# Surfaces That Shed Dust: Unraveling the Mechanisms

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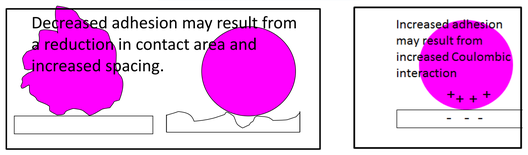
## Motivation:

**Uncontrolled adhesion of particles poses problems in many environments and many industries.**

Removal of particles is difficult, time consuming, requires specialized techniques, and is expensive.

*Wouldn't it be nice to be able to gently remove particles with an air stream, or a tap (on earth), or a "stickier brush" on the Moon, because it's not really sticking that much?*

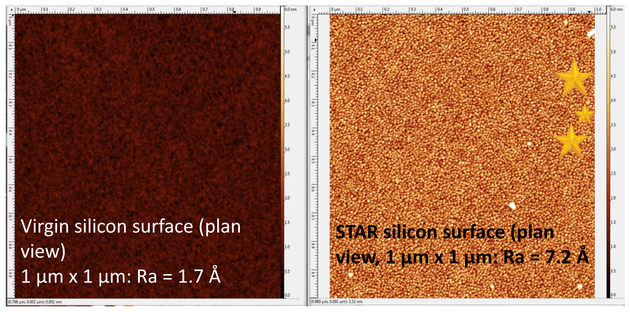
## Characterization:



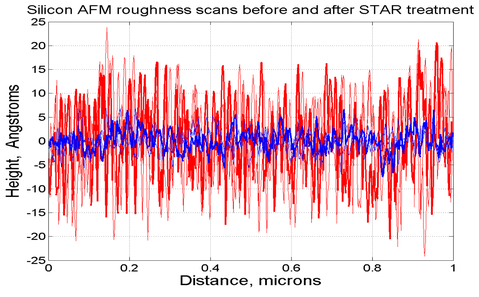

## Surface Morphology:

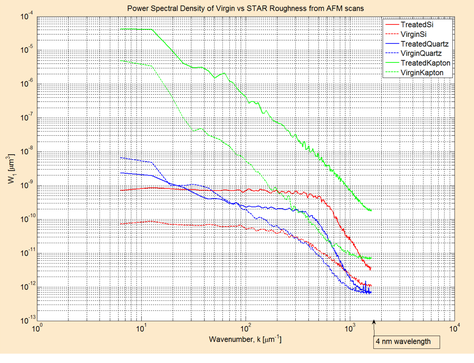
Atomic Force Microscopy was used to characterize changes following STAR ion beam processing. Increased roughness on all length scales was observed, leading to reduced van der Waals interactions.

**Atomic force microscopy** height images for virgin (left) and treated (right) silicon. The surface roughness after ion beam treatment is more than three times rougher, but still on the Angstrom level scale.



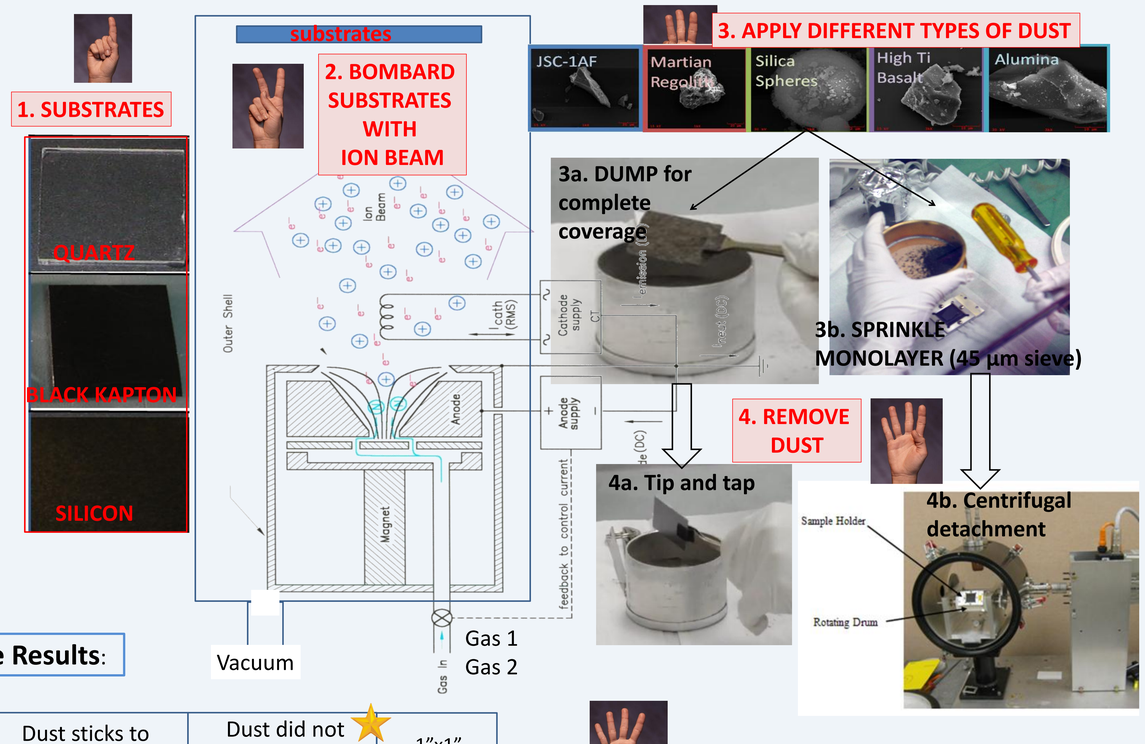

Representative line scans (3 each) from atomic force microscopy images showing increased roughness after STAR treatment. Red is after STAR treatment, blue is virgin. Power spectral density also shows increased roughness at all wavelengths.



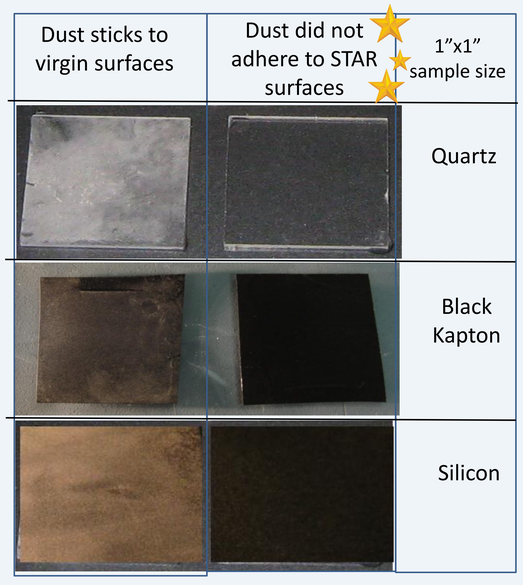




## The Experiments:

We wanted to find a way to reduce adhesion of particles by modifying the surface in ways which could reduce van der Waals and Coulombic interactions by tailoring surface morphology and chemistry. The experiments involved ion bombardment (STAR process: Surface Treatment Adhesion Reduction) using gases which were expected to shift work function to match that of lunar regolith. A low energy beam would limit the amount of material removal. The steps of the experiment, and results , are illustrated below.




## The Results:

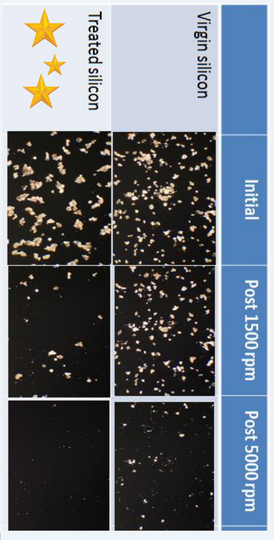



**5: COMPARE DUST ADHESION PERFORMANCE OF VIRGIN VS TREATED SURFACES**

**5a: Dump dust, tip and tap method**

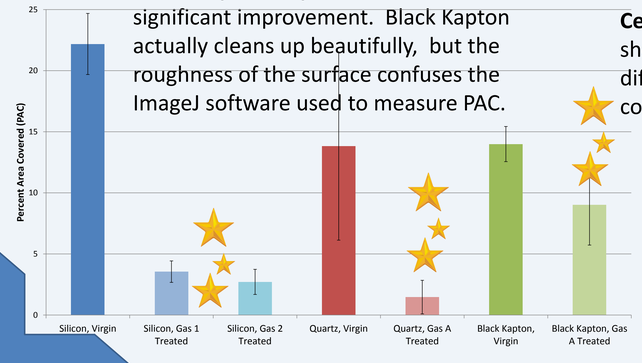
Left hand images are virgin surfaces still covered in a fine layer of dust; right hand images are STAR treated surfaces which no longer have dust adhered to the surface. All surfaces were fully covered in dust and had the same removal method. The white/cloudy appearance of the left images are from light scattering off the adhered dust.

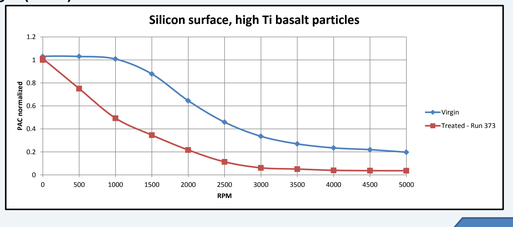
**5b: Centrifugal detachment.** STAR treated surfaces have fewer remaining particles for given rpm.



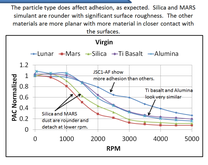

The **dump and tap method** shows significant improvement. Black Kapton actually cleans up beautifully, but the roughness of the surface confuses the ImageJ software used to measure PAC.

**Centrifugal detachment** also shows significant differentiation in percent area coverage (PAC).

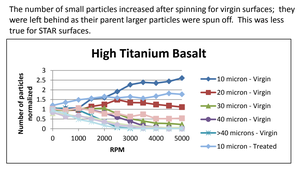


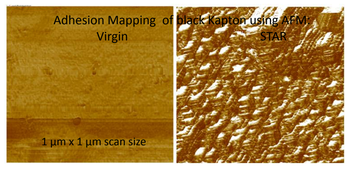

Want to know more? Cool.. little tidbits..

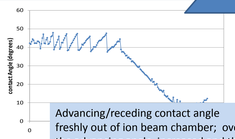



The particle type does affect adhesion, as expected. Silica and MARS simulant are rounder with significant surface roughness. The other materials are more planar with more material in closer contact with the surfaces.




The number of small particles increased after spinning for virgin surfaces; they were left behind as their parent larger particles were spun off. This was less true for STAR surfaces.



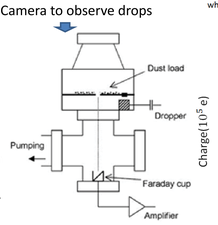

Advancing/receding contact angle freshly out of ion beam chamber; over time the advancing angle increased and the jumpiness went away indicating surface relaxation/reconstruction.

## Contact charging

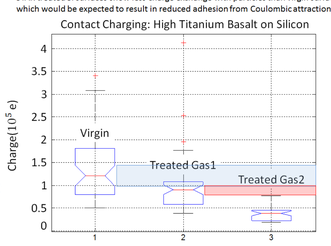
Charge can play a large role in adhesion. Intentional engineering of surfaces to reduce tribocharging between lunar regolith and surfaces was a goal of this work. It was effective for Si, but not for Kapton, indicating that this phenomenon is not necessary for the observed reduction in adhesion.

Video Camera to observe drops

Dust "dances" across vibrating substrate, exchanging charge, then drops into Faraday cup.

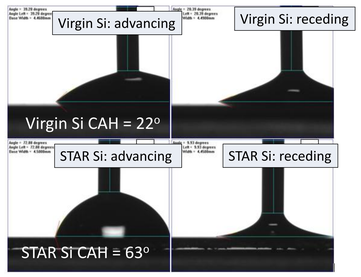



STAR treated Si surfaces show less charge exchange with particles than virgin surfaces, which would be expected to result in reduced adhesion from Coulombic attraction.

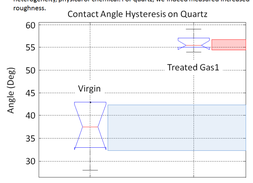



## Contact angle hysteresis:

Contact angle hysteresis (CAH) refers to the difference in advancing and receding contact angles. Higher CAH typically correlates with increased roughness of a surface, which could be expected to reduce adhesion by increasing spacing and reducing contact area. Large increases in CAH were observed for quartz and silicon; Kapton was too hydrophilic to get decent measurements.




Increased contact angle hysteresis is typically correlated with increased surface heterogeneity, physical or chemical. For quartz, we indeed measured increased roughness.




## Discussion, including a nod to theory

van der Waals force between sphere and plane $F_{vdW} = -\frac{A r_d}{6D^2}$

A is Hamaker constant, D is spacing (typically taken as 0.2 nm , $r_d$ diameter of particle.

$$A = 12\pi D_0^2 \sqrt{\gamma_p \gamma_s}$$

image force (uniform charge) $F_i = -\alpha \frac{Q^2}{16\pi\varepsilon_0 r_d^2}$

image force (patch charge) $F_i = \frac{\sigma^2 A_c}{2\varepsilon_0}$

σ is the surface charge density, $A_c$ is area of contact.

The equations describing the van der Waals force, image force for both uniform and patch charge models are well known. The problem is that the values of the parameters are not. Experimental studies routinely show large variation in adhesion forces and large deviations from theory due to uncertainty of separation, morphology, etc. This work was quite applied, specifically for dealing with bulk dust behavior in contact with surfaces. The results suggest that the largest "knob" is a change in roughness and "peakiness" of the modified structure leading to reduced contact area and additional separation, evidenced as well by CAH measurements.

I'll have some of those glasses!

## CONCLUSIONS:

Low energy ion beam treatment of polymer (black Kapton), quartz and silicon surfaces was shown to be highly effective in reducing adhesion of fine powders, which are typically difficult to dislodge from surfaces (< 50 µm).

- In all cases, significant increases in roughness across all wavelengths was observed. Increased spacing and reduced contact area are the largest contributors to reduced adhesion for all materials.
- Contact charging between silicon surfaces and lunar simulant was measured for STAR surfaces. A reduction of Coulombic interaction could play a role in reducing adhesion; however this was only measured for Si.
- The choice of gas feed for the ion beam does make a difference in the effectiveness of the treatment. Unfortunately, it is hard to separate whether this is driven by voltage differences which arise from the different gases, or a chemical phenomenon.
- Flat, angular particles adhered more strongly to surfaces than rounder, fluffier particles.
- Particle morphology had more effect on adhesion for virgin surfaces than STAR surfaces; the surface morphology dominated the adhesion behavior.
- Adhesion was observed to be time dependent after removal from ion beam chamber; adhesion reduced over time consistent with a newly treated surface being highly activated and charged.
- Reduced adhesion was observed in vacuum as well (previously published).

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