Electrodynamic Dust Shield for Space Applications

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Abstract

Dust mitigation technology has been highlighted by NASA and the International Space Exploration Coordination Group (ISECG) as a Global Exploration Roadmap (GER) critical technology need in order to reduce life cycle cost and risk, and increase the probability of mission success. The Electrostatics and Surface Physics Lab in Swamp Works at the Kennedy Space Center has developed an Electrodynamic Dust Shield (EDS) to remove dust from multiple surfaces, including glass shields and thermal radiators. Further development is underway to improve the operation and reliability of the EDS as well as to perform material and component testing outside of the International Space Station (ISS) on the Materials on International Space Station Experiment (MISSE). This experiment is designed to verify that the EDS can withstand the harsh environment of space and will look to closely replicate the solar environment experienced on the Moon.

1 Introduction

During manned Apollo missions, dust caused issues with both equipment and crew. Contamination of equipment caused problems with incorrect instrument readings and increased temperatures due to masking of thermal radiators. The astronauts were directly affected by dust that covered space suits, obscured face shields and later propagated to the cabin and into the crew's eyes and lungs. Robotic missions on Mars were affected when solar panels were obscured by dust thereby reducing the effectiveness of the solar panels.

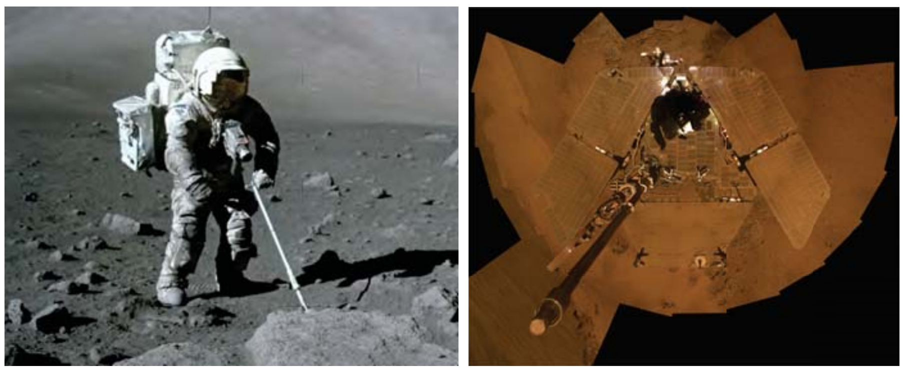

Figure 1: Dust issues on the Moon and Mars

1.1 The Electrodynamic Dust Shield

One of the primary technologies developed to alleviate such dust issues makes use of varying electric fields and is based on the electric curtain concept developed at NASA in 1967 by Tatoman et. al. and developed further by Masuda at the University of Tokyo in the 1970's. A dielectric particle placed in an electric field becomes electrically polarized as a result of partial charge separation, which leads to an induced dipole moment. The Electrodynamic Dust Shield (EDS) takes advantage of this induced dipole, by applying a non-uniform electric field. In addition to polarizing the particles, the non-uniform field generates a dielectrophoretic (DEP) force which moves the particles. This field is generated by applying a series of varying high voltage signals on a set of electrodes embedded in a high dielectric strength material.

Originally, acid etching was used to create the electrode pattern on a substrate. This method was used to create two types of panels which included indium tin oxide (ITO) on glass and copper on polyimide film. The ITO electrode pattern on glass was coated with a fluorinated ethylene propylene (FEP) laminate to provide a top layer with a high dielectric strength. This prevented the electrodes from breakdown while still maintaining a large DEP force to remove the dust. The ITO on glass was created for use on face masks, lens covers and solar panels.

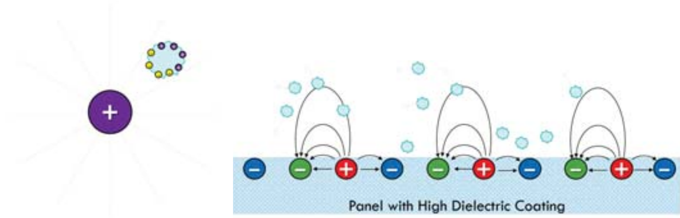

Figure 2: Dielectrophoresis used in particle removal

The second panel, made of copper on polyimide film, was coated with a top layer of polyimide which also provided a high dielectric strength coating. This was painted with a white space-rated thermal paint. The painted copper on polyimide film panel was created for use as a thermal radiator on spacecraft and equipment surfaces. Both processes produced panels that were very effective at clearing a range of dust particles, from 5 to 300 microns.

The panels were tested with a multitude of soil types in both air and vacuum. Tests were performed with a Mars simulant, JSC Mars-1 and Apollo 16 lunar samples in simulated environments. The JSC Mars-1 experiments were performed in an atmosphere composed of 95.5% carbon dioxide, 2.7% nitrogen, 1.6% argon, 0.13% oxygen, and 0.07% carbon monoxide at a pressure of 0.9 kPa. These conditions reproduced a pressure and atmosphere similar to the Martian environment. The Apollo 16 lunar sample experiments were performed at a vacuum of 1×10^{-6} kPa on a series of reduced gravity flights at one-sixth g to approximate the pressure and gravity of the lunar environment. The Apollo lunar samples were cleared from the glass panel with 97% efficiency. (Calle, Buhler, Johansen, Hogue, & Snyder, 2011)

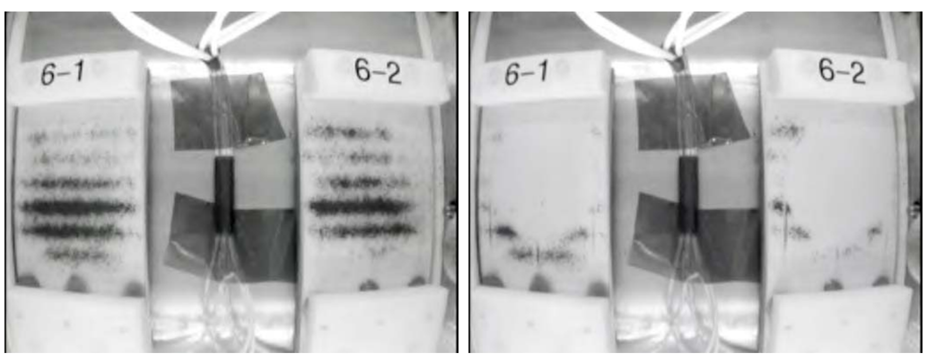

Figure 3: Apollo reduced gravity flight: Before and After

Testing was also performed to determine the effect of the coating on the efficiency of solar panels. The figure shows the voltage readings before, during and after dust removal. The voltage returns to 90% within 2 minutes of EDS is activation and gradually increases with time.

While this technology cleared dust effectively, the construction of the panels was time consuming, manually intensive and resulted in uneven electrode patterns

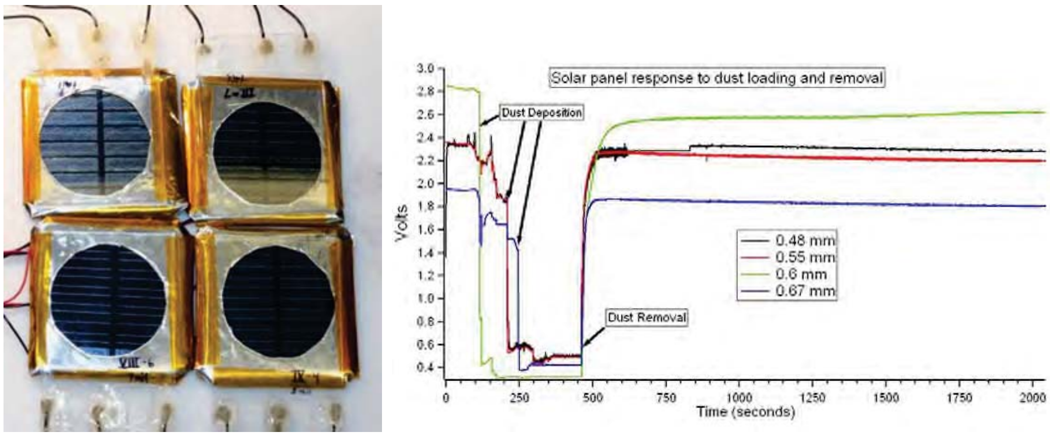

Figure 4: Solar panel performance with EDS

with high a rate of failure, typically >90%. In addition, the FEP layer that was used was not space-rated and was susceptible to scratching.

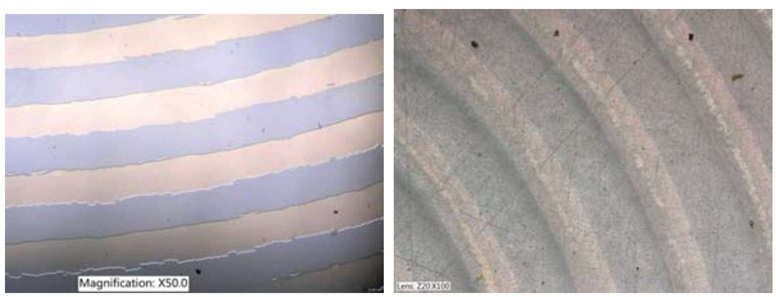

Figure 5: Issues from acid etch and FEP coating

1.1.1 Process Improvements

To improve the panels, the manual process was changed to a photo-lithography method. This produced panels more quickly, with much fewer defects in a shorter period of time (figure 6).

This has also provided an increase in the effective size of the panels that can be produced, for both ITO on glass and copper on polyimide film (figure 7).

In addition, the FEP layer was replaced with an anti-reflective coating to improve the performance for use in camera lenses and solar panels. The reflectance was reduced from 8% to approximately 1% over the visible spectrum (400 to 700 nm). The coating has been tested with an input signal amplitude of 2000V in air without breakdown. The coatings are also planned to undergo cycling in vacuum testing and thermal testing to determine if they can be rated for use in space applications (figure 8).

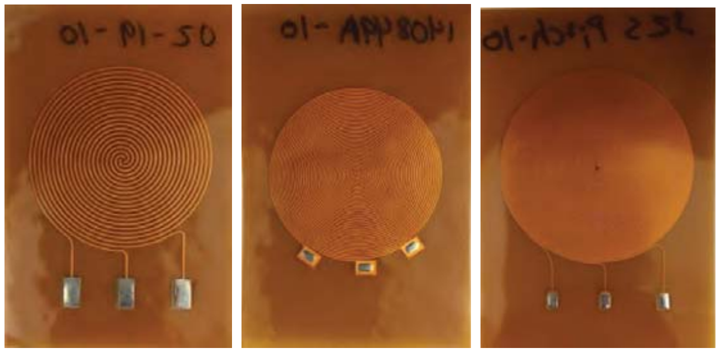

Figure 6: Photo-lithography method for copper on polyimide film

Figure 7: Range of sizes available with photo-lithography

Figure 8: Anti-reflective coating over ITO (left)

The increase in the precision of panel electrodes has led to further investigation into the effects of an increased electrode density. For a homogeneous sphere, the dielectrophoretic force is:

$$\left\langle \vec{F}_{\mathrm{DEP}} \right\rangle = 2\pi\varepsilon_{\mathrm{m}} R^3 \mathrm{Re}\left[\underline{K}(\omega)\right] \nabla |E|^2 \tag{1}$$

where ε_{m} is the dielectric permittivity of the medium, R is the particle diameter, K is the Claussius-Mossotti function, ω is the angular frequency, and $\nabla \mathrm{E}$ is the electric field gradient. From this, we see that the force is proportional to the square of the voltage and the inverse cube of the distance between the electrodes since $\nabla|E|^2 = 2 * E\nabla|E|$, $E \propto Vd^{-1}$ and $\nabla|E| \propto Vd^{-2}$.

Due to this relation, decreasing the distance between the electrodes should allow the voltage to be reduced while maintaining or increasing the DEP. However, this change in electrode spacing also affects the capacitive coupling between the electrodes. This coupling affects not only the panel operation, but the system driving the panels as well. The characteristics of the system must change with each modification in panel geometry, conductor and dielectric to optimize the DEP.

Figure 9: Photo-lithography method used in copper on polyimide film panels of increasing electrode densities

In order to test each panel effectively, a tunable power supply was developed. The supply is able to adjust many different parameters including the waveform frequency, rise time, and voltage as well as the number of phases (1, 2 or 3 phases). This allows many different types of design parameters to be tested to optimize the output for a particular panel configuration. Once parameters have been determined, a smaller, specific-use power supply can be manufactured for a particular NASA application.

Figure 10: Tunable EDS power supply

2 Conclusions

2.1 International Space Station

In an effort to raise the Technology Readiness Level (TRL) of the technology for space applications, our team plans to deploy the EDS external to the ISS on a future Materials International Space Station Experiment (MISSE). "MISSE is a series of external exchangeable test beds for studying the durability of materials...for the effects of atomic oxygen, vacuum, solar radiation, micrometeorites, direct sunlight, and extremes of heat and cold." The plan is to direct the EDS as an active experiment in the wake (aft) position. This will allow the EDS panels, materials and electronics to experience the effects of space without atomic oxygen which is present in other ISS orientations. This will most closely approximate the the lunar environment.

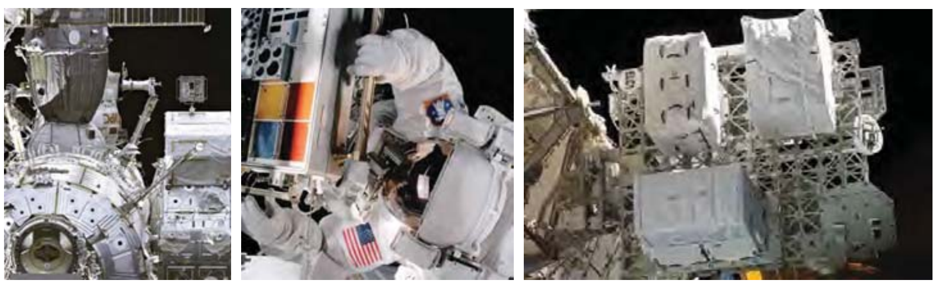

Figure 11: Locations of MISSE Platform

Our team is also pursuing other flight opportunities for lunar testing with Google Lunar X-Prize (GLXP) competitors. The current mission concept would fly the EDS on the footpad of a lunar vehicle. To determine the effectiveness of the EDS system, image analysis will be performed on the footpad before, during and after EDS activation. If successful in these test flights, the Technology Readiness Level (TRL) of the EDS will be raised to a sufficient level to be used in the protection of mission equipment for future NASA missions to the moon, asteroids, and Mars.

References

Calle, C., Buhler, C., Johansen, M., Hogue, M., & Snyder, S. (2011). Active dust control and mitigation technology for lunar and martian exploration. *Acta Astronautica*, *69*(11), 1082–1088.