Experiments of Dust Mitigation for Lunar Surface Exploration

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Motivation:

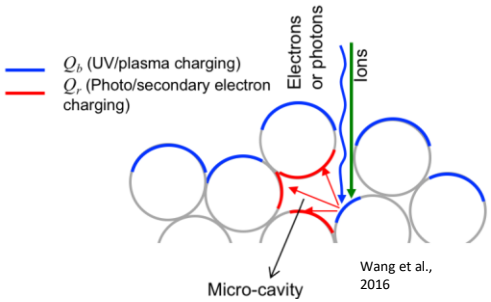
The surface of the Moon is covered in a layer of fine dust particles known as regolith. These dust particles tend to stick to surfaces such as spacesuits, optical lenses, and machinery, which causes a series of problems including:

- Damages to spacesuits due to the jagged shape of dust particles.
- Reduced power output of solar arrays due to dust coating the mirrors.
- Reduced thermal radiation efficiency of lunar landers and other equipment on account of dust covering thermal blankets.
- Failure of mechanical equipment due to dust clogging joints and seals.
- Respiratory health concerns for astronauts that could inhale any dust that is brought into living quarters.

We investigate using an electrostatic dust release mechanism as a means to efficiently shed dust off the surface of equipment to mitigate dust hazards to space exploration on the lunar surface.

Theory:

Patched Charge Model



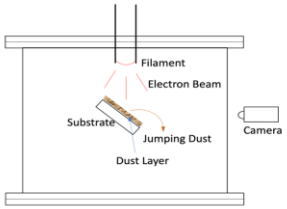
Wang et al., 2016

- The Patched Charge Model was developed to explain electrostatic dust lofting on the surface of the Moon and other airless bodies due to exposure to solar wind plasma and UV radiation.
- "Micro-cavities" absorb secondary electrons or photoelectrons emitted from neighboring particles, causing negative charges to build up on the surrounding dust particles.
- These negative charges can be substantially large due to the large electric field across the micron-scale distance.
- The repulsion between these negatively charged dust particles can be therefore large enough for the dust particles to be ejected off the surface.

$$Q \approx -0.5C\left(\frac{\eta T_{ee}}{e}\right),$$

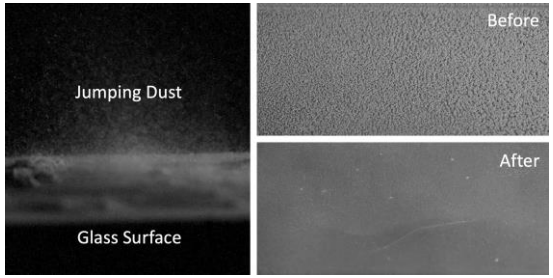
- Here, we assumed the size of microcavities is approximately the dust radius a. $C = 4\pi\varepsilon_0 a$ is the capacitance of a dust particle, η is an empirical factor between 4 and 8, and T_{ee} is the emitted electron temperature in eV. $\eta T_{ee}/e$ is the surface potential of the dust particle with respect to the ambient plasma, which is determined by the emitted-electron energy in the tail of the energy distribution, ηT_{ee}.

Method:

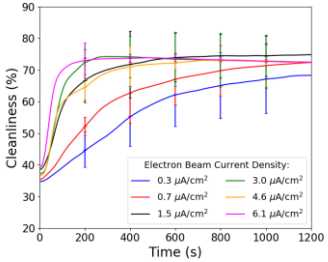


- Experiments are performed in a cylindrical vacuum chamber with a 50 cm diameter and height of 28 cm.
- JSC-A lunar simulant (<25μm diameter, $\rho \sim 2.9\text{x}10^3\ kg/m^3$) is sifted onto a flat sample of either glass or spacesuit material.
- Sample is tilted 45° relative to the filament.
- 80-230 eV electron beam is emitted from a hot filament with a negative bias.
- Chamber is filled with a background argon plasma at a pressure of $\sim 10^{-4}$ Torr.
- Tests are performed to investigate the effects of varying the electron beam energy, the beam current, the dust layer thickness and the surface sample.

Results:

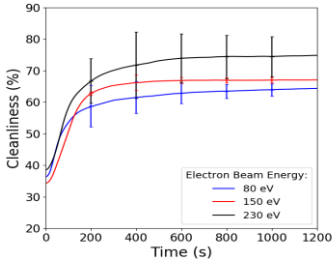


Beam Current Density:



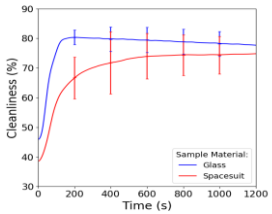
- All trials were done using a 230 eV beam energy.
- The data indicates that for beam current densities of 1.5 $\mu A/cm^2$ and above the sample reaches a similar cleanliness in the similar amount of time.

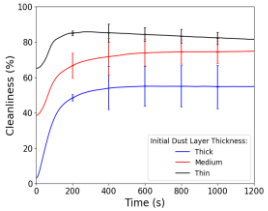
Electron Beam Energy:



- Beam energy tests were run with a beam current density of 1.5 $\mu A/cm^2$.
- These tests were done in order to quantify the effect of the electron beam energy on the level of cleanliness that can be achieved in a given time period.
- The data from these experiments shows that the beam energy of 230 eV achieves the highest level of cleanliness.

Surface Material & Initial Dust Layer Thickness:





- The surface comparison and thickness comparison tests were run with an electron beam energy of 230 eV and a current density of 1.5 $\mu A/cm^2$.
- The data shows that this method of dust mitigation is effective for both spacesuit material and glass.
- The initial dust layer thickness tests were all performed with the dust sifted onto a sample of spacesuit material.
- The test results show that the maximum cleanliness tends to decrease as the initial dust layer thickness increases.

Summary:

We have shown that the electrostatic dust release mechanism utilizing an electron beam demonstrated a new solution for lunar dust mitigation. Based on our observations the most effective combination of beam energy and current density is approximately 230 eV and 1.5-3 $\mu A/cm^2$. In addition to this, this method should be effective for cleaning a variety of materials.

Future Experiments:

Future work will be focused on removal of the last layer of dust particles to further improve the cleanliness.

References:

Wang, X., J. Schwan, H.-W. Hsu, E. Grün, and M. Horányi (2016), Dust charging and transport on airless planetary bodies, Geophys. Res. Lett., 43, 6103–6110.