Engineering the Adhesion Mechanisms of Hierarchical Dust-Mitigating Nanostructures

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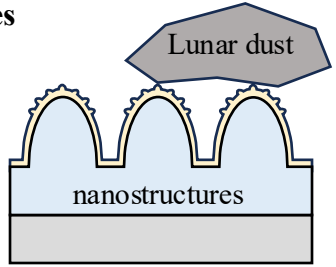

Figure 1. Hierarchical nanostructures that can mitigate adhesion of lunar particles

- **Goal:** Scratch-resistant **hierarchical nanostructured coating** to passively mitigate lunar dust adhesion from Van der Waal (VdW), electrostatic, and mechanical forces in space-relevant environment

Research Objectives

- **Goal:** Develop a new class of hierarchical dust-mitigation coating that can applied to metal, ceramic, and polymer surfaces
- **Key Innovation**: Enables deterministic control over structure geometry and material composition to **suppress dust adhesion contributions from VdW, electrostatic, and mechanical forces**
- **SOA:** Current passive dust-mitigating surface texture work only for limited polymers in terrestrial environments, does not mitigate electrostatic effects, and are not mechanically durable
- **Start TRL 2**: Initial modeling and preliminary dust mitigation properties demonstrated in ceramic nanostructures
- **End TRL 4**: Develop and validate adhesion model describing all contributing mechanisms, demonstrate dust mitigation in relevant space environment (vacuum < 10^{-6} Torr, temperature between 40 to 400 K, electrostatic potential from -150 to 5 V) and scalable transfer printing of coating on different materials

Approach

- Proposed nanostructures composes of **nanostructure geometry** with **nanoscale roughness** and heterogeneous composition and surface functionalization
- **Fabrication**: Develop processes to control geometric (structure radius, roughness, etc.) and material properties (conductivity, stiffness, etc.) to directly engineer particle-surface interactions
- **Modeling:** Construct multi-physical models to examine contact adhesion, non-uniform charging and dissipation, mechanical interlocking, and deformation mechanisms
- **Characterization:** Develop precise single-probe AFM and nanoindentation techniques to directly quantify contributions of nanoscale adhesion mechanisms
- **Scale-up:** Develop scalable processes to transfer print proposed hard nanostructures on arbitrary material and surfaces

Potential Impact

- Proposed nanostructured coating can mitigate adhesion from charged dust particles can be broadly applied to vehicle surface, mechanical machinery, optical windows, sensor surfaces, thermal radiators, and spacesuits in the lunar environment
- The proposed dust-mitigating nanostructured coating will consist of hard, high-strength material and will be designed to be resistant to mechanical abrasion and wear
- This technology contribute towards NASA's efforts in **Space exploration and establishing a Lunar base** by mitigating the adverse mechanical, electrical, and health effects of lunar dust
- The proposed passive dust-mitigation technology can also be adopted for other solid particulate contamination in other space environments beyond the Low Earth orbit