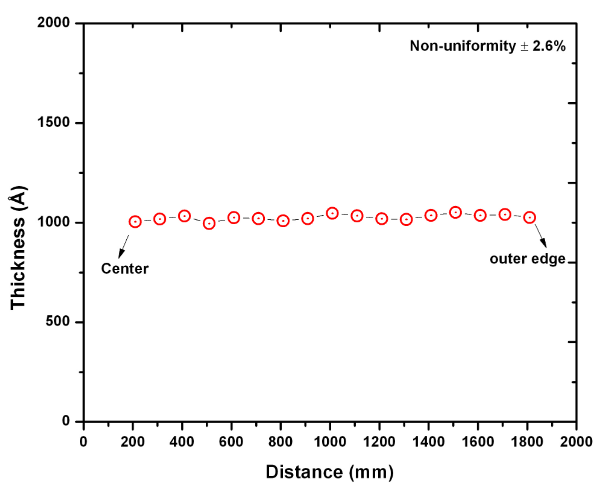

Figure 5. Thickness profiles of 3.6m mirror with a thickness uniformity of ±2.6%.

.

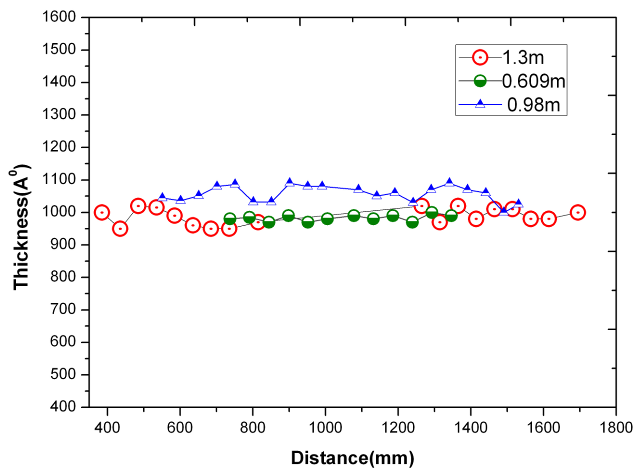

Figure 6. Thickness profiles of 1.3 m, 0.98m, 0.609m mirrors with thickness uniformities of ±2.5%, 2.36% & 0.97%.

The reflectance study of the test coupons are investigated using spectrophotometer and the reflectance measurement was measured relative to a STAN-SSH-NIST standard reference material (front surface protected aluminum mirror on fused silica substrate), whose reflectance was known. The spectrum is taken over the required wavelength region of 400-900nm. Test coupons from different positions of the same trial are measured for reflectance and the graphs are plotted and are shown in figure 7.

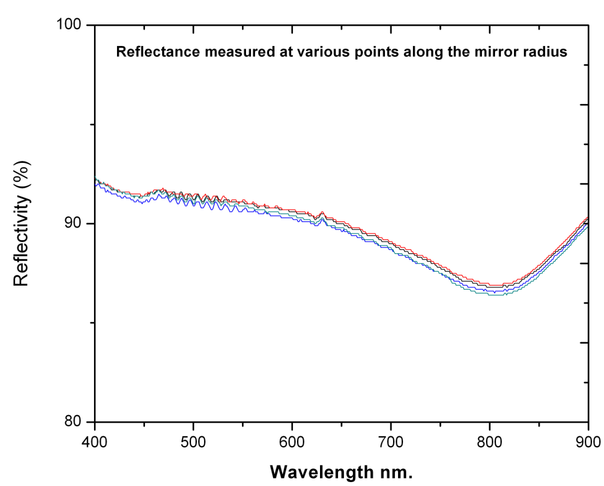

Figure 7. Reflectance measured along 3.6m mirror radius.

5. CONCLUSIONS

HHV has successfully designed and manufactured a fully automated and cost effective sputtering unit for the deposition of aluminum on large area astronomical telescope mirrors. The custom designed whiffletree arrangement is found to distribute the whole weight of the mirror over nine points with minimum deformation of the mirror. The aluminum coating on the mirror was optimized by investigating various power pressure combinations and optimizing magnetron position and the profile of the magnetron mask. This custom built mask has removed the complexity of using different masks for different mirrors, which in turn has enabled a uniform deposition thickness, (within ±3%) with good adhesion on all substrates. The reflectance values of the mirrors in the visible and NIR regions are found to be very close to the expected value.

REFERENCES

[1] David.A.Glocker., Ismuth shah.s.,[Handbook of thin film process technology.vol1& 2],Institute of physics (IoP)publishing,Bristol& Philadelphia(1995).

[2] Albrecht., Bodo.,W.D. (translator)., [The New Cosmos: An Introduction to Astronomy and Astrophysics], Springer, Berlin, New York: (2001).

[3] Kasturi.L.Chopra[Thin film phenomena], McGraw-Hill,New York(1969).

[4] Marcel Dekker., R. R., [Practical Design and Production of Optical Thin Films], Willey, New York, 294-298 (2002).

[5] http://www.eso.org/sci/publications/messenger/archive/no.97-sep99/messenger-no97-4-8.pdf.

.