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Discharge Breakdown Analyses

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Breakdown Analysis of Electrostatic Discharge

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Project Summary

Electrostatic discharge (ESD) and the associated material breakdown is the primary cause for spacecraft damage due to space environment interactions. This phenomenon occurs when the space plasma fluxes charge a craft to high voltages where insulating materials then break down. This failure allows current to flow freely through the material which; can damage or destroy onboard electrical systems. My work focuses on the effects of these breakdowns on suspect materials commonly used for electrical insulation in space. The USU Material Physics Group has performed ESD tests on hundreds of samples to date. The ESD damage sites of these samples have been analyzed for parameters including breakdown size, shape, location, thickness, and polymer type. More data has become available, including thickness, breakdown voltage, and breakdown E field. These results have been recorded in an *ESD Quality Summary Table*. Which we utilize for sorting potential correlations. Trends within this data have been identified and are being investigated more thoroughly.

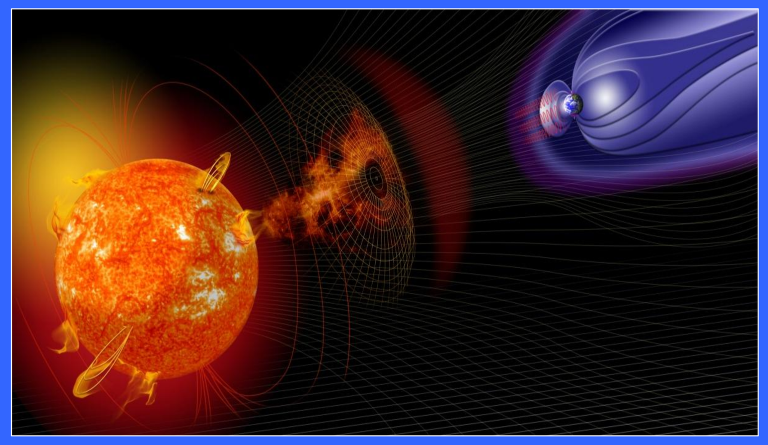


Figure 1. Solar Wind Diagram

Figure 2. Damaged solar panel due to and ESD event. These events account for more craft damage than any other environmental issue in space. Measuring the size of a breakdown compared to its breakdown voltage can help prevent further damage.

This research is specifically being done in conjunction spacecraft charging applications where point source charging is an issue. Other potentially useful applications for our research include the possibility of updating our nations existing power grid from alternating current (AC) to high voltage direct current (DC) current. Our work would be important to create insulating products to prevent coronal discharge in power lines.

Apparatus

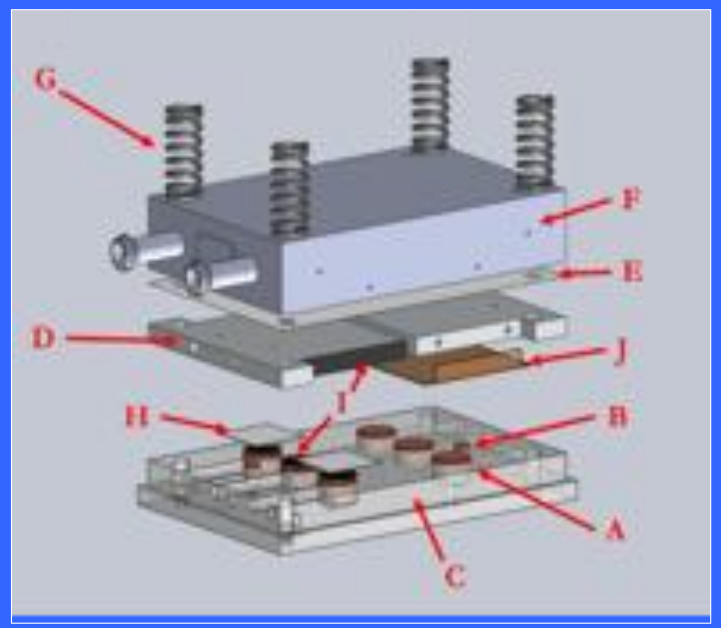


Figure 3. Materials Physics Group electrostatic discharge apparatus. This device is a simple parallel plate capacitor in high vacuum. The six electrode carousel applies up to 30 kV and can reach temperatures between 150 K and 350 K with a ℓ-N_2 reservoir and resistive heater.

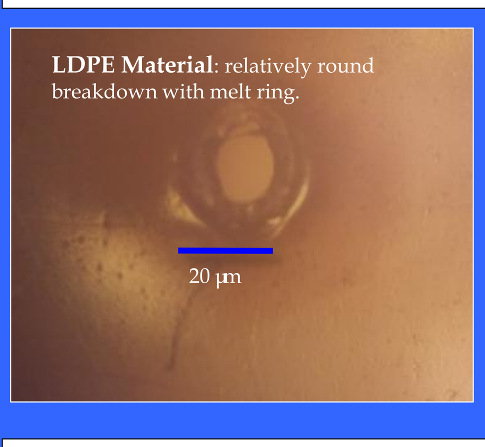
A) Copper electrodes.
B) Thermocouple electrodes.
C) Polycarbonate base.
D) Conductive sample plate.
E) Thermally conductive, electrically isolating layer.
F) ℓ-N_2 reservoir.
G) Adjustable compression springs.
H) Glassy sample.
I) Conductive padding.
J) Polymer sample

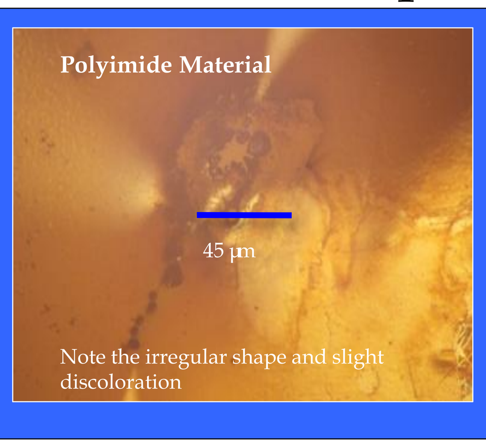
Procedure

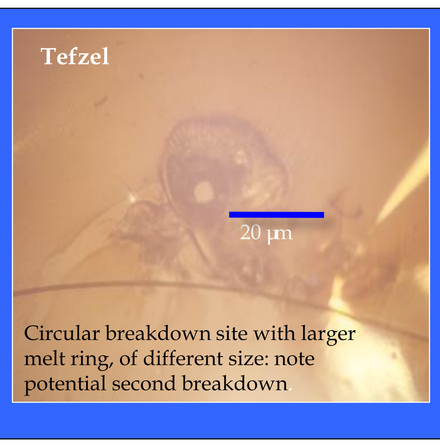
1. Breakdown samples were imaged under microscope
2. Measured along their major and minor axis using photo editing software.
3. Breakdown sites were categorized by site attributes within the matrix
4. Measured for thickness
5. This data was then entered into our database know as the *ESD Quality Summmary Table*.
6. Data from the matrix was sorted and information such as eccentricity, area, and breakdown field strength were extrapolated for graphing purposes.
7. This information was plotted graphically, curve fit functions were used to look for trends and correlations.

Our table is essentially a "living" matrix, capable of being updated with new test results in the future. Features within the table allow for categorical sorting to view and compare different parameters. Trends within the data set are compared graphically for analysis.

Breakdown Samples



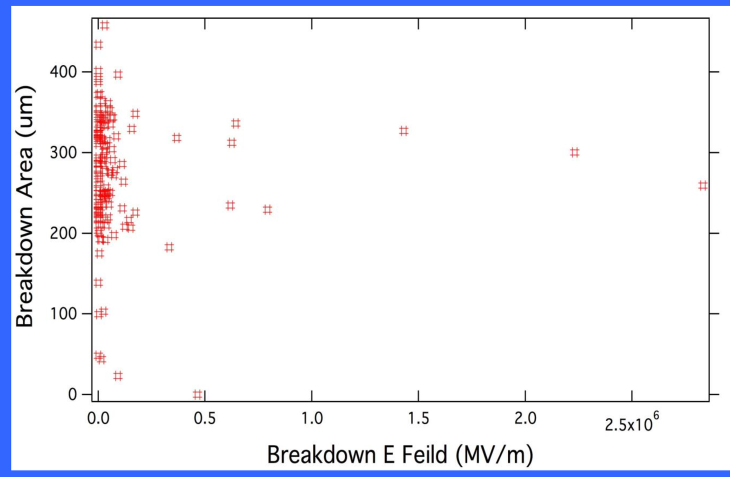


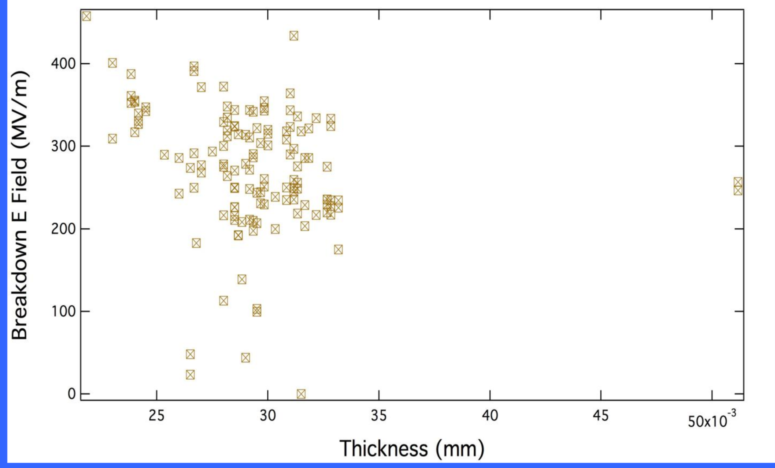


Breakdown Characteristics for Comparison

- Material Type
- Presence of char rings
- Melting
- Material deformation
- Discoloration
- Breakdown shape
- Size
- Irregularities
- Test type
- Number of breakdown sites
- Complete or partial breakdown

Breakdown E Field vs Breakdown Area and Thickness

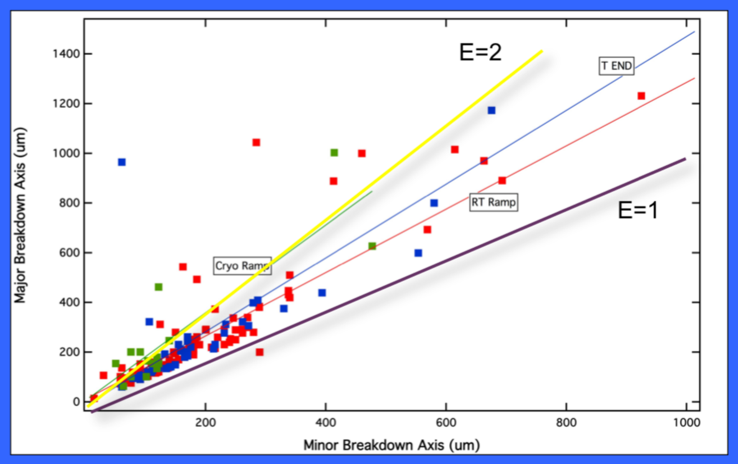




Comparison of ESD field strength to the resulting damage area and thickness is shown above. The initial hypothesis was that an increase in applied energy would result in greater material destruction. The total area of each breakdown site could not be measured accurately so a relative area was used by multiplying the major and minor axis together. Lack of observed correlation between E field and destroyed material tells us that there is a more complex process in the breakdown than previously thought. This data set includes all sample and test types found in our matrix

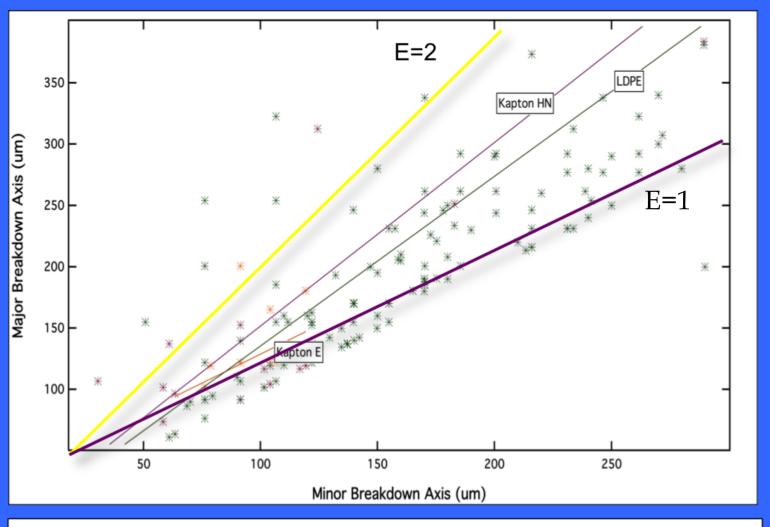
Breakdown Diameter Comparison

Test Type Comparison



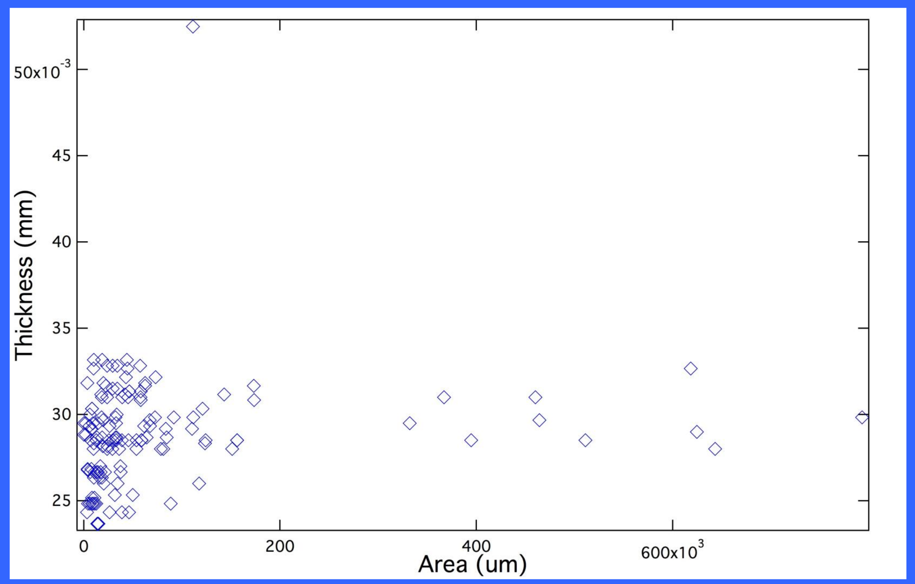
Graph Top Right: Comparison of breakdown site axes lengths for three test types. Cryo Temperature with Ramped Voltage, Time Endurance, and Room

Material Comparison



Comparison of breakdown site, axis lengths for LDPE and Kapton™ data.

Breakdown Site Area and Thickness



At left is a comparison of breakdown area and thickness. Area was approximated by multiplying the major and minor axis of each sample. This comparison includes each sample type in our matrix, as well as each test type. Sample thickness was measured and averaged for each sample with an uncertainty of +/- 0.005mm

Analysis

LDPE samples encompass 300 of the roughly 350 samples that have been tested to date. Our conclusions are strong for this material type, but may not be accurate for different materials. Specifics such as thickness, and E field strength were not available for all sample sets so our graphed data is not fully populated. Breakdown sites varied from being irregular to nearly circular, however measuring the area displaced by the discharge is very difficult so major and minor axis measurements were used to approximate the area. Finding a more accurate system of measuring this parameter might yield different results. We were unable to answer some of our initial questions, but may be able to do so with further investigation including a complete data set.

Analysis and Conclusion

Analysis of the ESD effected samples as shown here indicates:

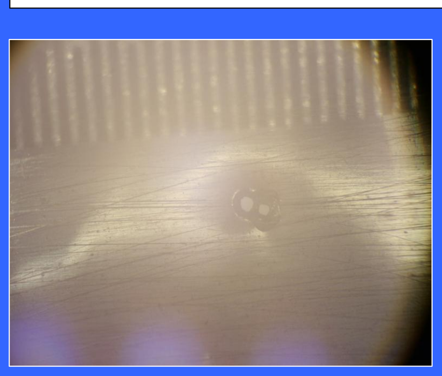
- Breakdown sites are elliptical rather than circular
- Material type does not influence size or shape of breakdowns
- Breakdown shape becomes more irregular with larger sized sites
- Increased breakdown E field does not influence damage area size
- There is no correlation between area and thickness of breakdown sites

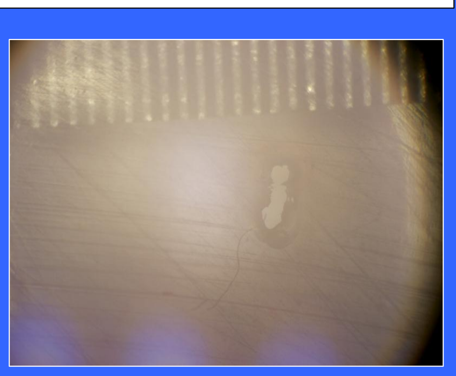
Our data set is predominantly populated with Low Density Polyethylene samples rather than a complete range of materials. Work is currently still being done to populate the matrix with different sample types. There also still exists potential to find trends within the current data set. For future work I would like to analyze the spatial variability of breakdowns on samples. Doing this would accomplish several things:

- Quality control
- Locate sample material defects and the relationship that exists
- Look closer at causes of breakdown related to our equipment.

Accurately mapping breakdown sites has many challenges associated with it but may tell us more about the process involved with material failure un high voltage scenarios. The ESD Table is designed in such a way that it can continue to be updated with new data so future work can continue and be compared to current results.

Twin and linked breakdowns





Shown at left are two LDPE samples with unusual breakdown characteristics. It is unknown presently why some samples fail at multiple locations, or why some sites become joined. It is thought that investigating the spatial variability of breakdown locations will aid in understanding this relationship.

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