9-9-2016

Dependence of Electrostatic Field Strength on Voltage Ramp Rate for Spacecraft Materials

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Recommended Citation

Krysta Moser, Allen Andersen and JR Dennison, "Dependence of Electrostatic Field Strength on Voltage Ramp Rate for Spacecraft Materials," USU Fall Undergraduate Research Orientation, Logan, UT, September 9, 2016.

Dependence of Electrostatic Field Strength on Voltage Ramp Rates for Spacecraft Materials

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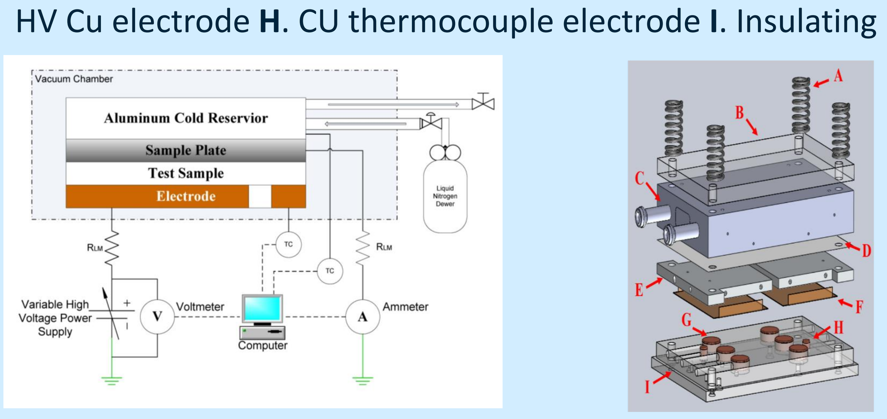
I. Introduction

The purpose of these experiments was to determine the electrostatic field strength (F_{ESD}) dependence of spacecraft materials on voltage ramp rates and endurance time. Spacecraft charging often occurs over long durations, from hours to decades. As mission lifetimes and the sensitivity and complexity of instrumentation increase, so does the need for describing the influence of the electrical aging processes on ESD.

Electrostatic discharge (ESD) and the associated material breakdown is the primary cause for spacecraft damage due to space environmental interactions [1]. This phenomenon occurs when the space plasma fluxes charge a craft to high voltages where insulating materials then break down. This breakdown allows current to flow freely through the material, which can damage or destroy on board electrical systems [2].

The results of these experiments are an important step toward determining the relationships between electrostatic field strength and voltage ramp rates. Understanding these relationships is important because it will help us understand ESD related anomalies and failures attributed to spacecraft interactions with the plasma space environment.

Figure 1 – ESD Assembly **A.** Adjustable pressure springs **B.** Insulating layer **C.** cryogen reservoir **D.** thermally conductive, electrically isolating layer **E.** sample and mounting plate **F.** sample **G.** HV Cu electrode **H.** CU thermocouple electrode **I.** Insulating base



This work was supported by a USU Howard L. Blood Scholarship and a NASA Space Technology Research Fellowship

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II. Past Work

Previous experiments done by the USU Materials Physics Group have tested the insulation polymers low density polyethylene (LDPE) and polyimide (Kapton HN) [4]. For these materials, F_{ESD} was determined using a custom high vacuum chamber as a sustained rise in I-V curves.

A maximum ramp rate of 500 V/s is recommended in ASTM D3755 standards [3]. The USU MPG ramp rates of approximately 20V/3.5s, however, resulted in substantially lower F_{ESD} values for LDPE and Kapton than tests conducted with the maximum recommended ramp rate. This breakdown field strength dependence on temperature and ramp rate can be seen in Figure 2.

Time dependent tests were conducted by applying a static field stress less than F_{ESD} across the material and measuring the endurance time to material breakdown. The results of these and other tests suggest that values of F_{ESD} that have been used by the spacecraft charging community can substantially overestimate F_{ESD} in common spacecraft situations with slower charging rates [4].

Figure 2 – Breakdown Test Dependence on T and dV/dt

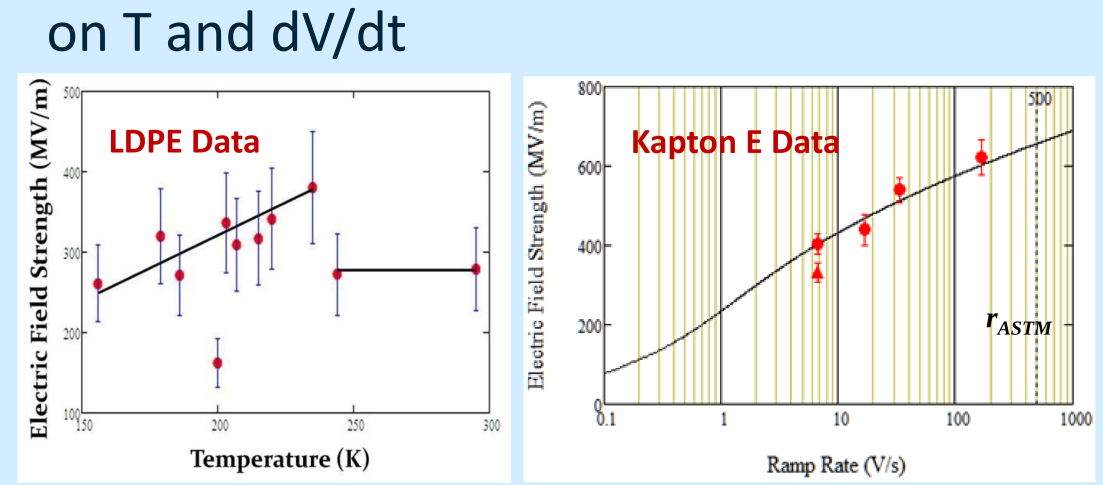
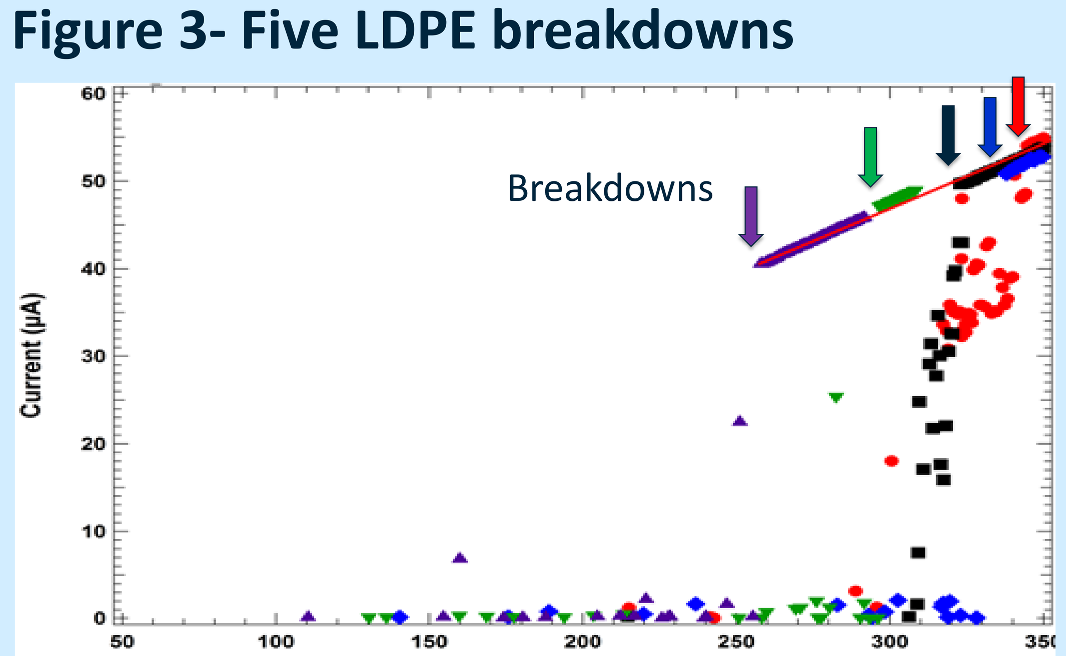


Figure 3- Five LDPE breakdowns



III. Experiment & Results

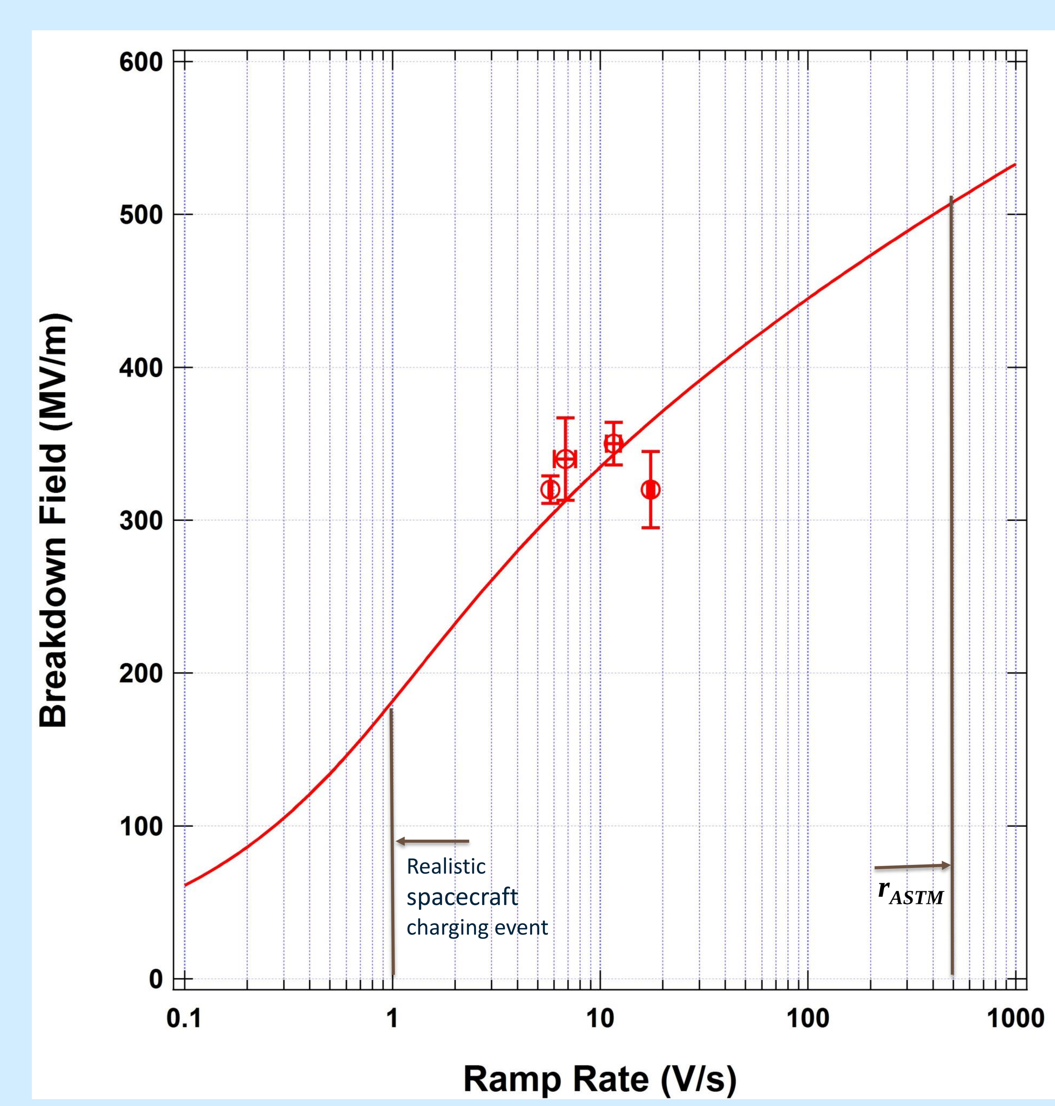
Samples of the materials to be tested were placed between a metal sample mounting plate and six highly polished copper high voltage electrodes. This allowed for testing of six samples during a single vacuum cycle. A spring clamping mechanism was used to apply uniform sample contact pressure of about 0.4 MPa, in compliance with standard methods (see Figure 1 for a diagram of ESD test assembly).

These experiments continued USU's Materials Physics Group's ramp rate testing on a new polymeric material, biaxially oriented polypropylene (BOPP). Approximately 100 individual tests were done using ramp rates ranging from about 5 V/s to about 18 V/s.

Each of these ramp rate tests were compiled into a single graph showing ramp rate versus the breakdown field at that ramp rate.

Figure 4 shows this final compilation of all 100 individual polypropylene ramp rate tests. Each point represents all tests done at that ramp rate.

Figure 4 – Ramp Rate vs Breakdown Field for BOPP



IV. Conclusions & Future Work

These data, as shown in Figure 5, were fit to a mean field theory for dielectric breakdown in highly disordered insulating materials, which assume uniform defect spacing and binding energies, that depends on ramp rate, r, with r_0=1 V/s [4]:

$$F_{ESD}(r) \approx F_{ESD}(r_0)\sqrt{1.1346\ \ln\left(r+\sqrt{1+r^2}\right)}$$

This mean field theory provides the fit to the data in Figure 4. At the ramp rates tested so far, the data seems to fit this theory. The implication is that the standard ASTM recommended ramp rate of 500 V/s can overestimate the electrostatic field strength for typical spacecraft breakdown by up to a factor of 6 or more.

To verify this overestimation, additional ramp rates will be done at the recommended ramp rate of 500 V/s to a more realistic 1 V/s, which is closer to an actual spacecraft charging situation.

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