2. Thermal Radiators for Lunar Exploration Missions

Two general types of thermal radiators are being considered for lunar missions: coated metallic surfaces and Second Surface Mirrors. Metallic surfaces are coated with a specially formulated white paint that withstands the space environment and adheres well to aluminium, the most common metal used in space hardware. AZ-93 White Thermal Control Paint, developed for the space program, is an electrically conductive inorganic coating that offers thermal control for spacecraft. It is currently in use on satellite surfaces (Fig 1). This paint withstands exposure to atomic oxygen, charged particle radiation, and vacuum ultraviolet radiation form 118 nm to 170 nm while reflecting 84 to 85% of the incident solar radiation and emitting 89-93% of the internal heat generated inside the spacecraft.

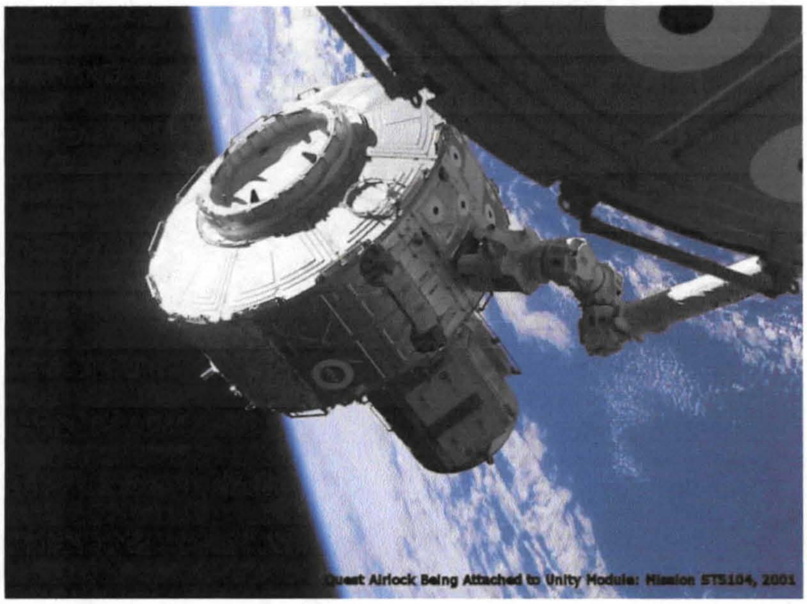

Figure 1. AZ-93 White Thermal Control Paint on the Quest Airlock attached to Utility Module on the International Space Station. [Courtesy NASA]

Second Surface Mirrors are transparent polymer films back coated with a thin layer of silver or aluminium. One such polymer is fluoroethylene polypropylene (FEP), which withstands exposure to atomic oxygen and vacuum UV radiation. Second Surface Mirrors have been extensively used on spacecraft (Fig. 2). This type of thermal radiator is used to provide thermal protection to complex spacecraft surfaces with many small or intricate components that are difficult to paint.

The thermal characteristics of the two types of thermal radiators will be clearly compromised if they are even partially covered with lunar dust. Many lunar exploration activities will likely disturb surface dust, propelling dust particles toward equipment and craft protected with thermal radiators. Implementation of the EDS for thermal radiators will mitigate this problem.

3. The Electrodynamic Dust Shield for Thermal Radiators

The Electrodynamic Dust Shield, a system based on the generation of changing non-uniform electric fields able to accelerate charged dust particles has been described in some detail elsewhere [1-4]. The EDS is a dielectric coating with a thin electrode grid running a multiphase AC signal in the milliwatt range which generate a non uniform traveling electric field. Electrostatically charged dust particles, such as those on the lunar surface, are carried along by the field under the action of the dielectrophoretic force set up by this non-uniform field. At high vacuum, simulating the lunar environment, dust removal takes place in less than one second.

Figure 2. The upper section of the Fermi Gamma Ray Space Telescope is wrapped in a Second Surface Mirror for thermal control. The telescope was launched in 2008. [Courtesy NASA]

The EDS coating can be applied to metallic and electrically insulating surfaces. For thermal radiators with painted metallic surfaces, a dielectric layer of 130 μm is added to separate the electrode layer from the metal surface of the radiator, as shown in Fig. 3 (top). The EDS coating for second surface mirrors adds a silver or aluminum electrode grid with an FEP layer to the silver/FEP or aluminum/FEP (Fig. 3 (bottom)).

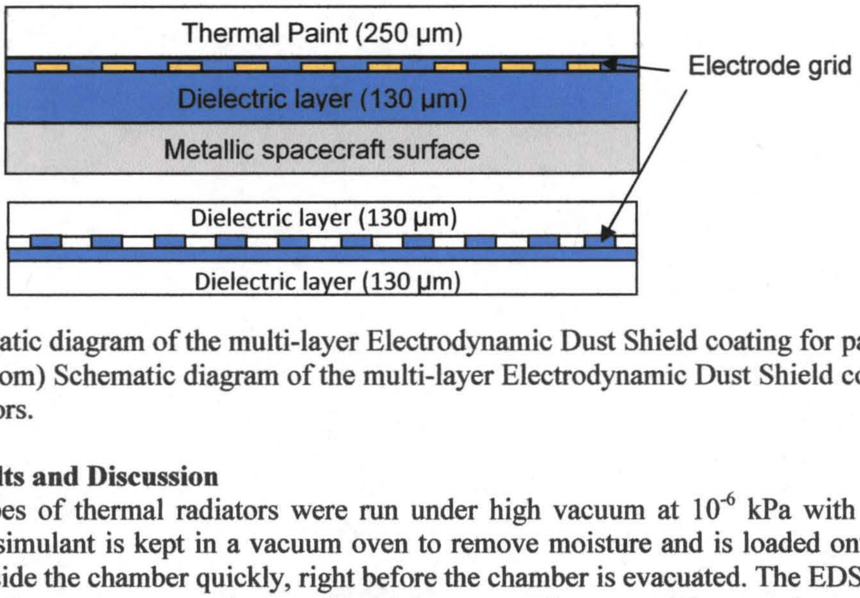

Figure 3. (Top). Schematic diagram of the multi-layer Electrodynamic Dust Shield coating for painted metallic radiators. (Bottom) Schematic diagram of the multi-layer Electrodynamic Dust Shield coating for second surface mirrors.

4. Experimental Results and Discussion

EDS units for both types of thermal radiators were run under high vacuum at 10^{-6} kPa with lunar simulant dust [5]. The simulant is kept in a vacuum oven to remove moisture and is loaded onto the dust delivery system inside the chamber quickly, right before the chamber is evacuated. The EDS units and the loaded dust delivery system are kept under high vacuum for several hours prior to each experiment. The dust delivery mechanism sprinkles dust on the EDS units under high vacuum conditions.

To determine the effectiveness of the dust removal, reflectance measurements for all three EDS radiators were performed with a Jasco V670 UV-Vis/NIR spectrometer Spectral data was collected for the EDS radiators before dust deposition (red lines) and after dust removal and activation of the EDS systems for dust removal. (Fig. 4). The percent difference between the clean EDS radiators and the post-run EDS radiators is very small, indicating that the cleaning efficiency is very high. The unusually high increase in the reflectance of the painted EDS radiator over the post-run EDS, which occurs at 196 nm (Fig. 4 (Bottom, right)) is suspected to be an artifact of the measurement. Additional measurements planned should clarify this result.

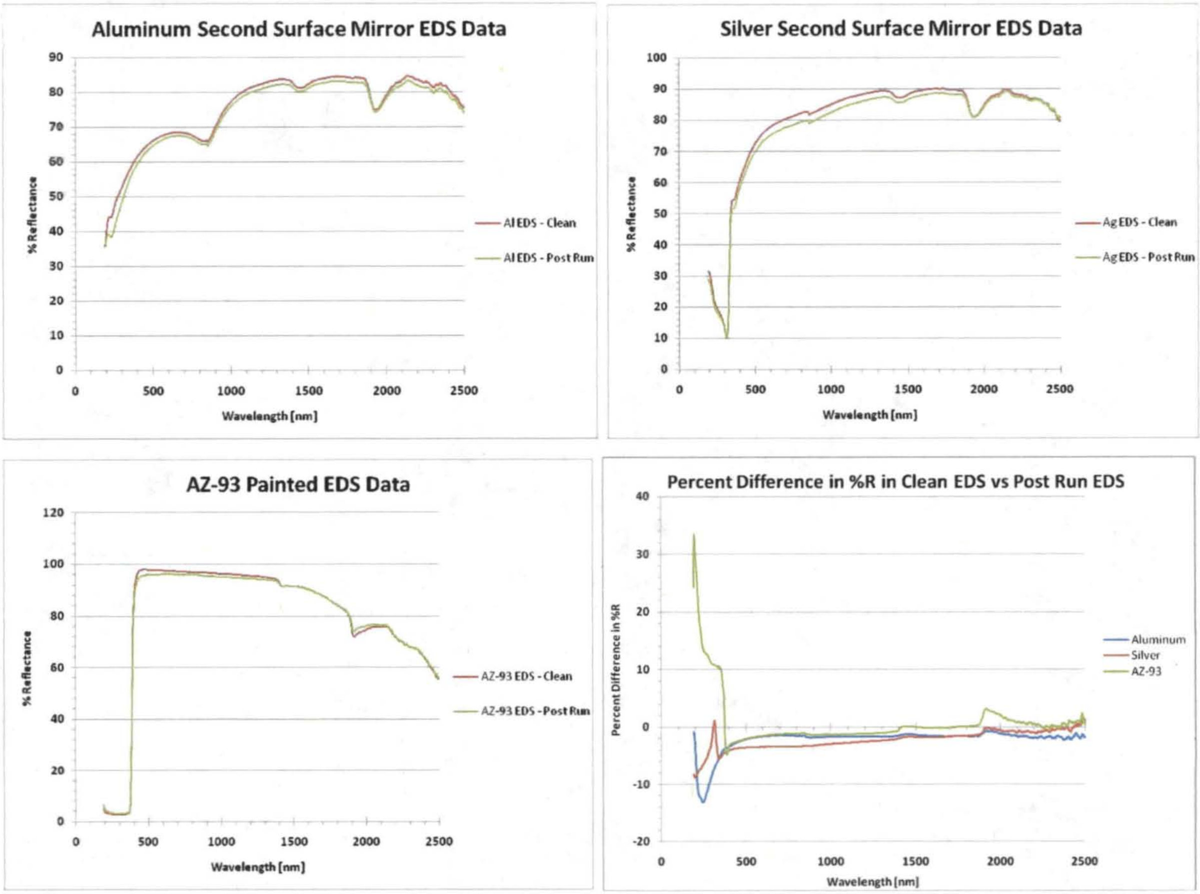

Figure 4. (Top). Reflectance spectra from 190 nm to 2500 nm for EDS on second surface mirrors (aluminum/FEP and silver/FEP) clean (red line) and after dust loading and removal (green line). (Bottom, Left) Reflectance spectra for AZ93 painted EDS radiators clean (red line) and after dust removal (green line). (Bottom, Right) Percent difference for each one of the three EDS radiators, blue line for Al/FEP, red for Ag/FEP, and green for the AZ-93 painted aluminum. The large peak on the AZ-93 at 196 nm appears to be an artifact of the measurement.

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