Temperature Dependence of Electrostatic Breakdown of Polymeric Insulators

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The temperature dependence of electrostatic discharge (ESD) of polymeric insulators has been measured by applying a high voltage across the polymer to induce an electric breakdown. The breakdown electric field was determined by a rapid rise in the I-V curves that were measured in a custom, high vacuum chamber in the temperature range of 150 K to 300 K. Our results show that the electrostatic discharge of the polymer Low Density Polyethylene (LDPE) to be 318±60 (±18%) MV/m with no significant variation over the full temperature range. The results are compared with thermodynamic models of the electric field range, aging process and limited prior measurements. The motivation for this research was the concern of spacecraft charging and the potential damage from electrostatic breakdown of polymers to be used on the James Webb Space Telescope, which will operate at temperatures down to 30 K.

**Motivation**

Why do we worry about the temperature dependent electrostatic discharge breakdown of polymeric insulators?

Spacecraft Charging: Plasma-induced charging due to interactions with the space environment account for almost half of all spacecraft failures and anomalies.

Modern communications systems and a myriad of products we use today rely critically on the use of spacecraft technology. The majority of spacecraft operate in a geosynchronous orbit, a distance from Earth not feasible accessible for repair.

**The James Webb Space Telescope (JWST)** (Fig. 1), being built by NASA and the European Space Agency, will be operating in the L2 Lagrange point, an even greater distance of 1.5 x10^9 m from the Earth, at temperatures as low as 30 K, and in an extreme plasma environment. Materials for JWST are the focus of this study.

Interaction with the plasma environment induces spacecraft charging, leading to charge build up on the craft and its internal components, and ultimately can cause electrostatic breakdown. Electron, ion, and photon charge-induced potentials can result in current spikes in the circuits or arcing (Fig. 2), thus damaging electronics, solar panels (Fig. 3), or other spacecraft components. Understanding how charge migration and dissipation occurs in insulators is crucial to mitigating the effects of spacecraft charging.

**Results**

Measurements of the temperature dependence of ESD show significant damage to samples at breakdown.

Analysis of the electrostatic breakdown for the material Low Density Polyethylene (LDPE) shows little or no temperature dependence in the range from -150°C to 25°C. For Kaption HN, a significant increase in breakdown voltage, with decreasing temperature in this range [Arnfield].

**Comparison to Previous and Future Studies**

Cone et al. predict a model (Fig. 6) for the mean time to failure (τ) as a function of high electric field, F, and temperature, T [Cone]. The model has two parameters, the maximum size of submicron cavities, A, and the change in Gibbs free energy, ΔG, for rupture of interchain van der Waals bonds. The activation energy for chain scission (or microvoid formation) is given by:

\[ \chi = \frac{\Delta G}{kT} \]

where \( \chi \) is the activation energy, \( \Delta G \) is the change in Gibbs free energy, and \( k \) is Boltzmann’s constant.

**Future Work**

Future research will collect more data between room temperature and the existing data, and at temperatures above room temperature. Along with additional temperature data, tests will be done to determine the endurance time dependence of electrostatic breakdown. Comparison to the endurance time model hopefully will allow determination of the microvoid width, A, and the change in Gibbs free energy, ΔG, of LDPE for direct comparison with similar results from dark current conductivity, radiation induced conductivity and electron emission measurements at USU.

**Acknowledgments**

This work was supported by a Utah State University Undergraduate Research and Creative Opportunities grant and funding from the NASA/JWST Electric Systems Working Group at Goddard Space Flight Center.

**References**


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