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

Krysta Moser
Utah State University

Allen Andersen

JR Dennison
Utah State University

Follow this and additional works at: https://digitalcommons.usu.edu/mp_presentations

Part of the Condensed Matter Physics Commons

Recommended Citation
Moser, Krysta; Andersen, Allen; and Dennison, JR, "Dependence of Electrostatic Field Strength on Voltage Ramp Rate for Spacecraft Materials" (2016). 14th Spacecraft Charging Technology Conference. Presentations. Paper 120.
https://digitalcommons.usu.edu/mp_presentations/120

This Conference Paper is brought to you for free and open access by the Materials Physics at DigitalCommons@USU. It has been accepted for inclusion in Presentations by an authorized administrator of DigitalCommons@USU. For more information, please contact digitalcommons@usu.edu.
I. Introduction

The primary objective of this work investigated the dependence of electrostatic field strength for spacecraft materials on voltage ramp rate, by applying an increasing electrostatic field until electrostatic breakdown occurred. At high enough electrostatic fields or after long times, insulators can breakdown, causing large current flow through the material: this breakdown is called electrostatic discharge (ESD). Enhanced understanding of prolonged exposure to high static electric fields (DC aging) of insulating materials based on expanded experimental studies is critical to understand the physics of highly disordered insulating materials, as well as for applications in spacecraft charging, high voltage DC power transmission cables and switching, thin film dielectrics, and semiconductor devices and sensors [2].

II. Theory

A common mean field approximation for breakdown that considers only mean defect energy, $\Delta G_{def}$, and mean defect density, $N_{def}$ is the Crine model [5,6].

\[ P_{bd} = \frac{2\Delta G_{def}^{\frac{1}{2}}}{\hbar} \sinh \left( \frac{m_r F}{2\Delta G_{def}} \right) \]  

A first order approximation for how $F_{E\text{ss}}$ depends on the ramp rate $dV/dt$, comes by assuming that the ratio at two different ramp rates is the same for breakdown fields and the probability of breakdown. Setting the ratio of (1) evaluated at $\Delta t = \Delta t_{bd}$ and $\Delta t = 1 \text{ s}$ equal to the ratio of the experimental ramp rate $r$ over $r_1$ and recalling that $\sinh^{-1}x = \ln(x + \sqrt{1 + x^2})$ we find

\[ F_{E\text{ss}}(r) = \frac{1}{11346} F_{E\text{ss}}(r_1) \sinh \left( \frac{m_r F}{2\Delta G_{def}} \right) \]  

Note: (2) corrects a typographical error found in [4]. This approximation is quite simple but as it neglects much of the ramping process.

For incremental voltage step-up tests the breakdown probability, $P_{bd}$, becomes

\[ P_{bd} = 1 - \left( \prod_{j=1}^{n} \left[ 1 - \alpha \Delta t \sinh \frac{\alpha j F r_j^2}{2\Delta G_{def}} \right] \right) \]  

(3)

III. Methods and Results

Standard step-up voltage tests [8] were performed in a custom high vacuum chamber (<10^-7 Pa base pressure) at room temperature (see Fig. 1) [7]. Samples were placed between a metal sample mounting plate and six highly polished Cu high voltage electrodes, using recommended ≤0.4 MPa uniform clamping pressure [8]. For ramp rate tests, voltage was incrementally increased at a constant time intervals until breakdown occurred, which was evident by an abrupt current increase followed by a ohmic linearly current above breakdown set by limiting resistors.

Figure 2 shows three step-up tests done at slow, medium, and fast ramp rates. Ramp rates shown in Fig. 2 vary from 20 V per 4 s up to 2000 V per 4 s [4]; standard protocols suggest rates less than 500 V/s [7].

Between 3 and 6 tests were done at each ramp rate; each point in Fig. 3 shows the average and standard deviation of the tests at a given ramp rate. Figure 3 shows the breakdown field versus ramp rate for three polymeric materials, Kapton E™ [9], Kapton HN™ [9], and bi-axially oriented polypropylene (BOPP). Also shown are the average $F_{E\text{ss}}$ and a fit based on Eq. (2).

Figure 2 clearly shows that faster ramp rates yield less information than the slow ramp rates.

- Faster ramp rates are limited by the resolution of the voltage step size, which in the case of fast ramp rates is quite large (see Fig. 2(a)).
- In contrast, the smaller step size in the slower ramp rate tests results in higher resolution and more continuous data (see Fig. 2(c)).
- The higher resolution data from lower ramp rates tests (Fig. 2(c)) exhibits more detailed physical information, including pre-arcing [7], field enhanced conductivity and possibly a threshold breakdown field strength, $F_{\text{threshold}}$.
- Fig. 4 shows other information from slower ramp rate tests.

IV. Conclusions

- Initial Kapton E™ ramp rate data showed strong dependence on a limit range of ramp rates, consistent with a proposed mean field theory, Eq. (2).
- Standard ramp rate data for Kapton HN™ and BOPP showed little ramp rate dependence. Kapton HN™ and BOPP data are consistent with a single average $F_{E\text{ss}}$.
- More data for additional ramp rates, lower uncertainties at a given ramp rate, and more diverse materials are required to test the applicability and accuracy of the mean value, mean field [Eq. (2)] and incremental voltage step [Eq. (3)] models.
- Slower ramp rates:
  - Better approximate spacecraft charging situations, where charging is most often very slow.
  - Allow higher precision and accuracy determination of $F_{E\text{ss}}$.
  - Produce data with more observable effects, such as pre-arcing and possibly field enhanced conductivity.

References


Utah State University
Krysta.Moser@aggiemail.usu.edu

This work was supported by a Utah State University Undergraduate Research and Creative Opportunities Grant, a NASA Space Technology Research Fellowship, and funding through NASA GSC and the James Webb Space Telescope.