N95-14081

THE REALUMINIZING OF THE 7-METER-DIAMETER SOLAR SIMULATOR COLLIMATING MIRROR

E. W. Noller
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA

BIOGRAPHY

E.W. Noller has been involved with space hardware design and the development of special space simulation techniques for flight projects at the Jet Propulsion Laboratory. He is a member of the original engineering team that designed the solar simulation system for the 7.62-m (25-ft) Space Simulator Facility. He has designed thermal vacuum simulator systems, beginning with Viking solar panels and continuing with the Magellan and TOPEX spacecraft solar-panel testing systems. He has researched vacuum deposition of thin and thick films on large composite reflectors, antenna elements, and metal optics. He is currently the cognizant mechanical engineer for the vector helium magnetometers on the Ulysses and Cassini spacecraft.

ABSTRACT

This paper describes the modification of a three-electron-beam (EB) gun system for vacuum depositing a highly reflective aluminum coating on a 7.01-m (23-ft) -diam nickel-plated aluminum collimating mirror. The mirror is part of the JPL 7.62-m space simulator that was recently modernized with a new high vacuum pumping system, solar lamp power supplies, solar optic lens system, and refurbished collimating mirror.

The 7.01-m 12,700-kg (14-ton) spherical collimating mirror was removed from this facility for replating with 381 μm (0.015 in.) of electroless nickel and polished to a specular finish for realuminizing. The space chamber served as the vacuum coating vessel for the realuminizing coating process. The mirror is the primary reflector for the solar simulation system and the aluminized reflective surface is its most critical performance element. The uniformity of thickness and high reflectivity of the coating in visible and near-ultraviolet (UV) light governs the accuracy of the beam for solar testing. The uniformity of the thin-film thickness also controls the durability of the mirror over time. The mirror was polished to a 64-percent reflectivity with a uniformity of 1.5 percent. The performance goal for the aluminizing was 89 percent with +/— 0.5-percent variation over the mirror.

KEY WORDS

Solar simulation; aluminizing; mirror.

INTRODUCTION

Aluminizing the 7.01-m-diam mirror with a 508-cm (200-in.) spherical radius was one of the major tasks in refurbishing the solar simulation system as part of modifications to the 7.62-m space simulator facility. These modifications are to be completed in this calendar year. Reconditioning and modifying the facility's mirror-coating equipment was part of the support activity required to complete the replating, reconfiguring, and polishing of the large mirror. The evaporation system, which had not been used for many years, needed reengineering and replacement of obsolete elements that were no longer reliable or serviceable. The goal for recoating the mirror was to improve control of the uniformity of reflectivity and the symmetry of aluminum thickness over the mirror's large area. The original system, developed in 1964, is part of the facility's support equipment. The mirror and simulator facility recently underwent a major modernization to the vacuum-pumping system and the solar simulation optical system. The 7.01-m-diam 12,700-kg spherical collimating mirror was electroless nickel plated and polished to a specular reflectance (Fig. 1).

The realuminizing process is one of the most critical elements in the performance and quality of the simulated solar environment. The reflective coating, in its uniformity of reflectivity in the visible and near UV, governs the accuracy of the beam for solar testing. The uniformity of the thin-film thickness controls the quality and durability of the mirror for

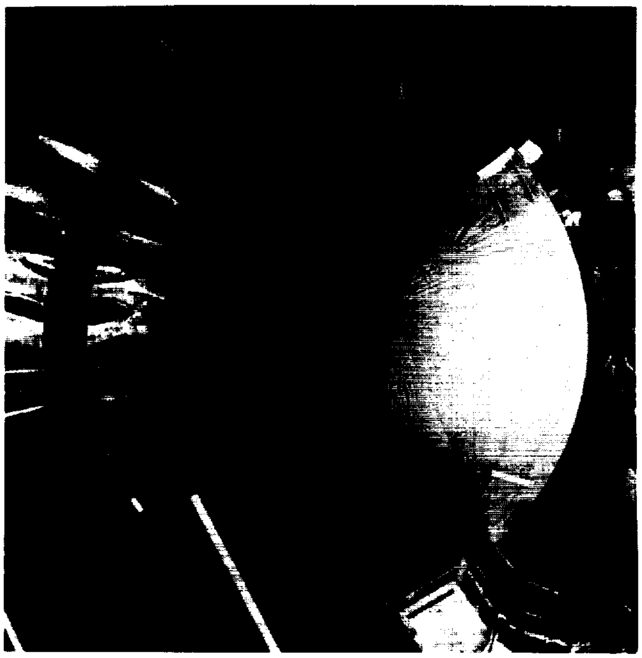

Fig. 1. 7-m mirror with cover bag.

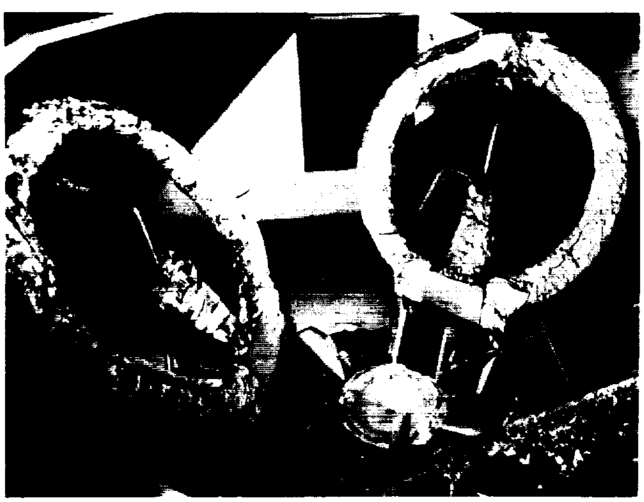

Fig. 2. EB gun source.

testing space hardware. Figure 2 shows the modifications to a three EB gun evaporation system used in the aluminizing process.

REQUIREMENTS FOR COLLIMATING MIRROR PERFORMANCE

The primary element in the solar simulation system is the collimating mirror, which relays the output of 37 lamps through two sets of lenses that are the integrating optics for collecting and projecting light onto the collimating mirror that then relays the light to the chamber testing area. The performance requirement is for a +/— 5-percent uniformity over the 5.63-m-diam solar beam test area. The mirror nickel surface was polished to a 64 percent reflectivity with a uniformity of 1.5 percent. To realize maximum reflectance (e.g., 90-percent reflectivity with 2.5 percent variation over the mirror diameter) from this high-quality surface, improvement in the control of the vapor source was needed. The operational cost savings in power consumption and Xeone lamp burn life and the high cost of recoating the mirror also drove the requirement for Optima coating, since it delivers a long usable service life in the testing environment.

SPACE SIMULATOR FACILITY CONFIGURATION FOR VACUUM-COATING OPERATION

The 25.9-m (85-ft)-high space simulation chamber has fully cryo-shrouded walls and floor, ten 121.9-cm (48-in.) cryo pumps with gate valves, and two turbo pumps. The 8.22-m (27-ft)-diam vacuum vessel has a test volume of 7.62-m (25 ft) diam inside the cryo shroud (Fig. 3). The mirror is located 24.3 m above the chamber floor in the horizontal position for aluminizing. The normal position for the mirror in the system is 7.5 deg off vertical. The mirror is supported from the chamber roof, and by three wiffel trees to 12 connections to the mirror rim. The mirror hangs face down and is leveled for optimum geometry for coating. The normal system location for the collimator is tilted 7.5 deg to relay the beam into the test volume. The aluminizing source is located at the center of a service work platform that is positioned 8.71 m (28.5 ft) below the mirror. The platform itself is located 9.14 m (30 ft) below the mirror and supported by cables inside the vacuum chamber during the aluminizing operation (Fig. 4). System control and operation is conducted from the cryo pump room, located half way between the mirror and source. Ports are clustered for utilities, viewing windows, and mechanical feed throughs for exposing the vapor source (Fig. 5). Power supplies are located nearby for the high-voltage bus supply to the guns. Transformers for the glow discharge system are also collocated (Fig. 6). All instrumentation and the control racks are on the platform surrounding the viewing port for the coating operation, along with

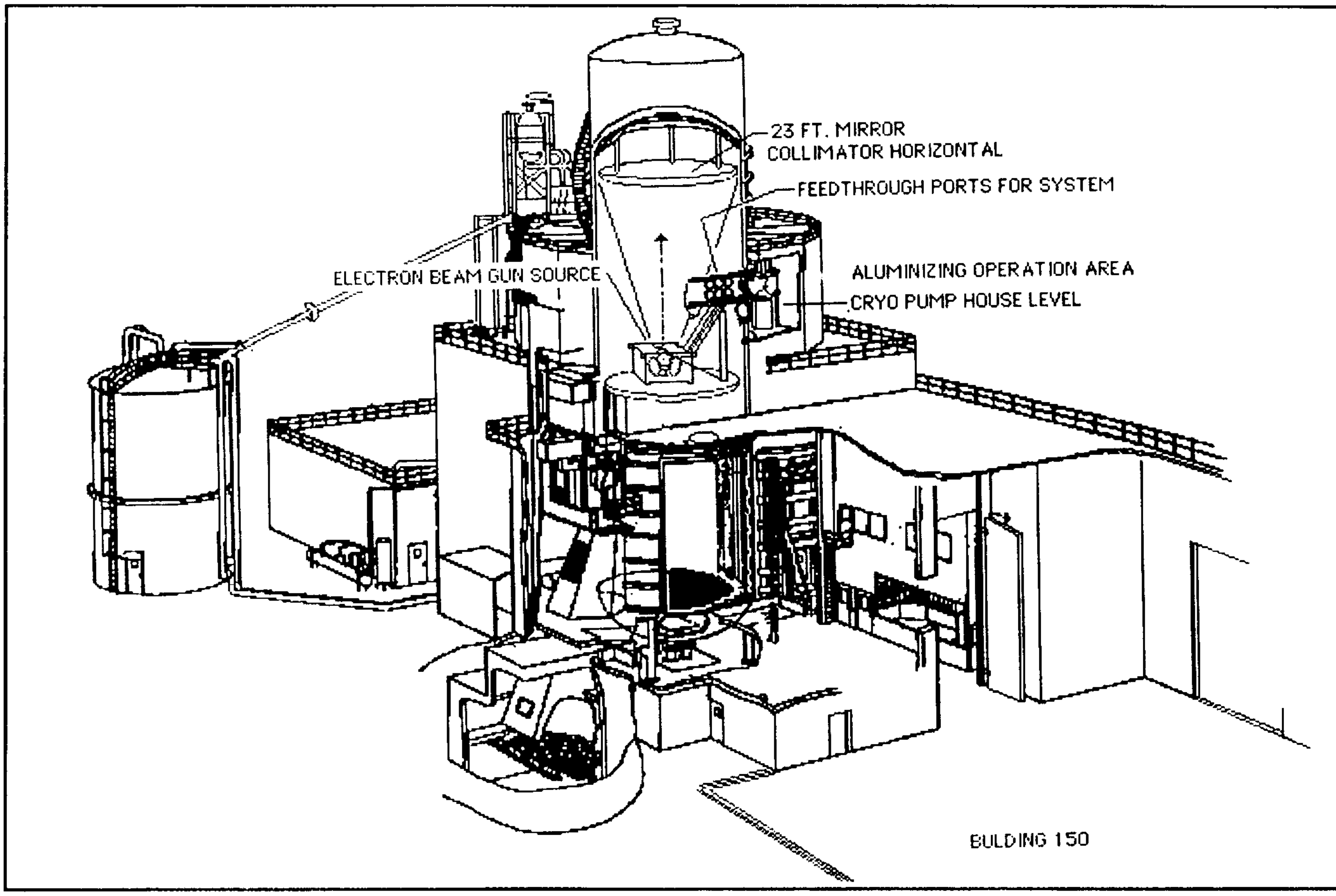

Fig. 3. View of the Space Simulator Facility.

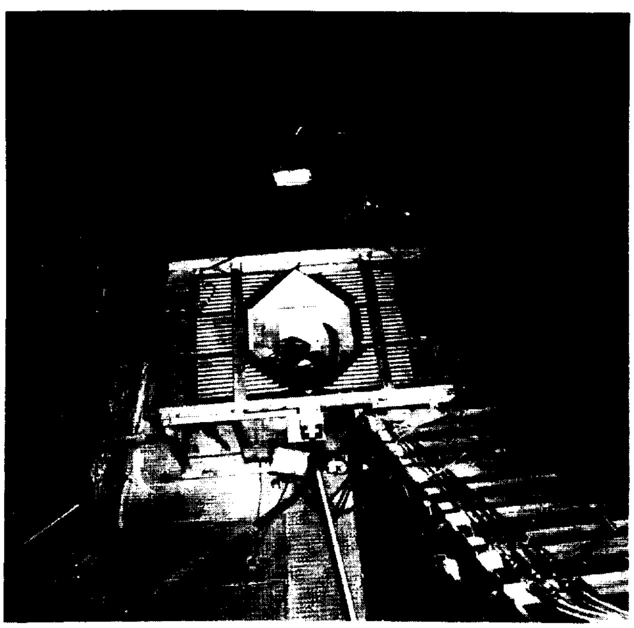

Fig. 4. Aluminizing equipment platform.

Fig. 5. Control center for aluminzing process.

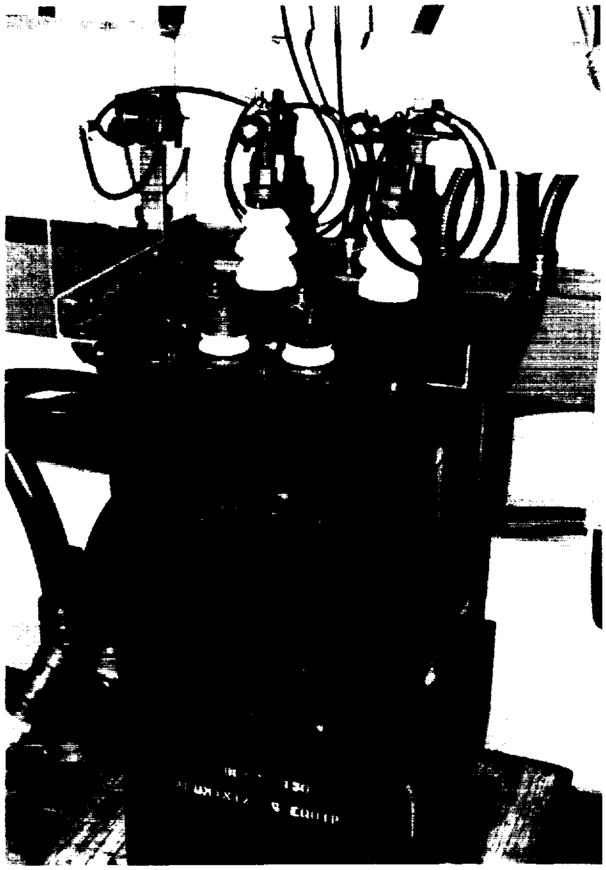

Fig. 6. Glow discharge transformer.

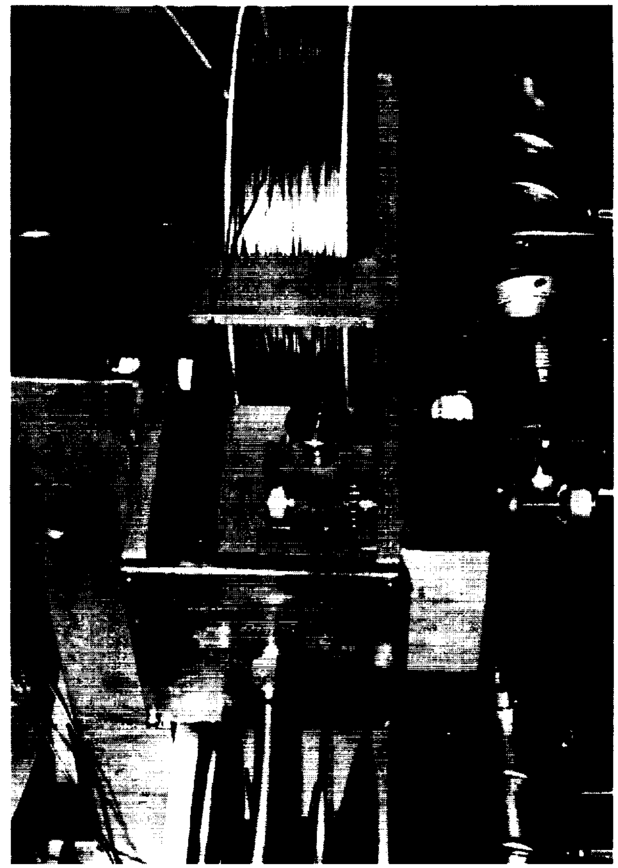

Fig. 7. Dual wire-feed assembly.

two telescopes and a television monitor. A vacuum-rated TV camera with a turning mirror looks through a port in the EB gun enclosure for close-up visual observation. Plasma cleaning is accomplished using a glow discharge source that consists of two concentric aluminum rings hanging 1.82 m (6 ft) below the mirror face supported by cables. The glow discharge was performed at 13.3 mPa (10^{-4} torr) at 10,000 volts (V) alternating current (ac) with partial pressure of argon gas for 20 minutes. The chamber cryo wall shrouds are masked by hanging mylar panels to keep the walls free from coating. The EB gun vapor source is located in a box-like housing with a horizontal guillotine-style shuttered opening that opens mechanically. The source is exposed to the mirror through the symmetrically wedged aperture formed by the open shutter halves. Three 270-deg guns are symmetrically positioned around a 14.6-cm (5.75 in.)-diam crucible supported on a water-cooled hearth. Two aluminum-wire-feed mechanisms adjacent to the crucible replenish the aluminum (Fig. 7). Five quartz-crystal-thickness monitors are located around the edge and a sixth is at the center of the mirror.

ELECTRON-BEAM GUN SYSTEM MODIFICATION

The EB gun system was developed in the early years of the space program for aluminizing the collimating mirror. The mechanics for steering the electron beams in the crucible were primitive and incapable of producing controlled beam movement at the high sweep rates required to affect vapor distribution. The primary change to the system was the use of a three-phase frequency generator with adequate power to drive the gun's primary focus coils above 10 Hz. The three-phase Helmholtz sweep coils are located at 30-deg off-vertical on each gun axis and are primary in keeping the beams from crossing over each other, which could cause superheated eruptions in the molten aluminum. The three-phaseinduced fields are used to move the beam from right to left along the axis of each electron gun. High-temperature thermocouples that sense cruci-ble temperature during evaporation were added to better monitor the thermal inertia in the molten aluminum during the aluminizing process. The experimental coating cycles that were made showed a direct correlation between beam power, aluminum level in the crucible, and evaporation rates. To supply adequate aluminum to the crucible for high-evaporation rates, a dual aluminum wire-feed system was added. To calibrate the system, five crystal-thickness monitors were used around the periphery of the mirror and one at the center during pratice coating runs.

EXPERIMENTAL DETAILS

Secondary electromagnetic steering coils are used to control the energy exchange between the surface of the molten pool of aluminum and the thermal energy in the beam. The blooming or defocusing beam enlarges the area of the beam image for heating the beam evaporation and is also used to counter wave action that distorts distribution to the mirror. The higher the power level in the gun, the more the evaporation rate increases ionization coupling and the better support for a secondary distribution source as a sole source distribution to the mirror.

A number of beam patterns were evaluated to sweep and raster the beam over the melt. The controlled beam-sweep system superimposed the two sweep signals to interdigitate the magnetic fields within the crucible area. The gun focus coil was moved in and out to preset limits at 10 Hz, and lateral Helmholtz sweep coils were set to 60 cycles at 3-phase 75 V ac.

The object of pattern change was to identify the beam excursion that gave the best symmetrical distribution pattern to the aluminum coating. The mechanism for uniformity improvement is thought to be a higher vaporization rate to increase the ionization coupling and form a new virtual source of distribution and thus help to obscure the beam image at the mirror surface. The unusually long path of up to 27.4 m magnifies the images of the source in the aluminized surface. Attempts have been made to image the source at the center and edges of the mirror with a pin-hole camera using plated glass.

The goal of generating a point source effect by patterning the beams over the crucible of molten aluminum was achieved by combining the sweep rates and patterns of the two magnetic coil systems. The results of changing the magnetic power in the two fields was observed in real time in the sensor at the center and in the sensors spaced symmetrically around the edge. The magnetic steering effect on source distribution was clearly observed, but when the beam power rate was raised significantly above 30 kW, it caused the beam to suppress the molten aluminum surface, resulting in waves on the surface with higher thickness ratios of 5:1 between the center and edge of the mirror coating and a nonsymmetrical coating thickness around the mirror edges. Deposition rates and coating thicknesses were displayed on the crystal monitors for finetuning the system. The best uniformity and thickness ratio produced from the practice testing was a 2:1 ratio (Fig. 8). The inverse square law and cosine-law distribution for open-crucible sources are generally reflected in the distribution pattern, but are difficult to calculate due to the dynamics of the beam-image size over the molten aluminum.

A procedure was then established from the test runs that produced a detailed set of conditions and control values for specific thermal levels, power/frequency settings, and subjective visual observations to position the beams properly for the coating operation. The dynamics and scale of a coating operation in such a large chamber produce an almost-unlimited number of variables that can influence the process. The protective mylar panels that cover the wall shrouds carry large surface deposits of aluminum from the coating operation and trap surface water. One of many variables to consider is thermal radiation from the evaporation source when the shutter exposes the hot source and causes the subsequent overcoating with fresh aluminum.

We used an aluminizing evaporation rate of 0.5 nm/s that was much slower than the normal standard of 1.0 nm/s for highly reflective coating. However, this slow deposition rate was offset by our ability to control surface water in the chamber by cooling the wall shrouds with liquid nitrogen and by the large number of cryo pumps. This water vapor control was crucial in achieving high-quality reflectivity and proper adhesion of the aluminum. Details of the final aluminizing operation are as follows:

MIRROR CLEANING AND PREPARATION

Final preparation of the mirror surface for aluminizing was accomplished as part of the termination process in the final polishing operation by a Tinsley Laboratory optician. The cleaning process consisted of washing the mirror surface with deionized filtered water and detergent and blowing it with dry nitrogen gas to remove all droplets of moisture. The mirror was fitted with a stainless steel wire grid supporting a cover bag that provided a nitrogen gas purge to protect the nickel surface for coating. This provided a water-mark-free surface without streaks.

CONCLUSION

Although this research represents preparation and qualifying tests for an adequate procedure for coating the mirror, a number of additional equipment modifications and variables in the process remain to be explored for a better thin-film coating. These variables can only be explored in the full scale dynamics of the vacuum facility. However, the facility's cost of operation precludes much experimentation beyond the specific reflectivity requirement for the collimator. Durability of the present coating should be usable for many years to come.

ACKNOWLEDGMENTS

The author would like to acknowledge the expertise and years of distinguished experience in large metal optics that was brought to the mirror task by Peter Taylor and Thomas Brooks, consultants to the Tinsley Laboratory. Their teamwork effort made the mirror preparation for coating a success.

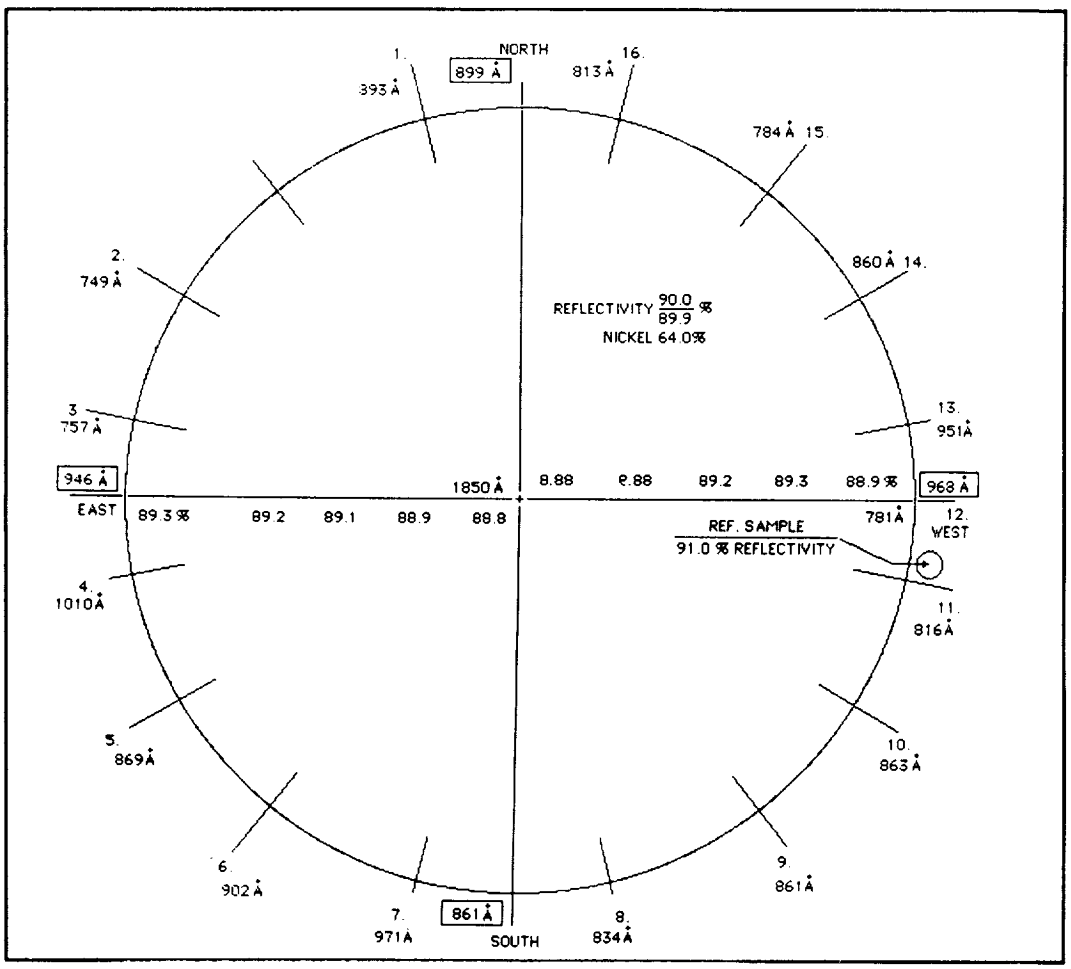

Fig. 8. Thickness and reflectivity map.

Table 1. Final aluminizing performance data.

Item	Performance Data
CHAMBER PRESSURE	
- At start of process	0.2 mPa (1.6 x 10^{-6} torr)
- End of run	1.2 mPa (9 x 10^{-6} torr)
PUMPING CAPACITY	
- 10 cryo pumps	@ 45,000 liters (l)/s = 450,000 l/s
- 2 turbo pumps	@ 2,200 = 4,400 l/s
CHAMBER WALL SHROUDS	120 °C
DEPOSITION	
- Rate	0.5 nm/s
- Total time	2 min, 59 s
POWER	
- Per EB gun	11 kW
- Total	33 kW
CRUCIBLE TEMPERATURE	1625 ° C
REFLECTIVITY	
- Test sample (Fig. 8)	91 percent
- Nickel test plate (15.2-cm diam)	64 percent
- Mirror at edges in visible light	90/89.98 percent (12 hrs at atmosphere)
- Mirror edge-to-center average	88.8/89.3 percent (post conditioning)
- Reflectivity map (Fig. 8)	

FURTHER ACKNOWLEDGMENT

The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.