PILOT EXPERIMENTS IN DIELECTRIC BREAKDOWN SPACE WEATHERING OF PLANETARY REGOLITH ANALOGS.

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Introduction: Energetic charged particles can penetrate deep into a dielectric material, be it a spacecraft's structure and electronics, or the regolith of an airless body's surface, resulting in deep dielectric charging. This process is dependent on the incoming particle currents, as well as on the target material's discharging timescale (the ratio of its permittivity to electrical conductivity). In permanently shadowed regions (PSRs) near the lunar poles, the discharging timescale of the cold, poorly-conducting regolith is predicted to be ~20 days [1]. Subsurface electric fields form to dissipate any net accumulation of charge; however, if the charge builds up faster than it can be dissipated, then the magnitude of these fields will increase.

Under the extreme conditions experienced during a large solar energetic particle (SEP) event, [1] predicted that the resulting subsurface electric fields in lunar PSRs are capable of causing dielectric breakdown (> 10^6–10^7 V/m^2). Dielectric breakdown explosively dissipates the electric field, and associated build-up of charge, by forming localized conducting channels of vaporized material [2]. Dielectric breakdown is anticipated to be a significant space weathering process in lunar PSRs [3, 4], which could play a significant role in creating the high porosity, possibly very glassy regolith properties observed therein [5, 6]. This putative process of "dielectric breakdown weathering" could be prevalent at many other bodies, including Mercury and asteroids in the inner solar system, as well as gas giant moons inside their planet's radiation belts [7]. We have begun a series of pilot experiments to explore deep dielectric charging starting with conditions approximating lunar PSRs, attempting to create conditions conducive to producing dielectric breakdown events in lunar regolith analog materials in the laboratory. This builds on our previous laboratory experiments [8, 9] that produced breakdown events, but not in conditions sufficiently simulating lunar PSRs (e.g. insufficient vacuum, charging via plates instead of incident charged particles, insufficient bake-out of samples).

CEnT Chamber: The Combined Environment Test (CEnT) Chamber at the Applied Physics Laboratory (APL) (Fig. 1) is used for simulation and test of spacecraft instrumentation, research purposes. The chamber can achieve ultrahigh vacuum of better than 10^{-8} torr via dry roughing pump and 10" cryo-pump. Low temperatures of -180°C can be achieved by pumped liquid N_2, and high temperatures of >300°C can be achieved with heating lamps and thermal plates. To simulate the space environment, the chamber also includes Deuterium and Xe lamps to simulate solar irradiance from ultraviolet through infrared wavelengths, and 50 and 100 keV electron guns to simulate energetic electron environment.

Instrumentation in the CEnT chamber includes a thermoelectric quartz crystal microbalance (TQCM) for quantifying outgassing, and a residual gas analyzer (RGA) for identifying outgassed molecules from 0-200 atomic mass units. In support of the dielectric breakdown experiments, we have added both a high-speed camera, viewing through a port (not shown) in the chamber door, and a small radio-frequency antenna to 'listen' for electromagnetic signatures of discharges produced by dielectric breakdown events.

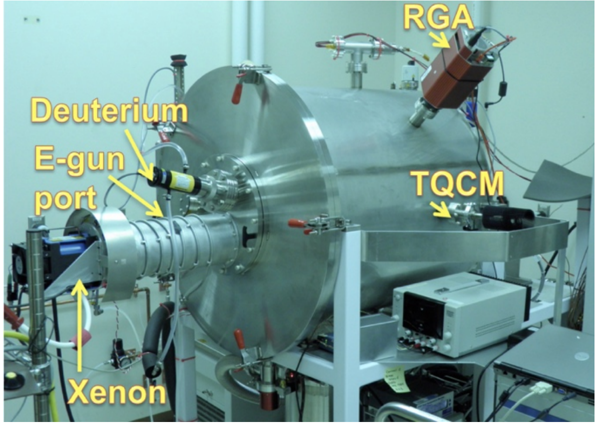

Figure 1. CEnT chamber at APL showing ***Deuterium and Xenon lamps in*** *electron gun* ***port****.*

The CEnT chamber's new 100keV from Kimbal Physics (Figure 2) will enable us to simulate lunar PSR electron flux conditions similar to certain types of SEPs [1, 3, 4]. Beam characterization is ongoing in preparation for initial experiment runs.

Pilot Experiment: The first full simulation experiment for dielectric breakdown will target a sample (~5 grams) of JSC-1A lunar regolith simulant in a ceramic sample holder (Figure 3) with a 100 keV electron beam for several hours near room temperature (~16°C as the cryo-pump cools the whole chamber). The entire run will be monitored by camera to detect possible flashes or sample displacement due to discharge (Figure 3), antenna to detect EM signature of discharge, and TQCM and RGA to detect ejected or outgassed products of possible breakdown events. The camera will also be utilized for before-after imaging of the sample for more subtle change detection over the course of the experiment. The simulant sample has been characterized pre-experiment by a scanning electron microscope (SEM) with X-ray spectrophotometer (XRS) add-on (Figure 4), and the sample will be re-examined by the same instruments to detect changes in grain morphology, signs of melting and vapor deposition, comminution, glass production, or other possible alternation effects of dielectric breakdown.

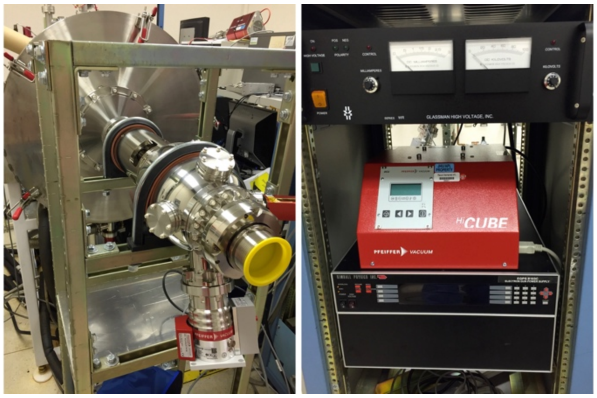

Figure 2. *New mounting of 100KeV electron gun.*

Figure 3. *(Left) Ceramic sample holder in predecessor experiment configuration. (Right) 'Explosion crater' in JSC-1A sample produced by discharge between two electrodes buried in regolith from predecessor experiment [8].*

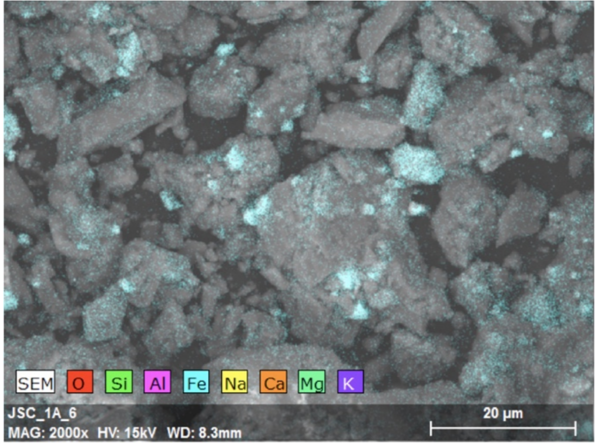

Figure 4. *Pre-experiment JSC-1A example XRS overlay showing iron flecks up to a few microns in size scattered throughout.*

Discussion: Predecessor experiments [8, 9] were conducted in poor space environment simulation conditions, from ambient conditions to a best vacuum of 10^{-6} torr, and they yielded inconclusive, but encouraging results. All predecessor experiments used electrodes buried in the sample (Figure 3) attached to a power supply to produce electric fields necessary for breakdown. These experiments successfully produced a number of discharge events, but it remained unclear whether the discharges proceeded through grains, across grain surfaces, or (in some cases) through what atmosphere remained in the chamber.

Electrode experiments produced explosions that formed craters in samples (Figure 3) up to a few mm in diameter, throwing out silica vapor and particulates, though the size of the crater produced decreased with increasing vacuum, leading to the suspicion that some of the explosive power was due to remaining atmosphere in the chamber.

Ongoing/Future Work: The CEnT chamber as of this abstract is undergoing final qualification and setup for the experiment. Results will be presented. If dielectric breakdown is observed to occur via any single method of detection or combination of methods (optical observation, change detection, EM signal, discharge product detection, sample alteration product observation), then the case for dielectric breakdown as a potentially significant factor of space weathering on airless bodies [4, 9] will have gained real experimental support. Such detection would suggest that a systematic future evaluation of how dielectric breakdown effects vary with different environments and targets (e.g. regolith simulant, spherical glass beads, broken glass beads, and possible actual lunar soil samples) may yield significant results. Additional future work could include determining the effect of cooled samples with lower self-discharge rates, introduction of induced magnetic fields and other radiation effects, varying electron energy and flux, using high energy protons instead of electrons, and other environmental variables.

References:

[1] Jordan et al. (2014*) JGR Planets* 119, 1806-1821. [2] Frederickson et al., (1992) IEEE Trans. Nuc. Sci. 39.6, 1773-1782. [3] Jordan et al. (2015) *JGR Planets* 120, 210-225. [4] Jordan et al. (2017) *Icarus,* 283, 352-358. [5] Gladstone et al. (2012) *JGR Planets* 117 E00H04. [6] Lucey et al. (2014) *JGR Planets* 119.7, 1665-1679. [7] Campins and Krider (1989) *Science* 245.4918, 622-624. [8] Shusterman et al. (2016) LPSC 47, #2263. [9] Jordan et al. *Icarus* in preparation.