Lunar Dust Adhesion Testing for Evaluation of Passive Adhesion-Mitigating Polymer Films

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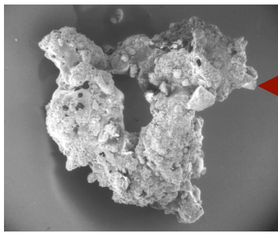
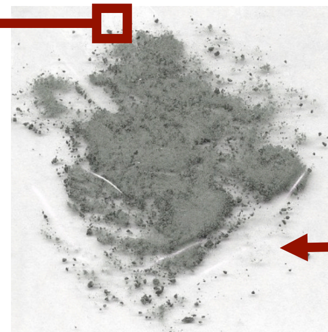
Outline

- Lunar dust adhesion and passive mitigation
- Particulate adhesion testing chamber
- Electric field effects on adhesion

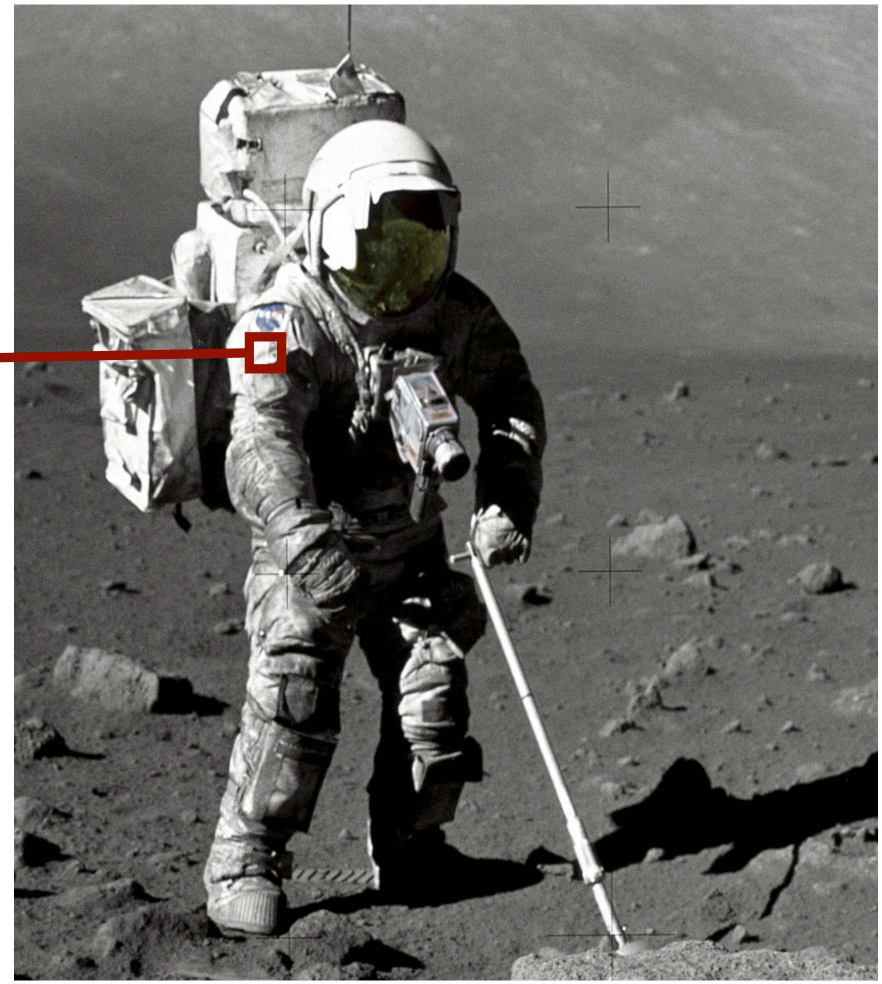
Lunar Dust

Composition: SiO_2, Al_2O_3, FeO





- Strongly Adhesive
- Destructive
- Toxicologically Hazardous



Preventing dust adhesion to spacesuits and equipment will be a critical component of safety and success of future lunar surface exploration missions.

Image Credits

Top : David McKay, NASA/JSC

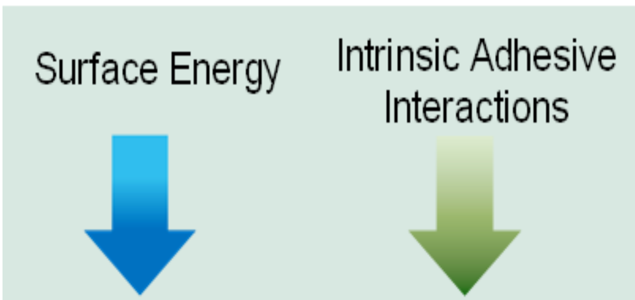
Middle:http://www.bccmeteorites.com/image7L5.JPG

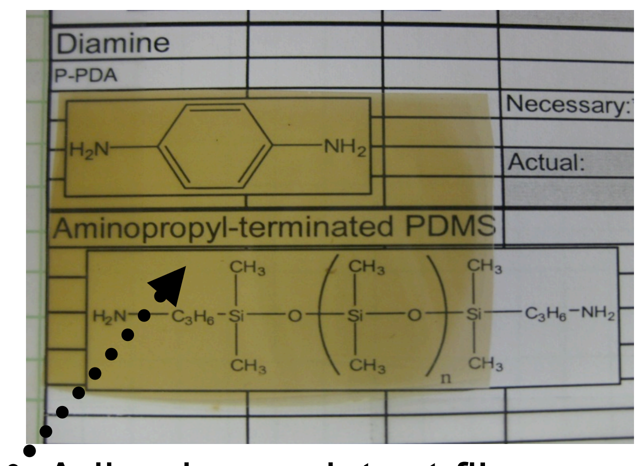
Bottom: NASA JSC: AS17-137-20979

Passive Dust Adhesion Mitigation/Evaluation

<u>Objective:</u> Design low surface energy polymer films that intrinsically resist dust adhesion

<u>Working Hypothesis:</u>





Adhesion resistant film

<u>Passive Mitigation Benefits:</u>

- Energy efficient protection
- Polyimides' extreme environment durability
- Curved surfaces protection
- Usable with active dust mitigation technology

<u>Summer 2009:</u>

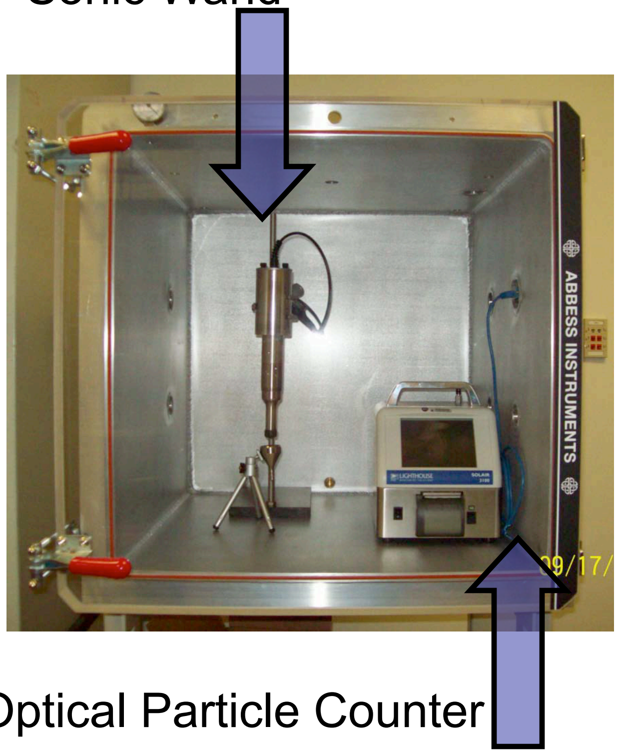
Copoly(imide siloxane) film synthesis

<u>Fall 2009 - present:</u>

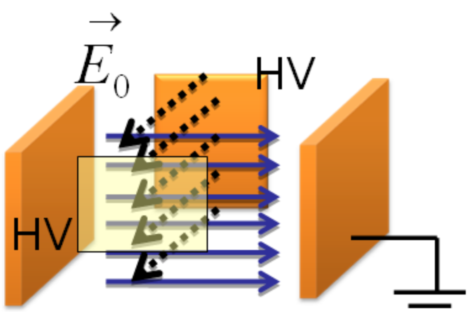
Adhesion research to evaluate passive dust mitigation approach

Adhesion Testing Chamber

Sonic Wand

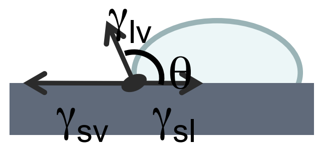


Optical Particle Counter

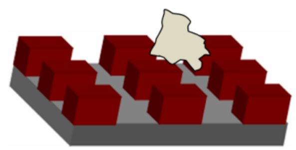


Electric Field Orientations

Aid in design of effective dust resistant materials



Correlate surface wetting and adhesion



Efficacy of topographical modification

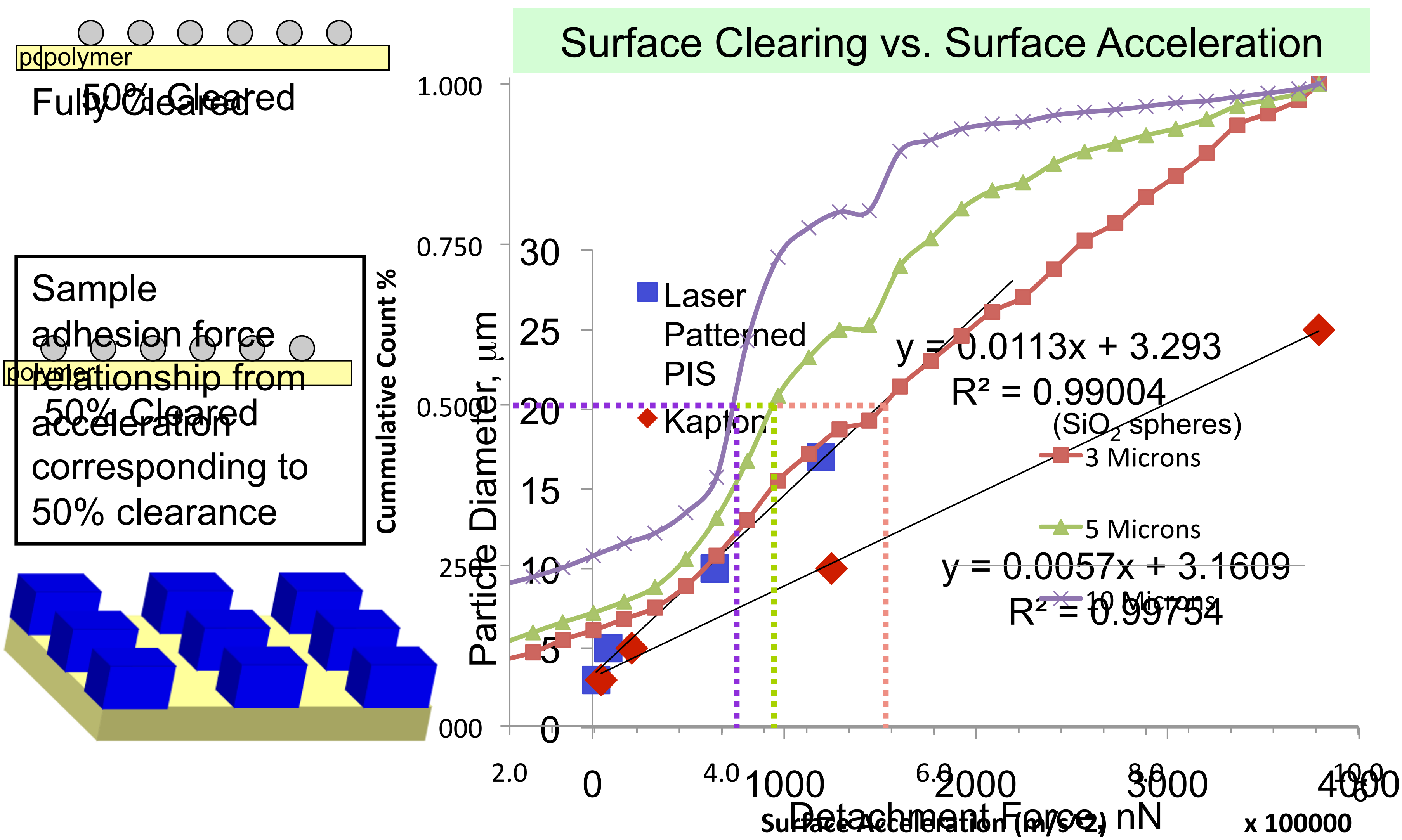
Improve understanding of range and significance of adhesion forces:

- Electrostatic
- van der Waals
- Capillary
- Contact

Study adhesion mitigation performance for simulated lunar features and activities

- Exposure to high electric fields strengths comparable to lunar terminator region predictions
- Descending into a lunar crater

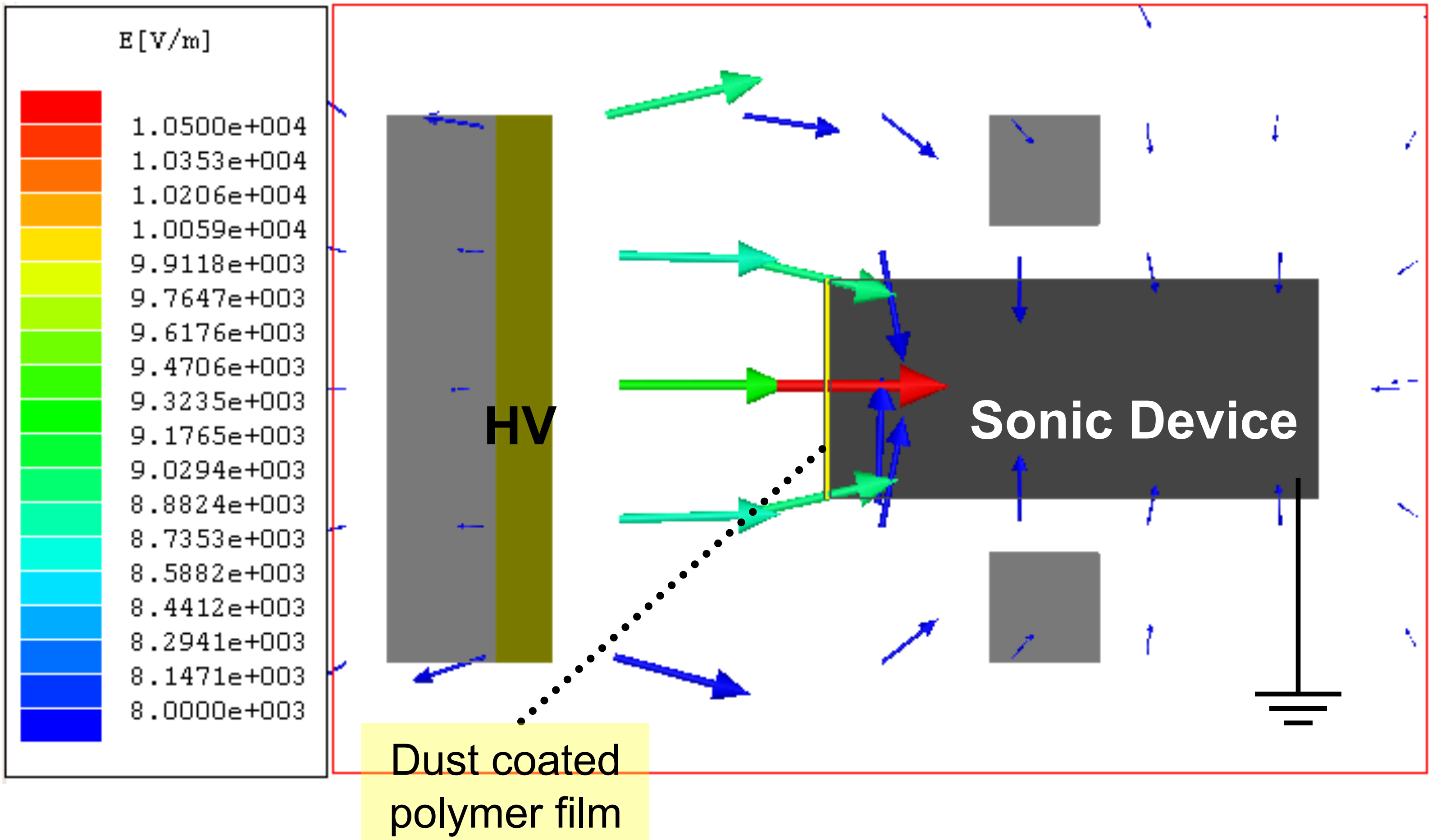
Sample Adhesion Testing



Maxwell 2D

E Field target: 1 x 10^4 V/m

Orientation: Normal to Sample face



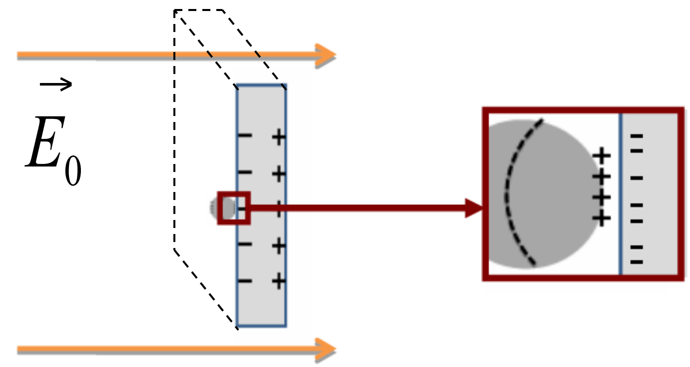
Electrostatic solver allows prediction of electric fields generated inside adhesion testing chamber

Modeling Electric Field Affects

Motivation:

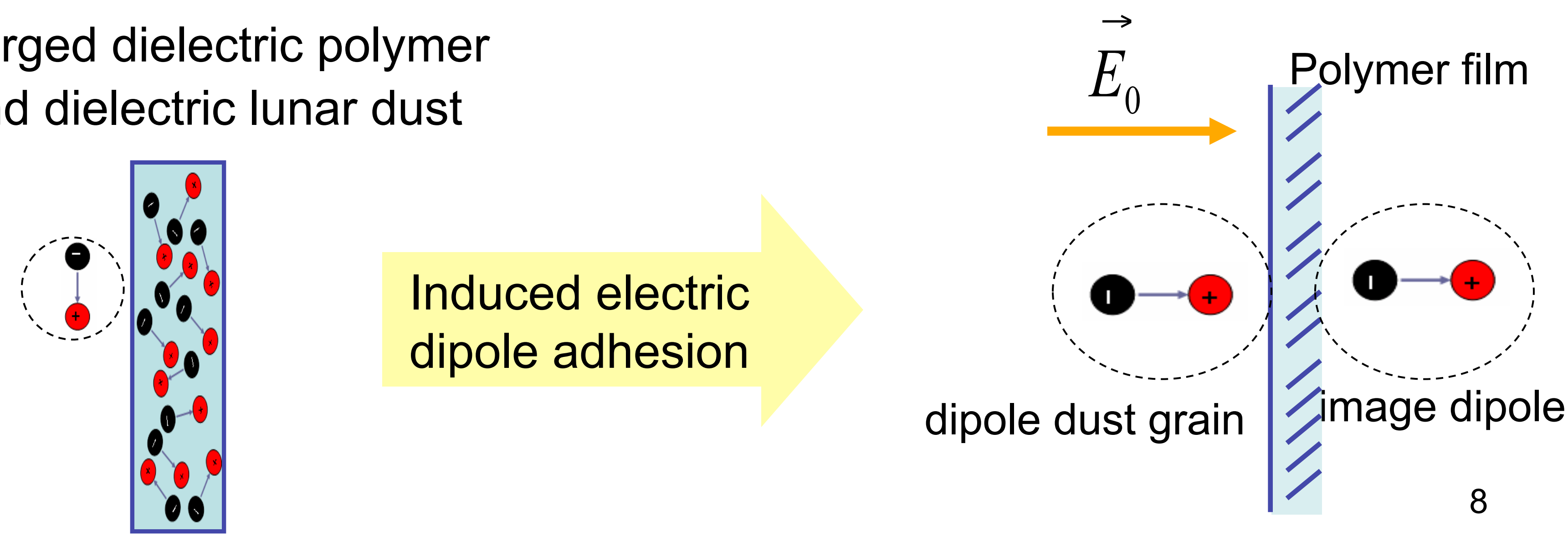
•Electric fields of magnitude kV/m → kV/cm have been predicted in lunar terminator regions.

• <u>How will such fields affect adhesion?</u>

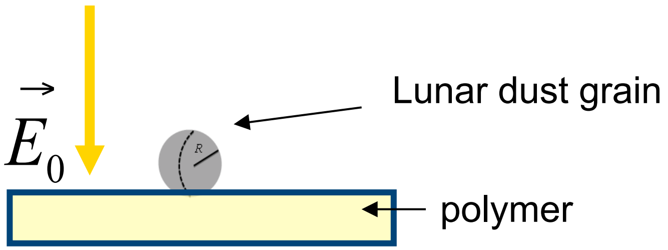


$$\vec{P} = \chi_e \varepsilon_0 \vec{E} = (\varepsilon_r - 1)\varepsilon_0 \vec{E}$$

Uncharged dielectric polymer film and dielectric lunar dust



Electrostatic Adhesion Model*



$$F_{ad} = F_{vdW} + F_{el} + \cancel{F_{cap}}^{\,0} + \ldots$$

Coulomb adhesion — Electric field detachment — Electric field induced adhesion

$$F_{el} = \alpha\left[\frac{q^2}{16\pi\varepsilon_1 r^2}\right] - \beta q E_0 + 4\gamma\pi\varepsilon_1 r^2 E_0{}^2$$

10 micron SiO_2 grain: E Dayside | E Lunar Terminator

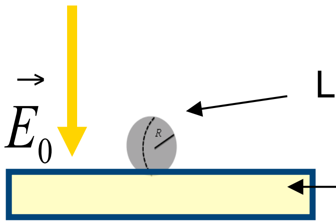
Electric Field [$V{\cdot}m^{-1}$]	Contact Charge** [C]	$F_{Coulomb}$ [pN]	$F_{Detatchment}$ [pN]	$F_{Induced}$ [pN]
1.0×10^1	10^4 e	4.5×10^3	1.13×10^{-2}	4.01×10^{-8}
1.0×10^2			1.13×10^{-1}	4.01×10^{-6}
1.0×10^3			1.13×10^0	4.01×10^{-4}
1.0×10^4			1.13×10^1	4.01×10^{-2}
1.0×10^5			1.13×10^2	4.01×10^0

$$F_{el} \approx \alpha\left[\frac{q^2}{16\pi\varepsilon_1 r^2}\right]$$

***Analog Model : Jones, T. B. *Electromechanics of Particles*. Cambridge: Cambridge UP, 1995.**

****Contact charge: Sternovsky, Z., Sickafoose, A., Colwell, J., Robertson, S., and Hora'nyi, M.," Contact charging of Lunar and Martian dust simulants"**

Relative Adhesion Forces



$$F_{ad} \approx F_{\mathrm{vdW}} + F_{\mathrm{el}}$$

$$F_{\mathrm{vdW}} = \frac{HR}{6d_o^{\,2}}$$

$$F_{\mathrm{el}} \approx \alpha\left[\frac{q^2}{16\pi\varepsilon_1 r^2}\right]$$

Critical Radius:

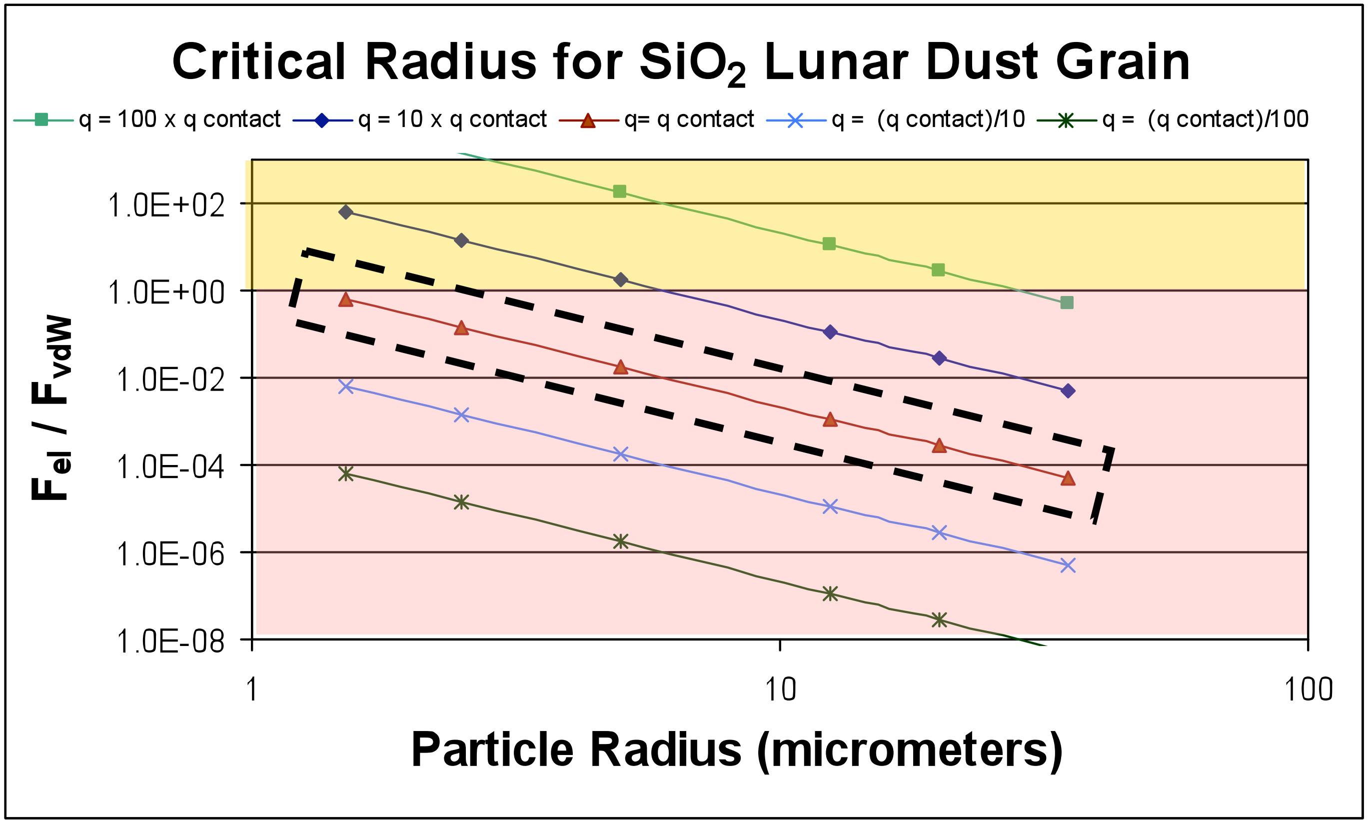
$$F_{\mathrm{vdW}} = F_{\mathrm{el}}$$

r< R_{crit}:

F_{vdW} dominates

r>R_{crit}:

F_{el} dominates



Contact charge: Sternovsky, Z., Sickafoose, A., Colwell, J., Robertson, S., and Miha'ly, H., "Contact charging of Lunar and Martian dust simulants"

Conclusions

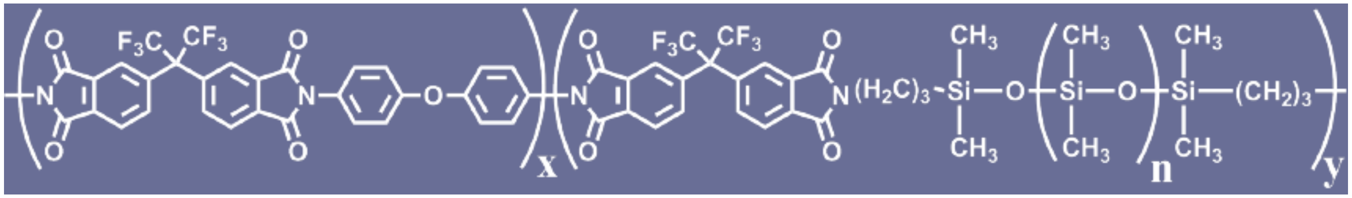
- Particulate adhesion testing is underway to evaluate efficacy of low surface energy and surface topography modified polymer films' adhesion resistance to lunar dust simulant.
- Preliminary electrostatic model indicates van der Waals interactions are more significant, suggesting efficacy of a passive mitigation approach.

Acknowledgments

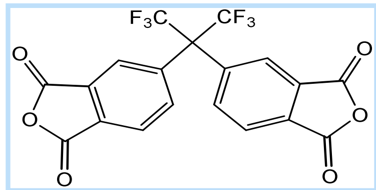
- NASA Langley Aerospace Research Summer Scholars Program
- Professor Shubho Banerjee and Professor Ann Viano, Rhodes College Physics Department
- Glen Davis, Rhodes College, Capacitor Device Fabrication
- Lunar Graduate Conference Organization Committee

Supplemental Slides

Composition Parameters

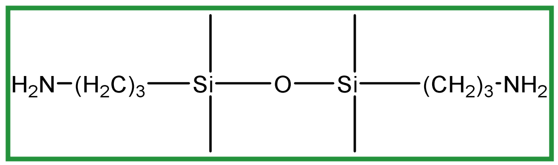


Dianhydride:

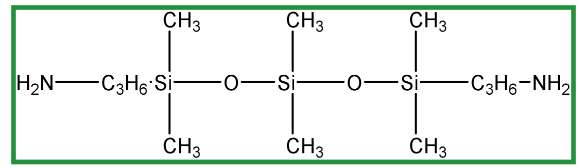


6FDA

Siloxanes

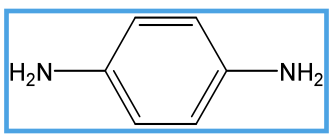


Disiloxane

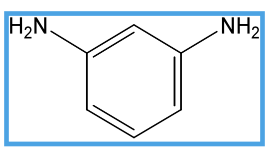


DMS- A11, A15, A21, A32

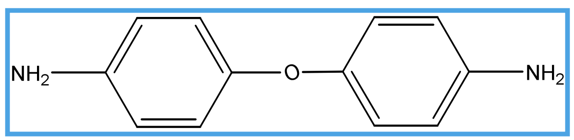
Diamines:



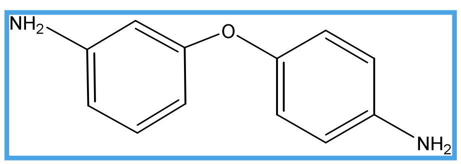
p-PDA



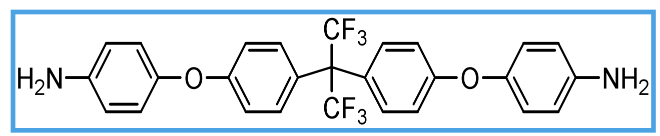
m-PDA



4,4'-ODA



3,4'-ODA



4 BDAF

Synthesis of Polymeric Films

•6FDA with varied PDMS oligomers and diamines were added in a controlled procedure into a 3-neck flask.

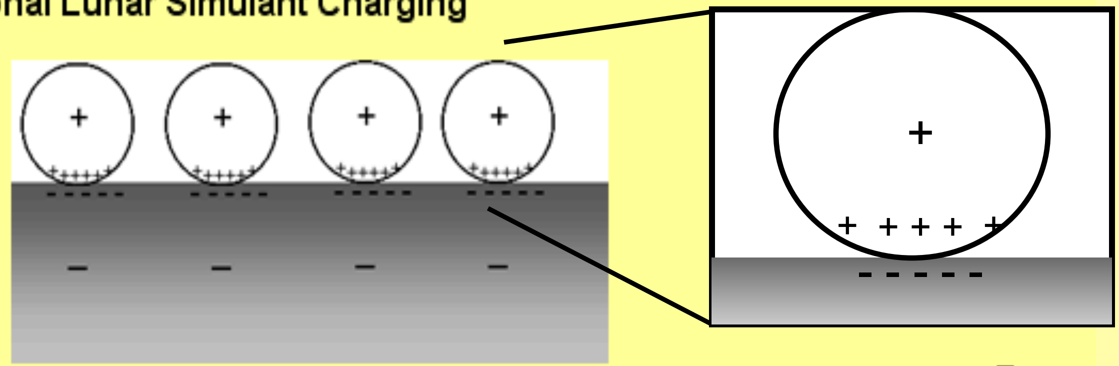
•Two solvents were used, Tetrahydrofuran and 1-Methyl-2-Pyrrolidinone, for a standard 20 % solid solution with the majority of films produced containing 10 weight % PDMS oligomer.

• Combination of solutions was mechanically stirred overnight under a constant nitrogen flow followed by film casting and thermal imidization

Image : Lillian Chen, "Synthesis and Characterization of Elastomer-modified Polyimide Films"

Fractional Charging

Fractional Lunar Simulant Charging



$$F_{\text{total}} = F_{\text{single}} + F_{\text{interaction}}$$

$$F_{total} = \frac{\xi q^2}{2\pi\varepsilon_1 R^2}\left[(1-f)f + \frac{\alpha'(1-f)^2}{8} + \frac{3\sigma_f f}{4R\rho\left(\frac{q}{m}\right)} + 4(1-f)[fS_1 + (1-f)S_2]\right]$$

Eq. 7.20: Jones, T. B. *Electromechanics of Particles*. Cambridge: Cambridge UP, 1995.

ξ	q [C]	R [m]	ε1[C^2/N•m^2]	f	ά
0.6	1.6E-14	5.00E-06	8.85E-12	0.1	1.268

σf [C/m^2]	ρ [kg/ m^3]	m [kg]	S1	S2	ks
5.09E-05	2520	1.32E-12	0.24	0.17	4

$F_{total} = 9.73 \times 10^{-8}$ [N]

$$F_{e1} \approx \alpha\left[\frac{q^2}{16\pi\varepsilon_1 r^2}\right]$$

$F_{el} = 2.92 \times 10^{-8}$ [N]